# STATE OF NEVADA COMMENTS
# ON THE U.S. DEPARTMENT OF ENERGY'S
# DRAFT ENVIRONMENTAL IMPACT STATEMENT
# FOR A
# GEOLOGIC REPOSITORY FOR THE DISPOSAL OF
# SPENT NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE
# AT YUCCA MOUNTAIN, NYE COUNTY, NEVADA

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# ENVIRONMENTAL REVIEW AND REGULATION FOR SITING A NUCLEAR WASTE REPOSITORY AT YUCCA MOUNTAIN, NEVADA

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*The U.S. Department of Energy (DOE) has proposed that the first geologic repository for high-level nuclear waste in the United States be sited at Yucca Mountain, Nevada. Repository siting was exempted by the Nuclear Waste Policy Act from the requirements for an environmental impact statement under the National Environmental Policy Act (NEPA) and, additionally, the DOE was prohibited by law from acquiring new empirical information for environmental assessment. Thus, no systematic, interdisciplinary evaluation of impacts based on site-specific data will occur before the Yucca Mountain environment is irreparably altered by site characterization. Exemption of siting activities for the nation's first geologic repository for high-level nuclear wastes from NEPA review is further evidence of the eclipse of NEPA in decision making, a trend that may foretell how controversial, technologically complex projects will be carried out in the future.*

The policy that established the program for siting the nation's first geologic repository for disposing of high-level nuclear waste was initially set forth by the Nuclear Waste Policy Act (NWPA) of 1982. In 1987, NWPA was amended by the Nuclear Waste Policy Amendments Act (NWPAA), which reduced the number of prospective sites in the western United States for a first repository from three to one and postponed the component of the program aimed at developing a second repository in the Eastern United States. This move allowed the US Department of Energy (DOE), the agency responsible for implementing the program, to concentrate its resources on the site at Yucca Mountain, located on the southwestern border of the Nevada Test Site (NTS). There has been no discussion of the diversity of environmental regulations that apply to the program and the implications of some of the unique regulatory features that exist and continue to evolve. These matters are of interest because the nuclear repository



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program authorized by NWPA and NWPAA may foretell how environmental review and regulation for complex and controversial technological programs could be carried out in the decades ahead.

The environmental compliance requirements that policymakers crafted for NWPA also provide insight to the eclipse of the National Environmental Policy Act (NEPA) in the decision-making process regarding environmental protection. Renwick (1988) contends that comprehensive, integrated environmental review has become secondary to statutory-specific environmental regulation of individual classes of pollutants or components of the environment. This situation has been characterized by a lessening of emphasis on the substance of NEPA policy to the extent that the law has evolved into a procedural one focusing on the environmental impact statement (EIS). What is particularly notable about the current high-level nuclear waste program in this respect is that NWPA exempts significant portions of it from even the procedural elements of NEPA. While there are provisions in NWPA to compensate in part for the fact that site characterization activities for a repository do not require an EIS and full NEPA review, this mandate has potentially far-reaching implications for the future of environmental management in the face of a continued weakening of NEPA, both substantively and procedurally. The principal issue analyzed in the present paper is the extent to which the environmental provisions in NWPA, coupled with other environmental regulations, compensate for the eclipsed effectiveness of NEPA for siting the nation's first geologic repository for high-level nuclear waste. This issue is important in light of Renwick's (1988) view that the eclipse of NEPA by other laws probably affords more environmental protection than was previously the case.

The spectrum of environmental compliance requirements that pertain to the DOE nuclear waste repository siting program includes unique, program-specific provisions set forth by NWPA, as well as the range of environmental statutes and regulations that apply to typical government actions. These requirements will in turn be reviewed below, but in order to evaluate them, it helps first to understand the general nature of the actions involved in siting a repository.

## The Proposed Action

Although the conception of a geologic repository for nuclear wastes preceeded the enactment of NWPA in early 1983, that milestone is an adequate one to depart from for this analysis. A reasonably complete view of what repository siting would entail was provided in a set of environmental assessments (EAs) issued by the DOE in the 1986, as statutorially called for by NWPA. Initially, in 1984, the DOE had issued draft EAs for nine candidate repository sites. By the time the final EAs were completed in 1986, the range of potential sites had been narrowed to three, ie, one each in the states of Texas, Washington, and Nevada. Of interest here is the EA for the Yucca Mountain site in Nevada (DOE



1986), which, like the other EAs, described a two-stage repository program in accord with the site selection procedures specified by NWPA. The siting stage, involving site characterization activities intended to determine site suitability for a repository, is to be followed by a second stage consisting of construction and operation.

The Yucca Mountain site is located wholly on federal land, the eastern third of which is on NTS and controlled by the DOE. The remaining two-thirds of the site is on either public trust land or military land under the administrative control of the Bureau of Land Management (BLM). Site characterization activities that are to be conducted away from the site largely will be on BLM land, but some ground-water monitoring wells and seismic refraction surveys are planned in Death Valley National Monument in California (DOE 1988a), which is controlled by the National Park Service (NPS). These matters are important in terms of which federal agency is responsible for environmental protection of the site, details of which will be addressed in a later section. It is also important to note that Yucca Mountain is located within the transitional zone (ecotone) between the Mohave Desert and the Great Basin Desert in a little-known, localized, and unique area situated on volcanic as opposed to sedimentary substrate, as is the remainder of the so-called "Transitional Desert" (Beatley 1980; Collins et al. 1981).

Some preliminary siting activities such as drilling, trenching, and seismic testing already have occurred at Yucca Mountain, even though field activities for site characterization as defined by NWPA have not formally commenced. The site has been studied by the DOE since the late 1970s and exploratory investigations were conducted up to 1986. These activities are described in the DOE (1988a) Site Characterization Plan (SCP) in context with the work that remains to be done in accordance with NWPA siting procedures. The remaining work involves additional geologic and hydrologic investigation, plus construction of an exploratory shaft facility (ESF) that will be used for underground testing of conditions in the repository horizon at Yucca Mountain. All of these activities and associated tests are discussed in the SCP. Of interest here are the actions that will be covered by environmental regulations, and most of these occur on the surface, where drilling, trenching, hydrologic testing, and construction of the ESF will cause disturbance.

Table 1, compiled from the SCP, summarizes individual aspects of site characterization that will be subject to environmental review and regulation. The types of activities to be undertaken include shallow and deep drilling, geologic trenching, infiltration studies, geophysical surveys, construction of the ESF, and construction of roadways for access to the study sites. Of primary interest from the perspective of environmental compliance are activities that involve disturbance of the surface, generation of dust and emission of potential pollutants, drilling and testing in the saturated zone, effluent discharges to the surface, use of water resources, regulated utility services, and disposal of wastes, including

TABLE 1. Proposed Site Characterization Activities for the Yucca Mountain Project

| Activity | Description | Number/area | Environmental attributes |
|---|---|---|---|
| Major drill holes | Several hundred to over 1000 m deep for water table and geologic testing; will need drill pads and use drilling fluids | 45–80 | Surface disturbance of 1 ha/site; drilling foam and wastes; radioactive materials; hydrogeologic testing and surface discharges |
| Other drill holes | 15–46 m deep for unsaturated zone exploration and geophysical testing; little or no surface preparation needed | 300–350 | Limited surface disturbance up to 600 m²/site |
| Trenching | 1–3 m deep by 2–4 m wide by 150 m long for geologic exploration and soil sampling | 20 | Surface disturbance of 0.1 ha/site |
| Infiltration studies | Shallow drilling to 15 m, pond construction, regolith removal to investigate water movement in the unsaturated zone | 80 plots | Surface disturbance of 0.1 ha and various numbers of shallow holes and ponds/site |
| Geophysical surveys | Seismic reflection and refraction, gravity, and magnetic surveys | 300–350 km of lines | Surface disturbance by vibrator trucks and dynamite charges |
| Exploratory shaft facility | Surface support facilities for underground testing; will include prefabricated buildings and trailers, dormitories, concrete plant, utility and sanitary facilities, rock storage pile, and related facilities | 13 ha | Surface disturbance; mining waste discharges and emissions; municipal, sanitary, and hazardous wastes; water supply |
| Access roads | Double oil-and-chip roadway to ESF plus bladed roads to outlying facilities, drill holes, trenches, and other study areas | 0.4 km paved and 63 km dirt | Surface disturbance of up to 700 hectares and floodplain modifications |



sewage and solid and hazardous materials. Almost all activities involve a degree of distrubance of the soil surface, biotic communities, and any cultural resources that might occur. Additionally, many of the exploratory activities will be located in floodplains where some of the most favorable ecological habitat at Yucca Mountain occurs. The EA estimates that up to 320 hectares of land could be disturbed during site characterization.

Dust emissions during surface disturbance will be controlled by sprinkling with water, and water also is required for drilling and mining activities. It is estimated that site characterization will require appropriation of water rights to about 500,000 cubic meters of ground water per year for 5 years, to be obtained from an existing well on the NTS. Use of radioactive materials and chemical tracers to study ground-water movement is also of regulatory concern, as is the generation and disposal of all wastes during site characterization. No unusual hazardous wastes are expected to be generated and, overall, the wastes involved in the project will be typical of those of any large construction and mining operation. Mined materials will be placed in a lined rock storage area and mining effluents will be discharged to the rock pile. Sanitary wastes will be disposed of via a septic tank and leach field. Both solid and hazardous wastes are to be stored on-site and ultimately disposed of off-site. A domestic water supply system will be installed, as will an electric utility system consisting of a substation supplied by an extension of an existing overhead power line. The types of environmental requirements to be involved in these activities are discussed in a later section.

## Framework for Environmental Review and Regulation

A complex array of environmental requirements apply to the repository siting program. These requirements involve environmental compliance with regard to guidelines and implementing regulations that typically apply to large federal projects and unique features established by NWPA that address only the high-level nuclear waste program. The program-specific environmental requirements that must be complied with are set forth by NWPA in the context of procedures that the DOE must follow for siting the repository and ultimately gaining authorization from the Nuclear Regulatory Commission (NRC) for construction. The requirements stem essentially from modifications made by NWPA to NEPA, and they affect how the DOE is to conduct environmental review for the siting project. Although the NRC is involved in authorizing construction and licensing the operation of a repository, it has no regulatory role during siting. While defense nuclear facilities constructed and operated by the DOE typically are exempt from regulation by the NRC, NWPA requires that high-level waste repositories be authorized and licensed because they are to be used for commercial as well as for defense purposes. Accordingly, NEPA applies to the regulatory actions taken by the NRC once a decision is made to construct a repository.

In addition to the environmental requirements and implementing regulations set forth by NWPA, including the modifications to NEPA, federal and state regulations that routinely apply to all projects help govern the DOE repository program. These include the unexempted portions of NEPA along with the specific requirements and regulations eminating from NWPA, all of which are discussed below.

*Environmental Requirements Established by NWPA*

The most significant aspects of NWPA from the environmental perspective are the partial exemptions from NEPA review provided to site characterization activities. There are two such provisions, in Section 112(c) and in Section 113(d), that exempt preliminary siting activities and all aspects of the site characterization program from preparation of an environmental EIS as called for by NEPA Section 102(2)(C) and from environmental review at international, state, and local levels under Sections 102(2)(E) and (F). In lieu of an EIS for site characterization, NWPA Section 112(b) requires that an EA be prepared for each site nominated for consideration as a candidate repository site. Such an EA has come to be known as a "statutory" EA (ie, specific to NWPA statutes) to distinguish it from an NEPA EA (Burton 1984). In a public statement (Mussler 1984), the DOE specifically noted that regulations for NEPA (40 CFR 1500-1508) do not apply to the statutory EAs.

The only guidance provided by NWPA for the EAs was that evaluations of site suitability were to follow a set of guidelines to be developed for recommending sites for repositories. These siting guidelines, mandated by NWPA section 112(a), were to address valuable natural resources, hydrology, geology, geophysics, seismic activity, effects on users of water rights, and proximity to atomic energy defense facilities, water supplies, populations, and to resource areas such as national parks, wildlife refuges, rivers, wildernesses, and national forests protected by federal law. Although it could be inferred that systematic, interdisciplinary environmental considerations in the NEPA sense should be included in the siting guidelines, they were not specifically called for by NWPA and subsequently were not included in the guidelines issued by the DOE under 10 CFR 960. It is important to note that NWPA Section 112(b)(3) prevents the DOE from undertaking new investigations for the EA and restricts preparation of the document to the use of existing information. This limitation upon acquisition of further empirical information for the EA had to be taken into account by the DOE when it prepared the siting guidelines, against which the statutory EAs would be evaluated. Because the candidate repository sites and the data base available for each of them were known to the DOE before the guidelines were prepared, it was natural for the DOE to develop guidance consistent with what was known about the sites. To have done otherwise by adopting criteria for which incomplete evaluative data were available could have led to a priori



disqualification of some if not all of the preselected sites. Deficiencies in site-specific information were called to the attention of Congress by federal agencies other than the DOE, but were ignored during hearings held on NWPA prior to its passage (Kraft 1988)

It also should be noted that the customary role of the NRC in evaluating environmental impacts for siting non-defense nuclear facilities was not provided for by NWPA during site characterization. In accordance with Section 114(d), NRC involvement in the high-level waste program was deferred until the repository-development phase, when construction authorization by the NRC is required. Licensing by the NRC of a constructed repository prior to its operation also is required by NWPA in Section 114(f), the section that declares repository development to be a major federal action requiring the DOE to prepare a NEPA EIS. Typically, the NRC role in authorizing and licensing nuclear facilities also is considered to be an action requiring NEPA compliance and preparation of an EIS. To accomodate this circumstance, the framers of NWPA sought to ease the demands of NEPA on the repository program by facilitating NRC environmental review requirements. This was accomplished through NWPA Section 114(f), which provides for the NRC to adopt the DOE EIS to the extent practicable. Such an action is the subject of proposed rule making by the NRC (1988) for NEPA review that has the effect of removing the NRC's obligation for environmental review of repository construction authorization by relying almost totally on the DOE's procedures for NEPA compliance. The ultimate significance of this issue will be pursued further in the next section.

Three other environmental provisions in NWPA Section 113 also affect how the DOE repository siting program is to be conducted. First, Section 113(a) calls on the DOE to minimize significant adverse environmental impacts identified either in comments on the DOE's SCP or in further assessments of the environment submitted as part of the SCP. Second, Section 113(b)(1)(A)(iii) requires that the SCP include plans for decontaminating and decommissioning a characterized site and for mitigating significant adverse environmental impacts if the site consequently is not used for a repository. Third, the theme of impact minimization, mitigation, and reclamation was carried forth to Section 113(c)(4), which required that the DOE take reasonable steps to reclaim the site and to mitigate environmental impacts from site characterization if the site ultimately is found unsuitable for repository construction. This provision was modified slightly by NWPAA in 1987 to provide for reclamation and mitigation of environmental impacts caused by site characterization "at any time" that a decision is made not to proceed with repository development at Yucca Mountain. Taken together, these three provisions of Sections 113 constitute the fundamental directions to the DOE for conducting environmental review for site characterization subsequent to issuance of the statutory EAs.

Another provision of NWPA having implications pertaining to environmental concerns is Section 116, as amended by NWPAA, which provides a role for the

State of Nevada, as an affected government, relative to monitoring and reviewing repository site characterization. Funding made available under the nuclear waste legislation for independent oversight of DOE activities can be used for environmental review and protection. For example, Section 116(c)(2)(B) of NWPA allows affected governments to submit a report that includes assessment of potential environmental impacts and provides the basis for requesting assistance for mitigating impacts. No guidance is provided by NWPA as amended for how this function is to be carried out and no plans currently are available that would allow insight into how effective the process might be.

### *NEPA Requirements*

Despite the partial exemptions from NEPA that NWPA provides for site characterization, there are requirements remaining that must be met by the DOE. All substantive provisions of NEPA remain in force, as well as the Council on Environmental Quality (CEQ) implementing regulations other than those concerning EIS preparation. Additionally, the DOE itself has a NEPA compliance regulation (10 CFR 1021) that reinforces the CEQ regulations by adopting them in whole.

Most notable among the environmental review requirements that remain applicable to DOE site characterization are those of 40 CFR 1501, 1505, and 1506 in the CEQ implementing regulations for NEPA. Among other things, these regulations require early planning that effectively integrates the objectives of NEPA policies into agency programs. An objective of this requirement is to assure that a systematic, interdisciplinary approach is taken that integrates environmental and social sciences into decisions affecting the environment. The intent of this unique statutory provision is that environmental effects and values will be sufficiently identified to allow their comparison to economic and technical analyses. To accomplish these goals, the DOE must follow procedures that ensure its decisions are made in accordance with the policies and purposes of NEPA.

As previously noted in the discussion of NWPA Section 114(f), the full force of NEPA environmental review applies to repository development, and the DOE is required to comply with NEPA and the CEQ regulations that establish generic contents for an EIS. In the past, nuclear facilities requiring licensing by the NRC have adhered to NRC guidance for preparing environmental documents. Under the NRC requirements for environmental review that existed when NWPA was passed, the procedures set forth in 10 CFR 60 and 10 CFR 51 for NEPA review and compliance pertaining to licensing a high-level nuclear waste repository would have required that a detailed environmental report on the project be prepared by the applicant, in this case the DOE. From this document, the NRC then would have prepared and EIS to fulfill its obligations under NEPA. A virtue of this arrangement is that it would assure that the DOE follows a reasonably rigorous set of guidelines for preparing the environmental report, as opposed to



the generic and far less detailed guidance set forth for EISs by CEQ under 40 CFR 1502. This would assure that, ultimately, an environmental review tailored to nuclear projects would be performed by the DOE for the Yucca Mountain site, albeit after the impacts of site characterization have occurred.

The NRC, however, has used the provision in NWPA Section 114(f) allowing it to adopt the DOE EIS to justify proposing revisions to its NEPA review procedures (NRC 1988). If adopted, the revisions would release the NRC from its traditional NEPA review obligation by allowing it to rely on the DOE procedures and EIS rather than conduct an independent environmental review. Additionally, the DOE would not be required to prepare an environmental report and the 10 CFR 51 guidance for detailed environmental documentation would cease to apply to the repository program. In effect, the EIS prepared by the DOE would constitute the only environmental review procedure for repository construction and there would be no specific guidance for the EIS other than the siting guidelines under 10 CFR 960 which, as noted earlier, were prepared to accommodate an EA effort that could not be supplemented by newly acquired data and information where gaps in knowledge about the site existed.

This is the situation as it stands, up to the granting of an authorization by the NRC for construction of a repository by the DOE. It is possible, as is the case with other licensable nuclear facilities, that further environmental review and EIS preparation subsequent to construction would be required for repository operation. The NRC has yet to decide how it will proceed in matters beyond construction authorization with regards to NEPA review and environmental compliance for all aspects of repository development, and doubtlessly is awaiting the outcome of its proposed revisions to the NEPA review regulations. Clearly, however, the NRC intends to avoid rigorous environmental review of the Yucca Mountain Project if possible.

### *Other Environmental Statutes and Regulations*

Federal and state environmental compliance requirements that apply to repository siting are derived from the nature of the proposed action described in a preceding section. Individual activities to be undertaken during site characterization render certain statutes and regulations applicable to the project, as shown in Tables 2 and 3 for federal and state environmental compliance requirements, respectively. The state requirements listed are specific to Nevada because NWPAA confined repository siting to the Yucca Mountain site.

For the most part, the federal environmental regulatory framework that applies to the repository program (Table 2) is similar to that for typical government projects. Consideration of air quality, water quality, hazardous wastes, threatened and endangered species, and cultural resources is provided by specific statutes and regulations. There are additional environmental requirements posed in this instance, however, that are potentially significant in light of the NEPA exemp-

**TABLE 2.** Principal Federal Environmental Statues and Regulations that Apply to the Yucca Mountain Project

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| Federal Land Policy and Management Act of 1976, 43 USC Section 1701-1784 (43 CFR Parts 2300 and 2800). |
| Organic Act of the National Park Service, 16 USC Section 1, and, National Park System Mining Regulation Act, 16 USC Sections 1901-1912 (36 CFR Part 9). |
| Floodplain Executive Order, E.O. 11988 (10 CFR Part 1022). |
| Endangered Species Act of 1973, 16 USC Sections 1531-1543 (50 CFR Sections 17.11, 17.12, 17.94, 17.95, and 17.96; 50 CFR Parts 222, 226, 227, 402, 424, 450, 451, 452, and 452; DOE/EP-0058). |
| National Historic Preservation Act of 1966, as amended, 16 USC Sections 470-470w-6. |
| American Indian Religious Freedom Act, 42 USC Section 1996 (36 CFR Part 296; 43 CFR Part 7). |
| Clean Air Act, as amended, 42 USC Sections 7401-7642 (40 CFR Parts 50, 51, 52, 58, 60, 61, and 124; Sections 81.300 and 81.400; DOE/EP-0062 and 0065; E.O. 12088). |
| Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act of 1976 and the Hazardous and Solid Waste Amendments of 1984, 42 USC Sections 6901-6991 (40 CFR Parts 124, 240-247, 260-264, 266, 270-271, and 280; E.O. 12088; State regulations). |
| Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977 and the Water Quality Control Act of 1987, 33 USC Sections 1251-1376; (33 CFR Parts 209, 320, 323-327, and 330; 40 CFR Parts 110, 116, 117, 121, 122, 123, 124, 125, 129, 133-136, 230, 233, 401, and 403; DOE/EP-0060 and 0061; E.O. 12088). |
| Safe Drinking Water Act, 42 USC Sections 300f-300j-10 (40 CFR Parts 124, 141, 142, 143, 144, 145, 146, 147, and 149; E.O. 12088). |

tions provided by NWPA to site characterization. Some of the characterization activities occur on lands controlled by the BLM or NPS. In these instances, statutes and regulations under the Federal Land Policy and Management Act (FLPMA) and the Organic Act of the National Park Service became applicable, requiring in turn that the BLM and NPS apply NEPA review to those activities. Only a small number of activities, principally geophysical surveys, are proposed on NPS land in Death Valley National Monument, but a major portion of site characterization will be carried out on BLM-controlled land adjacent to the NTS.

Under the terms of both the NPS Organic Act and FLPMA, the DOE must obtain authorization from the controlling agency to utilize land not under the jurisdiction of the DOE itself. This requirement will mean that the NPS and BLM must conduct environmental review under NEPA and the CEQ regulations for the granting of permission to the DOE to utilize the land. Accordingly, for the activities that these requirements apply to, traditional EIA should be performed.

A significant number of proposed site characterization activities, principally bore holes and geophysical surveys, will occur in floodplains. The DOE implementing regulations for floodplain protection (10 CFR 1022) require that an



**TABLE 3.** Principal State Environmental Statutes and Codes that Apply to the Yucca Mountain Project

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|---|
| Utility Environmenatl Protection Act, NRS 704.820 to 704.900 (Permit Requirements Proposed as Amendments to NAC 703.415 *et seq.*). |
| Appropriation of Public Waters, NRS 533.325 to 533.435 (Permit Requirements Covered by Administrative Procedure and "Regulations Concerning Preparation of Maps Under Application to Appropriate Water and Proofs of Appropriation", State Engineer, 1977). |
| Underground Water and Wells, NRS 534.010 *et seq.* (Regulations for Drilling Water Wells, NAC 534.010 *et seq.*). |
| Air Pollution, NRS 445.401 to 445.710 (Permit Requirements, NAC 445.430 to 445.716). |
| Nevada Water Pollution Control Law, NRS 445.131 to 445.354 (Discharge Permit, NAC 445.140 to NAC 445.170; Treatment Works, NAC 445.170; Diffuse Sources and Permit to Construct or Grade, NAC 445.199 to 445.234; Temporary Underground Injection Control Regulations, NAC 445). |
| Public Water Systems, NRS 445.361 to 445.399 (Water Quality, NAC 445.244 to 445.262; Water Supply, NAC 445.370 to 445.420). |
| Collection and Disposal of Solid Waste, NRS 444.440 to 444.630 (Solid Waste Disposal, NAC 444.570 to 444.748). |
| Disposal of Hazardous Materials, NRS 459.400 to 459.600 (Hazardous Waste Disposal, NAC 444.8500 to 444.9335). |

environmental assessment be conducted for such activities. While this requirement is far from comprehensive in its coverage of the DOE project, if complied with, it will nonetheless help assure that some activities on DOE-controlled land receive environmental review that otherwise may escape coverage.

Most of the important environmental regulations for the State of Nevada (Table 3) that apply to the DOE project are derived from delegated federal authority. Specifically involved are compliance requirements associated with the Clean Air Act, the Clean Water Act, the Resources Conservation and Recovery Act, and the Safe Drinking Water Act. For the protection of biological and cultural resources, Nevada relies primarily on federal statutes and has no significant requirements of interest in the context of the repository program. Neither does the state have a comprehensive environmental review law that can compensate for the NEPA exemptions provided by NWPA. One state statute is of interest in this respect, and that is the Utility Environmental Protection Act. This statute requires that an EA be performed for new utilities, and it likely will apply to those proposed for site characterization and for repository construction.

Site characterization activities proposed in Death Valley, California, by the DOE include geophysical exploration and installation of up to 30 ground-water monitoring wells. Although these activities will occur on NPS land, environmental statutes of the State of California will apply; these include the California Environmental Quality Act (CEQA), the state's equivalent of NEPA. Unless California agrees to transfer lead agency status and liability to the federal government, CEQA will apply to the activities in Death Valley and will encompass an array of specific state requirements. The California Energy Commission is handling affairs relative to the DOE repository siting that impinge upon the state, and how state environmental requirements will be applied has not been determined.

## Outlook for Environmental Review and Regulation

There are at least two ways to gain insight into how effective the regulatory framework that applies to the Yucca Mountain Project might be for protecting the environment. One approach is to evaluate the actions already taken to implement NWPA, NWPAA, NEPA, and their various specific environmental requirements. This will indicate the extent to which the intentions of various environmental requirements are being achieved by the implementing agencies. Another tactic is to assess the potential effectiveness of the regulatory requirements that have yet to be implemented, and to evaluate the historic record that is analogous to the present situation. Institutionally, there are four entities that have roles in environmental protection at Yucca Mountain: the DOE, the NRC, the BLM, and the State of Nevada. The NPS is responsible for protecting portions of Death Valley National Monument from the limited site characterization activities planned to occur there. The State of California could become involved in Death Valley via CEQA, but the likelihood of this occurring is not known, and the extent of site characterization activities planned in California is relatively minor with respect to the overall DOE siting program.

### *Implementation of Environmental Requirements by the DOE*

The principal responsibility for assuring that the regulatory framework provided by NWPA is developed and implemented rests with the DOE. To this end, the DOE has approached fulfilling its environmental requirements in a stepwise manner, consistent with actions called for in NWPA.

In accordance with NWPA, the initial step taken by the DOE was promulgation of the siting guidelines. These guidelines fell short of compensating for the NEPA exemptions because they did not address the environment in a comprehensive, interdisciplinary sense, but instead equated protection of the environment to compliance with single-medium environmental statutes. Although legally moot in this context, the US Supreme Court ruled in the landmark Calvert Cliffs case that compliance with specific laws does not substitute for a systematic, interdisciplinary perspective on environmental review and assessment meant to be taken in complying with NEPA (Rogers 1977; Jain et al. 1981). It must be noted, however, that the trend is to rely increasingly on laws other than NEPA for environmental protection while retaining the EIS procedures for advocacy purposes (Renwick 1988).



The next environmental step taken by the DOE was preparation of the statutory EAs. There were two handicaps imposed upon these documents. First, because the assessment process was not undertaken in the context of NEPA, no standard guidance such as CEQ and NRC regulations for NEPA environmental review applied. Instead, the DOE adapted the siting guidelines that had been developed knowing that incomplete information would be available for the EA process. This precluded the agency from taking a comprehensive, interdisciplinary approach to environmental protection and was a serious deficiency imposed upon the Yucca Mountain EA because little site-specific information existed for the area, making it impossible to carry out a comprehensive environmental review. In this respect, concerns that had been expressed earlier during Congressional hearings on NWPA about the lack of a sufficient base of empirical information for the EAs to succeed were realized (Kraft 1988).

In the end, the statutory EA for Yucca Mountain (DOE 1986) was recognized by the State of Nevada as an ineffective document for environmental review and was contested in a case yet to be heard by the courts (*Nevada v. Herrington*, No. 86-7307, 9the Circuit of Appeals). The DOE has sought to uphold the efficacy of the statutory EA and has continued to use it as the basis for all subsequent environmental planning decisions. To this end, the DOE has used the finding of no significant impacts to justify a decision not to obtain comprehensive, site-specific environmental baseline information at Yucca Mountain prior to initiating site characterization. The DOE's policy is that comprehensive monitoring for detecting adverse environmental impacts is unnecessary, and instead of demonstrating that it will minimize impacts to all segments of the environment, has tailored a piecemeal prog.am to comply with individual requirements based upon the findings in the statutory EA (DOE 1988b, c). Nowhere does the DOE recognize the unique ecological naturè of the Yucca Mountain site and the fact that it occurs on an inadequately studied ecotone (Beatley, 1980; Collins et al. 1981). Plans have been issued by the DOE that include compliance with parts of such laws as the Clean Air Act, the Endangered Species Act, and the National Historic Preservation Act (DOE 1988d), but that fail to address ecological integrity and resources protection. There is no comprehensive environmental program that integrates all aspects of the Yucca Mountain environment into a systematic, interdisciplinary environmental review prior to site characterization activities being undertaken and before potentially irreversibly altering the unique and fragile desert environment at Yucca Mountain. However, after site characterization has been initiated and impacts incurred, the DOE plans to establish an environmental baseline for use in preparing the repository EIS mandated by NWPA for NEPA compliance. This actions will come too late to describe the environment before it is significantly altered by site characterization, an acknowledgement made by DOE (State of Nevada 1987).

The absence of an environmental baseline prior to site characterization can be expected to preclude effective reclamation planning as viewed by NWPA and

NWPAA. In the preliminary SCP (1988a), the DOE has presented no reclamation plans as called for under NWPA Section 113(b) as part of planning for site characterization. Thus, as the DOE program now stands, it cannot be expected to fulfill the requirements of NWPA and NWPAA to reclaim the Yucca Mountain site in the event that the site is not used for repository development. Of even more fundamental importance to state government and the provisions of NWPA and NWPAA that provide for environmental oversight and impact assistance, the actions planned by the DOE to alter the site before baseline information is available will preclude others from making an accurate assessment of impact potential and resources needed to mitigate the inevitable impacts associated with site characterization.

Consideration of environmental protection by the DOE next can turn to the extent to which it is likely to comply with specific federal and state environmental regulation. To this end, the State of Nevada (1988) reviewed the DOE record for complying with state and federal environmental requirements at Yucca Mountain prior to 1986. It was found that between 1976 and 1986, the DOE complied with no state regulations and with only the Endangered Species Act and the National Historic Preservation Act among the federal requirements that applied. During this time, a total of 98 drilling operations were conducted, 20 of which were major holes requiring drill pads, use of drilling fluids, and access roads of several kilometers' length each. Additionally, 21 geologic trenches were constructed, up to 160 kilometers of seismic lines were run, and numerous semi-permanent seismic, hydrologic, and meterologic monitoring stations with roads to them were installed. It was estimated that up to 200 hectares of land surface were disturbed for the activities undertaken by the DOE prior to 1986. These actions were not addressed by comprehensive NEPA review, and 11 of the drilling operations located in floodplains were not reviewed in accordance with the federal floodplain regulations (Table 2). Among the important state requirements that the DOE failed to comply with were drilling and water resources protection regulations and air quality requirements. To date, the DOE has made no attempt to reclaim disturbed sites that no longer are used for the repository siting program.

The results of its survey led the State of Nevada (1988) to critique the compliance record at the DOE nuclear facilities throughout the nation as well as operations at the NTS (DOE 1988e). It was found that the DOE typically had a poor environmental compliance record in Nevada and seldom adheres to state and local regulatory requirements. The State concluded that the DOE cannot be counted upon to protect the Yucca Mountain environment in accordance with specific statutes other than possibly the Endangered Species Act and the National Historical Preservation Act, which it seems that the DOE usually complies with. This finding is consistent with what has come to be known, even by the DOE's own admission, as a typically poor record with respect to health, safety, and environmental compliance (Walker 1987; DOE 1988f; General Accounting Office 1988; DOE 1988g) attributable to the traditionally self-regulatory nature of



the DOE and the correlary lax attitude generated toward environmental oversight and responsibility (US Senate 1987).

### *Implementation of Environmental Requirements by Other Agencies*

In addition to the DOE, other federal agencies that are involved in the repository program include the NPS, BLM, and ultimately the NRC. The latter is involved in a regulatory role with respect to authorizing repository construction and licensing its operation. Because construction and operation are considered by NWPA to be major federal actions, NEPA applies to the NRC role in the repository program subsequent to site characterization. Historically, the NRC has exercised a responsible role in environmental review of nuclear projects, but because NWPA allows the NRC to adopt the DOE EIS for the repository, the NRC cannot be counted on to exercise independent environmental review in this instance. The action taken by the NRC (1988) to amend its NEPA review regulations to delete the requirement for an environmental review and an independent EIS confirms the intent by the NRC to avoid active involvement in environmental aspects of the repository program and instead to accept the DOE's actions.

The role to be played by the NPS in environmental review and regulation of repository siting activities is relatively minor because of the limited extent of activities to be undertaken by the DOE on land under NPS jurisdiction. Regulations governing environmental review for activities in national parks (Table 2) require that the review be documented. Accordingly, the NPS is expected to have an EA performed and documented for any drilling and seismic surveys conducted by the DOE for repository siting activities in Death Valley National Monument in California.

It seems that one of the best prospects for environmental review of DOE site characterization at Yucca Mountain ideally should rest with the responsibility that the BLM has to review proposed actions on land under its jurisdiction. This includes the site for the exploratory shafts planned by the DOE, as well as many of the other geologic and hydrologic studies based on the surface. In accordance with FLPMA regulations, the BLM should independently review the potential impact of the proposed DOE activities and conduct the review in pursuit of NEPA compliance. In its review of compliance actions for the Yucca Mountain Project prior to 1987, the State of Nevada (1988) found that in the past, the BLM has always adopted the DOE's documentation associated with environmental review, including the EA prepared for the Yucca Mountain site (DOE 1986). It is anticipated that for future site characterization activities planned by the DOE, the same procedure will be followed by the BLM, ie, adoption of existing DOE documents as opposed to independent review based on field studies and information gathered by the BLM itself. Thus, in fulfilling its obligations under FLPMA and NEPA, it seems unlikely that the BLM will conduct comprehensive, interdisciplinary environmental review of repository siting activities based upon field information specific to Yucca Mountain.

## Summary and Conclusions

The national program for disposal of high-level nuclear waste has progressed sufficiently since passage of enabling legislation (NWPA) in 1982 to provide insight to how effective provisions for environmental review and regulation are likely to be regarding siting a geologic repository and to the broader implications for environmental policymaking. With respect to the repository siting program now underway at Yucca Mountain, Nevada, there are three categories of requirements for environmental review and regulation: those set forth by NWPA that are specific to this program, the generic NEPA requirements not exempted by NWPA, and the traditional federal and state environmental statutes and regulations. Site characterization was exempted from regulation by the NRC and from the NEPA requirement for an EIS. Consequently, environmental review was relegated to the statutory EA mandated by NWPA and guided by the DOE's siting guidelines rather than by CEQ and NRC regulations. The siting guidelines were prepared in light of the prohibition imposed by NWPA on the acquisition of new data and information for preparation of the statutory EAs. As a result, there were no provisions in the guidelines for comprehensive, integrated EIA. Instead, assessments were based on the potential for compliance with traditional federal environmental statutes and regulations designed to protect individual components of the environment. The NEPA exemptions granted by NWPA thus excused the DOE site characterization program from the systematic, interdisciplinary review that is unique to NEPA. While the shortcoming could in part be compensated for by applicability of other environmental statutes, most notable by FLPMA, it is unlikely that the potential to replace what was sacrificed by the exemption granted by NWPA will be fulfilled. Unfortunately, NWPA and its indifferent attitude toward NEPA environmental policies signaled that political expediency is more important to policymakers than environmental rationality.

In the final analysis, it can only be concluded that both the procedural and the substantive intent of NEPA were compromised by NWPA with respect to DOE site characterization activities at Yucca Mountain. This is further evidence of the current eclipse of NEPA, which in this instance is more serious than that characterized by Renwich (1988), involving cases in which the compromising of NEPA's intent ultimately was compensated for by compliance with other federal environmental statutes and regulations. It is well recognized (Caldwell 1985; Bartlett 1986) that the substantive policies set forth by NEPA have been overshadowed by its procedural requirement for an EIS and that sight has been lost of the rationality NEPA sought to establish for environmental decision making. What is new with the advent of the nation's nuclear waste policy is the replacement of NEPA's procedural regulations with the self-regulatory authority



that traditionally has characterized DOE nuclear programs, resulting in environmental problems of immense proportion regarding waste management (US Senate 1987; General Accounting Office 1988; Walker 1987; DOE 1988g). This is a precedent of significant importance and implication to environmental policymaking.

While the framers of NWPA may have envisioned that NWPA requirements regarding impact monitoring, mitigation, and reclamation of site characterization activities would compensate for the NEPA exemption, that is not proving to be the case. This is because the DOE has based all of its environmental program for site characterization on the findings in the statutory EAs, which were fundamentally flawed by virtue of NWPA having prevented science from playing its proper role as an integral tool in policy analysis. The provision that no new field studies could be undertaken was a crippling one also directly related to the NEPA exemptions provided by NWPA. Thus, the lack of systematic, interdisciplinary assessment, the self-regulatory nature of the environmental program, and the absence of analysis based on empirical information stem from a deferrment of NEPA procedures granted to the DOE by Congress. Last, even the independent oversight role that is provided to the affected state government, in this case Nevada, has been compromised by the failure of the environmental assessment and analysis process for site characterization to be based on comprehensive, site-specific information subjected to integrated, interdisciplinary evaluation. This is because actions taken by the DOE in the course of implementing its environmental and site characterization programs, which are being based on incomplete site-specific information, potentially could exclude an option or alternative course of action that proper oversight might find more in accordance with appropriate analysis of empirical information.

Should characterization of the Yucca Mountain site lead to a decision in accordance with the siting policy in NWPA to proceed with repository development, the consequent environmental review implicit in NEPA for such major federal actions will once more be threatened by the provisions in NWPA, allowing the NRC to adopt the EIS prepared by the DOE. To this end, the NRC has proposed revisions to its NEPA compliance regulations that will excuse the DOE repository program from current NRC regulations pertaining to nuclear projects. The results will be that the DOE will not be required to prepare an environmental report and, rather than being guided by the traditional bevy of NRC environmental standards and guidelines pertaining to nuclear projects, will again follow its own siting guidelines that led to the deficient EA and the subsequently flawed environmental program based on it. The deficiencies stemming from the prohibition on gathering empirical data for the statutory EA that in turn led to weak siting guidelines again will be evident in the repository EIS prepared to those same guidelines instead of to the traditional guidance required by the NRC for nuclear projects. Once more, the substantive intent of NEPA that comprehensive interdisciplinary assessment be conducted for federal actions will have been thwarted, forcing the environmental review process to rely on the strength of traditional environmental statutes that address single components of the environment rather than providing an integrated approach to EIA. Renwick (1988) stated that the shift to laws other than NEPA probably protects the environment more than would be the case under NEPA. This may be so where at least the procedural requirements of NEPA remain unimpaired and where statutes apply that address ecological integrity. However, in the case of siting a geologic repository for high-level nuclear waste, NEPA's procedural foundation was set aside and subsequently replaced by flawed practices that clearly fail to assure adequate protection of the environment. This is a new and threatening twist to the demise of NEPA, resulting from the failure of policymakers to see that the potential of NEPA is fulfilled. There soon must be a resolution of the issue with respect to whether or not the public preference for environmental protection is being served by the trend away from the concepts of environmental rationality, ecosystem integrity, and ecological resource values represented by NEPA.

## References

Bartlett, R. W. 1986. Rationality and logic of the National Environmental Policy Act. *Environmental Professional* 8:105–111.

Beatley, J.C. 1980. Fluctuations and stability in climax shrub and woodland vegetation of the Mojave, Great Basin, and Transition deserts of southern Nevada. *Israel Journal of Botany* 28:149–168.

Burton, E. S. 1984. Statutory environmental assessments under the Nuclear Waste Policy Act of 1982: Process, content, and status. In *Proceedings of the 1983 Civilian Radioactive Waste Management Information Meeting*, pg. 245–247, CONF-831217, February, Washington D.C.: Department of Energy.

Caldwell, L. K. 1985. NEPA's unfulfilled potential. *The Environmental Forum* 2(1):38–41.

Carter, L. J. 1987. *Nuclear Imperatives and Public Trust: Dealing with Radioactive Waste*. Washington, DC: Resources for the Future, Inc.

Collins, E., O'Farrell T. P., and Rhoads, W. A. 1981. *Annotated Bibliography for Biologic Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada*. Report No. EGG 1183-2419, Goleta, California: EG&G Santa Barbara Operations.

Davenport, J. H. 1986. The law of high-level nuclear waste. *Tennessee Law Review* 53(3):481–526.

Jain, R. K., Urban, L. V., and Stacey, G. S. 1981. *Environmental Impact Analysis: A New Dimension in Decision Making*. New York: Van Nostrand Reinhold Co.

Kraft, M. E. 1988. Evaluating technology through public participation: The nuclear waste disposal controversy. In *Technology and Politics*, M. E. Kraft and N. J. Vig (eds). Durham, NC: Duke University Press.

Mussler, R. M. 1984. Environmental assessments required to support nomination of sites. In *Proceedings of the 1983 Civilian Radioactive Waste Management Information Meeting*. pp. 243–244, CONF-831217, February, Washington, DC: Department of Energy.

Renwick, W. H. 1988. The eclipse of NEPA as environmental policy. *Environmental Management* 12(3):267–272.



Rogers, W. H., Jr. 1977. *Environmental Law*. St. Paul, West Publishing Co.

State of Nevada. 1987. *Environmental Program Planning for the Proposed High-Level Nuclear Waste Repository at Yucca Mountain, Nevada*. NWPO-TR-001-87. Carson City, NV: Nuclear Waste Project Office.

State of Nevada. 1988. *A Role in Environmental Compliance for the State of Nevada During Site Characterization of the Proposed High-Level Nuclear Waste Repository Site at Yucca Mountain, Nevada*. NWPO-TR-008-88. Carson City, NV: Nuclear Waste Project Office

US Department of Energy. 1986. *Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada, Vols. 1-3*. May, DOE/RW-0073. Washington, DC: OCRWM.

US Department of Energy. 1988a. *Site Characterization Plan*. December, DOE/RW-0199. Washington, DC: OCRWM.

US Department of Energy. 1988b. *Environmental Monitoring and Mitigation Plan for Site Characterization*. December, DOE/RW-0208. Las Vegas, NV: NVO.

US Department of Energy. 1988c. *Environmental Regulatory Compliance Plan for Site Characterization*. December, DOE/RW-0209. Las Vegas, NV: NVO.

US Department of Energy. 1988d. *Draft Environmental Program Review*. December, DOE/RW-0207. Washington, DC: OCRWM.

US Department of Energy. 1988e. *Environmental Survey Preliminary Report: Nevada Test Site, Mercury, Nevada*. April, DOE/EH/OEV-15-P, Washington, DC: ES&H/OEA.

US Department of Energy. 1988f. *Environmental Survey Summary*. September, DOE/EH-0072. Washington, DC: ES&H/OEA.

US Department of Energy. 1988g. *Environment, Safety, and Health Needs of the US Department of Energy: Volume 1: Assessment of Needs*. December, DOE/EH-0079. Washington, DC: ES&H.

US General Accounting Office. 1988. *Energy Issues*. November GAO/OCG-89-16TR. Washington, DC: GAO.

US Nuclear Regulatory Commission. 1988. NEPA review procedures for geologic repositories for high-level waste: Proposed rule. *Federal Register* 53(87):16131–16147.

US Senate. 1987. *Nuclear Protection and Safety Act of 1987 (S. 1085) and Accompanying Report 100-1073 (Calendar No. 334)*. September 24, Washington, DC: 100th Congress, 1st Session.

Walker, M. L. 1987. *Statement of the US Department of Energy Assistant Secretary for Environment, Health, and Safety, M. L. Walker*. 10 February, Serial No. 100-8, p. 64–67. Washington, DC: Congressional Record, 100th Congress, 1st Session.

# ATTACHMENT B

# Siting America's Geologic Repository for High-Level Nuclear Waste: Implications for Environmental Policy

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ABSTRACT / Siting a geologic repository for isolating high-level nuclear waste up to 10,000 years is a controversial undertaking never before attempted in the United States. The Nuclear Waste Policy Act of 1982 exempted repository siting from important requirements for environmental review under the National Environmental Policy Act. In December 1987, the Nuclear Waste Policy Amendments Act identified Yucca Mountain as the first site to be characterized for a high-level nuclear waste repository. In light of the unproven nature of the technology being evaluated, the scientific uncertainties associated with Yucca Mountain, and the lack of proven methods for risk evaluation, the environmental policies for repository siting represent a significant departure from more traditional, comprehensive, and interdisciplinary environmental review for siting nuclear projects. The policies warrant further study by those interested in how present as well as future decisions about complex technologies may be made.

Deciding where to locate a geologic repository for disposing of high-level nuclear wastes in the United States is a complex issue. The policy that dictates the siting program was set forth by the Nuclear Waste Policy Act of 1982 (NWPA), which subsequently was amended by the Nuclear Waste Policy Amendments Act of 1987 (NWPAA). Davenport (1986) and Frishman (1986) reviewed the intricate legal matters concerning high-level nuclear wastes, and Carter (1987) and Cooper (1988) provided accounts of the multitudinous policy-making considerations and involved history leading to the current program. Others discuss the wide range of technical issues involved in developing a repository (Roxburg 1987, Chapman and McKinley 1987) and the myriad socioeconomic considerations associated with facility siting (Colglazier 1982, Walker and others 1983). Missing from these reviews is a perspective on the normative implications of the present nuclear waste program to environmental policy. Such a perspective is important because the program has generated numerous but inadequately studied controversies regarding standards of environmental review for complex technologies.

While the issues faced by the nation in disposing of as much as 50–100 tons of commercial and defense high-level nuclear wastes by the year 2000 or shortly thereafter are of considerable importance, relatively stringent and comprehensive environmental review called forth by the National Environmental Policy Act (NEPA) has been compromised by NWPA and NWPAA of the sake of political expediency (Carter 1987, Cooper 1988, Clary and Kraft 1988). In light of what is generally perceived as the prevailing public attitude in favor of vigilant environmental protection and the contradictory eclipse of and unfulfilled potential of NEPA, it is important to be aware of how current nuclear waste policy is evolving and what its potential implications are to the future of decision making for protecting the environment (Caldwell 1985, Bartlett 1986, Renwick 1988).

KEY WORDS: Environmental policy; Nuclear wastes; National Environmental Policy Act; Nuclear Waste Policy Act; Yucca Mountain

## The Repository Siting Program

### Background History

A detailed history of events leading to passage of NWPA in early 1983 is provided by Carter (1987), who shows that, simply put, nuclear weapons and nuclear energy are examples of technologies that have created large quantities of wastes for which a proven and acceptable management solution does not exist. When the United States adopted nuclear technology, it was believed that reprocessing of high-level radioactive wastes would be a significant component of the management scheme ultimately adopted by the federal government. The failure of recycling as an option for waste management resulted in consideration of various alternative permanent disposal methods with the prevailing view being that disposal in deep geologic repositories was the preferred alternative. This is the concept that was adopted and incorporated into NWPA, which authorized the Department of Energy (DOE) to undertake a program for developing two repositories, one in the western United States and a second in the eastern portion of the nation.

Because the decision to pursue the repository solution had been evident as early as 1979 and was formally made by the president in 1980, the DOE had initiated its repository siting program in advance of passage of NWPA. In so doing, it was natural that the agency should seek sites on its own reservations that held the promise of being acceptable from the standpoint of waste containment. However, technical and advisory studies pointed to salt deposits as a preferred medium for geologic disposal and none of DOE's reservations was underlaid by salt beds or domes. For this reason DOE initiated investigations to locate suitable salt deposits in addition to undertaking studies on lands it controlled. Thus, before NWPA was conceived, DOE had identified potential repository sites: in basalt at the Hanford Reservation, Washington; in welded tuff at Yucca Mountain, Nevada, which borders the Nevada Test Site (NTS); and at seven locations underlaid by salt deposits in Louisiana, Mississippi, Texas, and Utah.

Once DOE started considering sites on land it did not control, it became clear that the agency faced significant difficulties in dealing institutionally with other federal agencies and with state governments. States often questioned the technical adequacy of sites, and they demanded a strong voice in repository decisions. Consequentially, DOE turned to congressional support for the repository siting program and worked to create national legislation for establishing siting procedures and dealing with states' rights (Carter 1987). This effort resulted in passage of NWPA, which was signed into law in early January 1983.

## Environmental Review under the Nuclear Waste Policy Act

The procedures set forth in NWPA for selecting a suitable repository site were complex, intricately crafted, and reflected a delicate balance between technical and political considerations. Primacy in selecting repository sites was to be given to technical factors, even though the NWPA specified that a first repository would be located in the west and a second one in the eastern United States. This concession to regional politics and equity was essential and constituted a significant compromise to repository siting procedures. A role was also provided for state and local governments to participate in the siting process. However, this role eventually was compromised as DOE increasingly asserted its authority over states in the face of public opposition and controversy surrounding the site selection process (Carter 1987, Gervers 1987, Kraft 1988, Clary and Kraft 1988).

The NWPA contained several provisions that guided environmental review of potential repository sites, and that served to eclipse NEPA as a comprehensive policy act for environmental protection. Sections 112(f) and 114(f) limit the analysis of alternatives that normally would be addressed under NEPA. Section 112(f) represents congressional premises that: (1) a repository is needed, (2) the appropriate timing for construction of the repository is as specified in the statute, and (3) deep underground burial is the desirable means to dispose of high-level radioactive waste and spent nuclear fuel. These premises are presumably not subject to litigation (Montagne 1985). Section 114(f) states:

> "compliance with the procedures and requirements of this [Act] shall be deemed adequate consideration of the need for a repository, the time of the initial availability of a repository, and all alternatives to the isolation of high-level radioactive waste and spent nuclear fuel in a repository."

Sections 112(e) and 113(d) exempted DOE from major environmental reviews required by NEPA Sections 102(2)(c) and 102(2)(E), which require preparation of comprehensive environmental impact statements (EISs) and consideration of alternative courses of action that might involve conflicting uses of the same resources. The NWPA also exempted DOE from NEPA Section 102(2)(F), which requires recognition of the worldwide and long-range consequences of decisions. Lastly, Section 112(b)(3) required DOE to use available data for environmental assessments (EAs) rather than acquiring more empirical information needed for comprehensive evaluation of each site. An important consequence of the exemptions to NEPA is that less emphasis was given to considerations of alternative actions, which is the heart of the EIS as per Council of Environmental Quality (CEQ) regulations 40 CFR 1502.14.

The NWPA Sections 114(d) and 114(f) limit the customary role of the Nuclear Regulatory Commission (NRC) in evaluating environmental impacts for siting of nuclear facilities by restricting involvement to licensing once a construction site is selected and by requiring the agency to utilize DOE's EIS to the extent practicable. This, in effect, let DOE identify potential repository sites while being exempt from the stringent environmental regulations typically enforced by NRC in siting America's nuclear facilities.

Lastly, three western and three eastern sites were to be recommended for site characterization studies by

1985 and 1989, respectively. Consequently, NWPA defined a rapid schedule of tasks for DOE, even though the scientific community concluded that insufficient time would be available to obtain necessary scientific and technical information by established deadlines (Clary and Kraft 1988).

### Narrowing the Number of Sites for Characterization

During the same time that DOE was focusing on the nine preselected sites for the first repository, it was also developing the siting guidelines and preparing the statutory EAs required by NWPA. The simultaneous development of the guidelines and the EAs assured that no undue problems with evaluating a site would arise. In accord with NWPA procedures, once the EAs were prepared for the nine sites, DOE selected three for intensive site characterization that was to involve both surface and underground investigations of geology, hydrology, and other environmental conditions. In May 1986, DOE released the EAs and announced that sites at Hanford, Yucca Mountain, and Deaf Smith County, Texas, were the choices for characterization (Department of Energy 1986a).

Because of the absence of comprehensive site-specific environmental information and the lack of completed site characterization plans for describing proposed actions, the EAs were not well received by the affected states and the public (Clary and Kraft 1988). Moreover, the DOE analysis that ranked the sites in order of suitability for repository siting revealed that DOE had not designated the top three for characterization but instead had chosen the fifth in rank (Hanford, Washington) over the second (Richton, Mississippi) (Department of Energy 1986b). This was seen as a victory for the State of Mississippi, which had vigorously opposed being a host state to a DOE repository (Carter 1987, Gervers 1987). It subsequently was learned in congressional investigations and elsewhere that DOE had shown a bias in favor of the sites associated with DOE reservations and had suppressed unfavorable environmental and geological information reflecting adversely on the Hanford and Yucca Mountain sites (US House of Representatives 1986, US General Accounting Office 1988, Johnson 1988, Crowe and others 1988, Wells and others 1988, Szymanski in press).

Additional controversies also developed during this stage of the site selection process. The DOE did not completely share information it possessed with either affected states or the public (Clary and Kraft 1988). Questions arose concerning technical considerations affecting site suitability (Carter 1987, Brown 1987a, Strolin 1987). Moreover, DOE's consultation process became controversial because of the perception that environmental review was not adequately addressed in the siting process (Kraft 1988, Clary and Kraft 1988). As a result of these perceived or real problems, initial openness to the nuclear waste program turned to opposition (Gervers 1987).

### Designation of Yucca Mountain for Characterization: Questions of Technical Adequacy

Controversy and opposition to the DOE siting program resulted in political stalemate. Congress therefore concluded that the program was flawed and redirected it (Brown 1987a, Cooper 1988). Thus, in late 1987 the NWPAA was passed. The act mandated that only one repository be constructed instead of two and that Yucca Mountain be the only site to be characterized for suitability.

Issues of technical adequacy for a geologic repository at Yucca Mountain have immense consequences because of the requirement that the site be suitable for containing highly radioactive wastes for 10,000 years. Safely isolating wastes for such a period of time is a unique and ambitious undertaking never before attempted. This challenge makes geologic repository siting and development entirely different from all previously undertaken large-scale efforts. The geologic and hydrologic histories and characteristics of the host setting must be better known than any geologic area ever studied. An unprecedented demand thus is being placed upon science and technology to identify a primary geologic barrier that will protect nuclear wastes from interaction with the natural geohydrologic setting. Projections of the performance of the geologic barrier require an understanding of the interaction of the various geologic factors and processes within the natural repository setting. Geohydrologic, geochemical, thermal, and mechanical factors and processes, as well as tectonic behavior, all relate to one another. Their coupled effects on waste isolation and integrity of the repository must be clearly understood if the repository performance is to be predicted.

There is a growing body of information that is providing insights to the geologic and geophysical setting of the area (e.g., *Journal of Geophysical Research* 1987, Johnson 1988, Center for Neotectonic Studies 1988, Center for Volcanic and Tectonic Studies 1988, State of Nevada 1985). These studies concern structural relationships within a regional framework and have, among other things, delineated zones of weakness affecting the stability of the Yucca Mountain area. Ongoing research has identified six major site suitability issues for the evaluation of the site for a potential high-level nuclear waste repository:

(1) effects of future tectonic events on site integrity,
(2) effects of future volcanism on site integrity,
(3) potential for contamination of the, regional aquifer beneath the site,
(4) effects of future climatic variation on the hydrological regime and integrity of the site,
(5) the nature of moisture and gas movement through the unsaturated zone at the site, and
(6) the nature of extractable natural resources at the site and the consequent potential for future human intrusion that could compromise site integrity.

Resolving these and other issues of similar significance that will arise as more is learned about the science of siting a geologic repository will challenge the state of the art of science itself (Johnson 1988). Already, available geophysical testing technologies have been found inadequate for delineation of the subsurface and stratigraphy to the degree of refinement required. Additionally, the science of hydrology in the unsaturated zone is in its infancy, and there is little agreement regarding validation of existing and new computer modeling techniques for analysis of existing conditions and for predicting hydrologic response to other geologic processes such as tectonism and variable heat flow. Such problems become critical in view of the philosophy behind deep geologic waste disposal: that the geological system in which the repository is developed is the primary barrier for waste isolation.

Effective waste containment relies upon the known geologic and hydrologic characteristics of the site and the setting, an ability to predict how future processes and events will alter the known characteristics, and means of evaluating the risks involved. Consequently, effective waste containment requires complex but inadequately developed capabilities (Kraft 1988). The concept of performance assessment for a repository and the information needed to accomplish it involve intricate problems whose solutions are constrained by the primitive nature of risk assessment and evaluation methods (Freudenburg 1988).

There are other reasons for concern over the siting program, one of the most significant being the DOE decision to rely on the statutory EA for the Yucca Mountain site as evidence that adverse impacts are unlikely to result from site characterization (Department of Energy 1986c). Accordingly, DOE does not intend to conduct comprehensive environmental baseline investigations before the site is disturbed by characterization activities (Department of Energy 1988a). Limited monitoring for impacts once characterization is underway may occur for sensitive biota at the site, archeological resources that would be directly disturbed, total suspended particulates in the atmosphere, and limited parameters for groundwater resources at Yucca Mountain. There will be no measures of ecosystem integrity, no basis for comprehensive environmental review and evaluation, and the gaps in information existing in the EA with regards to air and water quality, land, use, soils, ecosystems, noise, and aesthetics will remain unfilled prior to site disturbance (State of Nevada 1987).

An example of the potential environmental problems that can arise as a result of inadequate information and evaluations in the statutory EA is the issue of threatened and endangered species and critical habitat at Devil's Hole and Ash Meadows in California and Nevada. The statutory EA mentions these protected resources but fails to provide any useful information into potential impacts from site characterization activities at Yucca Mountain, about 50 km to the north. During recent studies of Devil's Hole, Ash Meadows, and the associated groundwater basin, on which Yucca Mountain borders to the west, evaluation of existing information illustrated that groundwater impacts at Yucca Mountain can be expected to affect Devil's Hole and Ash Meadows (Winograd and others 1988). On the strength of such concerns, the US National Park Service filed a protest over DOE's application for water rights at Yucca Mountain (Williams 1989). This action almost certainly will bring the US Fish and Wildlife Service and the Endangered Species Act into consideration because of the number of protected species and habitats involved and the recognition of the criticality of groundwater in a basin already experiencing excessive consumption (Fish and Wildlife Service 1983, 1985). Issues such as these were not resolved by the statutory EA because it did not contain results of a more rigorous environmental review.

## Discussion and Conclusions

The program for siting a geologic repository for disposing of America's high-level nuclear waste and its implementation by DOE involve a number of considerations with respect to how environmental policy should be conceived and implemented for technologically complex and controversial projects. These include issues such as the federal policy for environmental review with respect to the role of NEPA, the role of organizations and individuals in technological review, the technical adequacy of the repository program, and assessments of the risks involved.

Environmental review for the siting program was guided by several important statutory provisions of

NWPA. Extensive site-specific scientific information, based upon systematic interdisciplinary methods, was not required for each potential repository site. Sections 112(f) and 114(f) limited the discussion of the full range of alternatives that would normally be applied to the first repository under the full force of NEPA. Sections 112(e) and 113(d) exempted DOE from environmental reviews required by NEPA Sections 102(2)(C), (E), and (F). The requirement for an EIS in accord with CEQ regulation 40 CFR 1500-1508 was replaced by a NWPA-mandated statutory environmental assessment designed to evaluate siting guidelines promulgated by DOE itself (Mussler 1984). The adequacy of environmental review was also constrained by the deadlines established by NWPA (Kraft 1988).

The NWPA Section 112(b)(3) hastened preparation of the statutory EAs by requiring DOE to use available data for the assessments rather than acquiring the comprehensive. empirical information needed for evaluating each site. This meant that the siting guidelines developed and applied in the statutory EAs could not call for evaluation of criteria for which data failed to exist. If such evaluation were called for, the consequence would be that some of the nine predetermined sites would be disqualified a priori. To accommodate this situation with respect to potential environmental impacts in the absence of full scientific information, DOE equated environmental protection with the intent to comply with individual federal environmental laws. Merely by expressing the intent to comply, and without conducting full regulatory reviews, DOE was able to conclude in the statutory EAs that no significant impacts would occur as a result of site characterization activities. Because of the NEPA exemptions granted by NWPA, the ruling reached by the courts in the landmark Calvert Cliffs case stating that compliance with environmental regulations does not relieve an agency from the necessity of performing a comprehensive, integrated review of potential impacts, does not apply to the DOE position (Rogers 1977).

The NWPA also limited environmental review of the DOE siting program by the NRC. Under 10 CFR 51, the NRC typically requires strict environmental review for siting nuclear facilities, but Congress reduced NRC involvement in the siting process. By rendering CEQ and NRC regulations for NEPA review inapplicable to site characterization, NWPA assured that the statutory EAs to be prepared by DOE would be governed only by the siting guidelines subsequently to be prepared by DOE itself under 10 CFR 960.

The exemptions from NEPA review granted to repository site characterization studies by NWPA, coupled with the prohibition on new studies to provide empirical information needed for comprehensive environmental evaluation, must be assessed by those interested in the future of environmental policy. Scholars of NEPA have observed that the potential of NEPA has yet to be realized (Caldwell 1985, 1987), that the rationality embodied by NEPA is unique among environmental laws (Bartlett 1986), and that the current trend is toward an eclipse of NEPA by other laws (Renwick 1988). The eclipse of NEPA is especially of concern because it is the only legislation that calls for the systematic, interdisciplinary assessment of environmental consequences in the repository siting program. In the case of repository siting, regulations requiring NEPA review were replaced by a set of evaluative guidelines conceived by the same agency that was to follow them and with full knowledge of where the gaps in information existed that could impede the evaluation. This regulatory approach is basically one of self-regulation. Numerous studies have attributed environmental, health, and safety problems at DOE facilities to similar forms of self-regulation (US Government Accounting Office 1986, US Senate 1987, Department of Energy 1988b, National Academy of Sciences 1988).

The fact that complete environmental information was not obtained before Yucca Mountain was designated as the only site to be characterized for suitability as a repository has additional implications. Examination of the legislative history indicates that NWPAA contains the presumption that Yucca Mountain is qualified until there are adequate data that would clearly disqualify it. However, this presumption works in concert with the fact that DOE has used only existing or available data for the siting process. These guidelines, combined with the fact that alternative sites are not being characterized, do not ensure that the best or safest available site is selected. Once Congress made the decision to only characterize the Yucca Mountain site under provisions of NWPAA, no other site could be substituted without clear demonstration that Yucca Mountain is unacceptable for compelling scientific reasons (Cooper 1988). The burden of proof for determining whether Yucca Mountain is unacceptable is placed on DOE. As shown by Brown (1987b), it is difficult for the party with the burden of proof to sustain that burden if challenged by others who assert that the burden has not yet been met. In part, this difficulty is due to the fact that environmental problems are complex, and environmental assessments often are not able to predict impacts with reasonable certainty (Lemons 1986, Freudenburg 1988). The placement of the burden of proof on DOE, combined with the fact that neither DOE nor Congress is willing to consider characterization of alternative sites at this time or in the forseeable future, increases the likelihood of a final decision being made to develop a repository at Yucca Mountain (Cooper 1988).

In terms of what policy best guides environmental review, there is the implication here that Congress was wrong to eclipse statutes and concepts embodied in NEPA and that the action may establish a precedent for future complex, controversial programs. What must be recognized is that the final decision concerning where to locate the geologic repository for high-level nuclear wastes is one of the most technically and ethically complex decisions that the nation faces. The potential consequences of a repository are far-reaching because the risk of an ultimate failure will be borne by future generations over the next 10,000 years. In the context of politics, such a vast period of time and the concept of future generations are beyond the capacity of many to understand and deal with in a meaningful way (Bishop and others 1978, Partridge 1981). Inadequacies in scientific understanding of the Yucca Mountain site due to a lack of comprehensive information thus imply unknown and unperceived risks to the distant future. Because of the complexity of the issues, the highly uncertain consequences associated with siting a geologic repository for high-level nuclear wastes, and the primitive nature of risk assessment and risk evaluation procedures, it is impractical that any individual or even one federal agency can know what constitutes the best or most acceptable consequences.

Given the fact that there is room for judgment in the face of uncertainty about repository decisions in general, and Yucca Mountain specifically, the question remains whether the best national policy is one that sets aside portions of NEPA that recognize the need for systematic, interdisciplinary review of environmental decisions. Such a policy discounts the very type of information and procedures necessary to make more open and fully informed decisions about complex technologies. Thus, it seems that a full analysis is needed of the implications of the nation's current nuclear waste policy on the future of policy making for environmental review and protection.

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## Literature Cited

Bartlett, R. V. 1986. Rationality and the logic of the National Environmental Policy Act. *The Environmental Professional* 8:105–111.

Bishop, W. P., D. H. Frazier, I. R. Hoos, P. E. McGrath, F. S. Metlay, W. C. Stoneman, and R. A. Watson. 1978. Proposed goals for radioactive waste management. NUREG-0300. US Nuclear Regulatory Commission, Washington, DC, 22 pp.

Brown, G. E., Jr. 1987a. US nuclear waste policy: Flawed but feasible. *Environment* 29:6–7, 25.

Brown, D. A. 1987b. Ethics, science, and environmental regulation. *Environmental Ethics* 9:331–350.

Caldwell, L. K. 1985. NEPA's unfulfilled potential. *The Environmental Forum* 2(1):38–41.

Caldwell, L. K. 1987. The contextual basis for environmental decisionmaking: Assumptions are predeterminants of choice. *The Environmental Professional* 9:302–308.

Carter, L. J. 1987. Nuclear imperatives and public trust: Dealing with radioactive waste. Resources for the Future, Inc., Washington, DC, 473 pp.

Center for Neotectonic Studies. 1988. Evaluation of the geologic relations and seismotectonic stability of the Yucca Mountain area. October, 1988. Mackay School of Mines, University of Nevada, Reno, 156 pp.

Center for Volcanic and Tectonic Studies. 1988. Regional importance of post-6 m.y. old volcanism in the Southern Great Basin: Implications of risk assessment of volcanism at the proposed nuclear waste repository at Yucca Mountain, Nevada. September 1, 1988. Report Number 10, University of Nevada, Las Vegas, 39 pp.

Chapman, N. A., and I. G. McKinley. 1987. The geologic disposal of nuclear waste. John Wiley & Sons, New York, 280 pp.

Clary, B. B., and M. E. Kraft. 1988. Impact assessment, policy failure, and the Nuclear Waste Policy Act. 10–12 March 1988. Western Political Science Association, San Francisco, California, 35 pp.

Colglazier, E. W. 1982. The politics of nuclear waste. Pergamon Press, New York, 264 pp.

Cooper, B. 1988. Legislative redirection of the nuclear waste program. 28 February 1988. Symposium, Waste Management 1988. University of Arizona, Tucson, Arizona, 12 pp.

Crowe, B. M., F. W. Perry, B. D. Turrin, S. G. Wells, and L. D. McFadden. 1988. Volcanic hazard assessment for storage of high-level radioactive waste at Yucca Mountain, Nevada. Paper Number 6372. Page 153 *in* Abstracts with program—1988, 84th annual meeting, Cordilleran Section, Geological Society of America, 29–31 March 1988, Las Vegas, Nevada.

Davenport, J. H. 1986. The law of high-level nuclear waste. *Tennessee Law Review* 53:481–526.

Department of Energy. 1986a. Recommendation by the Secretary of Energy of candidate sites for site characterization for the first radioactive-waste repository. DOE/S-0048. US DOE, Washington, DC, 9 pp.

Department of Energy. 1986b. A multiattribute utility analysis of sites nominated for characterization for the first radioactive-waste repository: A decision-aiding methodology. DOE/RW-0074. US DOE, Washington, DC, 129 pp.

Department of Energy. 1986c. Environmental assessment:

Yucca Mountain Site. Nevada Research and Development Area. Nevada. DOE/RW-0073. US DOE. Washington. DC. 902 pp.

Department of Energy. 1988a. Environmental program overview. DOE/RW-0207. US DOE. Washington. DC. 52 pp.

Department of Energy. 1988b. Environment. safety. and health needs of the US Department of Energy. Volume I: Assessment of needs. DOE/EH-0079. US DOE. Washington. DC. 40 pp.

Fish and Wildlife Service. 1983. Determination of endangered status and critical habitats for two fish species in Ash Meadows. Nevada. *Federal Register* 48(172):40178–40186.

Fish and Wildlife Service. 1985. Determination of threatened status with critical habitat for six plants and one insect in Ash Meadows. Nevada and California and endangered status with critical habitat for one plant in Ash Meadows. Nevada and California. *Federal Register* 50(97):20777–20794.

Freudenburg, W. R. 1988. Perceived risk. real risk: Social science and the art of probabilistic risk assessment. *Science* 242:44–49.

Frishman. S. 1986. High-level waste repository siting: A state perspective. *Tennessee Law Review* 53:527–540.

Gervers, J. H. 1987. The NIMBY syndrome: Is it inevitable? *Environment* 29(8):18–20, 39–43.

Johnson. C. A. 1988. Oversight—a key ingredient in the high-level waste repository program. 4 November 1988. American Nuclear Society International Conference. Washington. DC. 5 pp.

*Journal of Geophysical Research*. 1987. Geophysical investigations of radioactive waste disposal sites in the western United States. *Journal of Geophysical Research* 92(B8):7783–7864.

Kraft. M. E. 1988. Evaluating technology through public participation: The nuclear waste disposal controversy. Pages 253–277 *in* M. E. Kraft and N. J. Vigs (eds.). Technology and politics. Duke University Press. Durham. North Carolina.

Lemons, J. 1986. Ecological stress phenomena and holistic environmental ethics: A viewpoint. *The International Journal of Environmental Studies* 27:9–30.

Montagne. C. H. 1985. The initial environmental assessments for the nuclear waste repository under Section 112 of the Nuclear Waste Policy Act. *Journal of Environmental Law* 4:187–229.

Mussler. R. M. 1984. Environmental assessments required to support nomination of sites. Pages 243–244 *in* Proceedings of the 1983 civilian radioactive waste management information meeting. CONF-831217. US Department of Energy. Washington. DC.

National Academy of Sciences. 1988. Safety issues at the defense production reactors: A report to the Department of Energy. National Academy Press. Washington. DC. 68 pp.

Partridge. E. (ed.). 1981. Responsibilities to future generations. Prometheus Books. Buffalo. New York.

Renwick. W. H. 1988. The eclipse of NEPA as environmental policy. *Environmental Management* 12:267–272.

Rogers. W. H., Jr. 1977. Environmental law. West Publishing Company. St. Paul. Minnesota. 281 pp.

Roxburg. I. S. 1987. Geology of high-level nuclear waste disposal: An introduction. Chapman and Hall. New York. 229 pp.

State of Nevada. 1985. Comments on the US Department of Energy Draft Environmental Assessment for the Yucca Mountain Site: Volume I. March 1985. Nuclear Waste Project Office. Carson City. Nevada. 212 pp.

State of Nevada. 1987. Environmental program planning for the proposed high-level nuclear waste repository at Yucca Mountain. Nevada. NWPO-TR-001-87. Nuclear Waste Project Office. Carson City. Nevada. 127 pp.

Strolin. J. C. 1987. Nuclear waste disposal: A national dilemma with significant implications for Nevada. *Nevada Public Affairs Review—Legislative Issues* 1:78–83.

Szymanski, J. S. Conceptual considerations of the Death Valley groundwater system with special emphasis on Yucca Mountain. Nevada. DOE/RW-0000. US Department of Energy. Las Vegas. Nevada (in press).

US General Accounting Office. 1988. Nuclear waste: DOE's handling of Hanford Reservation iodine information. GAO/RCED-88-158. US GAO. Washington. DC. 27 pp.

US House of Representatives. 1986. Staff investigations into DOE's selection of three sites for characterization as the nation's first repository for high-level radioactive waste. Subcommittee on General Oversite. Northwest Power. and Forest Management and subcommittee on Energy Conservation and Power. 99th Congress. 2nd Session. October 1986. Washington. DC.

US Senate. 1987. Nuclear Protections and Safety Act of 1987 (S. 1085) and Accompanying Report 100-1073 (Calendar Number 334). 100th Congress. 1st Session. 24 September 1987. Washington. DC. 48 pp.

Walker. C. A., L. C. Gould. and E. J. Woodhouse. 1983. Too hot to handle: Social and policy issues in the management of radioactive waste. Yale Press. New Haven. Connecticut.

Wells. S. G., L. D. McFadden. C. Renault. B. D. Turin. and B. M. Crowe. 1988. A geomorphic assessment of quaternary volcanism in the Yucca Mountain area. Paper Number 2266. Page 242 *in* Abstracts with program—1988. 84th annual meeting. Cordilleran Section. Geological Society of America. 29–31 March 1988. Las Vegas. Nevada.

Williams. O. R. 1989. Protest to water application number 52338: Filed with the Nevada State Engineer. 3 January 1989. US National Park Service. Denver. Colorado. 1 pg.

Winograd. I. J., B. J. Szabo. T. B. Coplen. and A. C. Riggs. 1988. A 250,000-year climatic record from Great Basin vein calcite: Implications for Milankovitch theory. *Science* 242:1275–1280.

# ATTACHMENT C

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# FRAMEWORKS FOR DECISIONS ABOUT NUCLEAR WASTE DISPOSAL

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*(Received December 18, 1988)*

Recent decisions have established Yucca Mountain, Nevada, as America's first characterization site for a high-level nuclear waste repository. The decision remains controversial because it generated numerous understudied and unresolved value-laden public policy issues. This paper describes several alternative frameworks for assessing decisions about nuclear waste disposal, and is intended to supplement our previous study on the Yucca Mountain repository.

KEY WORDS: Nuclear waste, environmental ethics.

## INTRODUCTION

In a previous paper, we describe how America's policies for disposal of high-level commercial and defense nuclear wastes are governed by national legislation such as the National Environmental Policy Act (NEPA), the Nuclear Waste Policy Act (NWPA), and the Nuclear Waste Policy Amendments Act (NWPAA).[1] The NWPAA recently established Yucca Mountain, Nevada, as the nation's first characterization site for a high-level nuclear waste repository. In our aforementioned paper, we show how NWPA, NWPAA and decisions made by the Department of Energy (DOE) have generated controversial but understudied value-laden public policy issues.

Examples of such issues include the following: First, NEPA is considered to be one of the most important pieces of national legislation calling for protection of environmental values. The NWPA exempted the repository site selection process from important NEPA requirements. This reduced the rigor of environmental assessments, and made it appear that debates should be focused primarily on technical and economic factors rather than on more broad environmental values described in NEPA. Second, NWPA originally required open participation, consultation, and cooperation between people with different interests and values. However, many DOE decisions and Congressional actions were consistent with more narrow technological perspectives regarding repository site selection, and therefore did not sufficiently allow for public participation as mandated by NWPA.[2] In addition, DOE did not foster cooperation and consultation with Nevada nor compliance with state

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environmental regulations as required by NWPA.[3] Third, many DOE decisions were based upon scientifically inadequate environmental assessments.[2] This violated the ideals of science that call for open discussion, dialogue, and debate regarding scientific issues. Fourth, NWPAA established Yucca Mountain as the only site for characterization and therefore disregarded the concern for an equitable sharing of risks between different parts of the country as originally mandated by NWPA. Fifth, NWPAA provides compensation to Nevada for being repository host, but also imposes restrictions upon the state in order for it to receive said compensation. Nevada contends that the compensation is manipulative because of the requirement that basic and existing rights and duties be relinquished.[4] Sixth, many people distrust decisions made by government and corporate experts in the nuclear industry because of perceptions that the public has not been fully informed of risks or allowed to participate in decisionmaking, and because protection of the environment, health, and safety of people has been inadequate under existing legislation and administrative decisions.[5,6]

The Yucca Mountain siting decision remains controversial. In addition, the General Accounting Office's (GAO) recent report documents that the nation's cleanup of nuclear wastes may cost more than $130 billion.[6] In comparison, the federal government spent $160 billion last year on all domestic discretionary programs. These budgetary demands will intensify pressure to do something about the nuclear waste cleanup issue. However, a lasting solution to the nuclear waste problem requires that adequate scientific information, as well as open debate and discussion of controversial value-laden public policy issues be part of the decisionmaking process. Such a solution is not likely to be forthcoming unless frameworks for assessing public policy decisions are better understood.[5,7]

In the remainder of this article we discuss alternative perspectives and frameworks for assessing value-laden decisions about nuclear waste disposal. This paper supplements our previous paper on the Yucca Mountain siting decision, which contains an in-depth analysis of events leading to the decision and a discussion of public policy issues which it generated.[1]

## FRAMEWORKS FOR MAKING DECISIONS

A fundamental dilemma surrounding nuclear wastes concerns the tension that exists between: (a) our knowledge of the long-term effects of nuclear waste, and (b) our awareness of the fact that the longevity of nuclear wastes gives rise to both scientific, political, and ethical uncertainty in our assessment of its practical consequences. Given this dilemma, what decisionmaking frameworks exist that can guide decisionmaking?

### 1. *Citizen Participation and Acceptability of Nuclear Waste Siting Decisions*

An important component in public policies involving siting nuclear waste repositories is the determination of risk and the level of risk that is deemed to be acceptable. Following environmental assessments that provide an indication of the probability and magnitude of environmental and public health risks, decisions are made that in effect declare a certain level of risk to be acceptable.

The nuclear waste repository issue historically has been controversial, in part, for the technical reason that although a nuclear energy program exists it cannot be considered safe in the absence of a repository, and for the political reason that a repository has yet to be developed. The controversy involves several fundamental perspectives that influence decisionmaking about nuclear wastes.

The technological perspective is most common in decisions about nuclear waste disposal. It is highly analytical, and includes tools such a probability theory, decision and cost-benefit analysis, systems dynamics, and econometrics. Proponents of the technological perspective hold that the technical and organizational problems of managing a problem as large and complex as nuclear wastes are enormous. They maintain that the public cannot be expected to grasp the many scientific and technical issues. Further, they perceive that fundamental differences people have about how nuclear wastes should be handled generate endless debate and controversy. The technological perspective holds that if an agency such as DOE is given responsibility to accomplish tasks according to a specific schedule, then it must be given authority to manage and guide the program. This implies that while people and state representatives with different interests may review and comment on DOE documents, they would not be brought into the actual working or decisionmaking process. Also inherent in the technological perspective is the view that DOE can correct some conflicts through public relations activities, but ultimately Congress will need to exert the federal authority over states. This is, of course, exactly what happened in the passage of NWPAA.[1]

Decisions about complex technical issues that contain value-laden questions are typically made by technical/scientific experts who have a technological perspective. Such experts analyze value-laden questions in separate fact-value terms.[8] This type of analysis results from three factors: (a) Such decisionmakers have primarily scientific/technical backgrounds and therefore do not always understand the application of moral reasoning to ethical questions, (b) Much administrative discretion exists for rule-making, and (c) A lack of conceptual clarity of relevant words/phrases for ethically based decisions exists, as for example in the NEPA statement of purpose. A consequence is that science is given the role of assessing environmental impacts and risks, and evaluation of acceptability of impacts/risks is left to the political process or whatever ethical process might exist.[9] This solution isolates questions of epistemological and methodological uncertainty from influence by environmental ethics. Doubts about the validity and authority of scientific analyses and their resolutions are left to members of the scientific/technical community, in this case DOE. For purposes of ethical analysis, what remains after internal review by DOE scientific/technical experts is usually regarded as definitive. The fact that impact/risk assessment and uncertainty arguments regarding theory and method are largely confined to the DOE scientific/technical community prevents them from being a part of broader forms of ethical and public policy arguments that may undermine the legitimacy of an information gathering and decisionmaking process controlled primarily by scientific/technical experts.

Bella *et al.* discuss the democratic perspective, which maintains that the fundamental issue of nuclear waste management is the relationship of citizenry to institutions of power.[5] Is the relationship to be based upon trust or force, cooperation or manipulation? Repository siting decisions involve issues of citizen participation, distributive justice, concepts of freedom, and centralized versus decentralized decisionmaking.[5,10] Consistent with fundamental ideals of a democratic society, what is required is that institutions of power attempt to resolve conflicts in ways that are accountable to the public trust and not dominated by these institutions themselves.

In contrast to the technological perspective, the democratic perspective strives to develop procedures to integrate science and ethics in the formulation of public policy, so that they are not dealt with as separate fact-value issues in decisionmaking.

One approach is to demand that the general public or policy-making representatives become literate in the basic epistemological issues of evidence, uncertainty, and hypothesis, while simultaneously demanding that scientists learn to make concise, articulate defenses of why the best available evidence supports one conclusion instead of another.[8] The ethical validity of a particular decision is determined less by the particular values or goals that the decision may serve than it is by the incorporation of epistemological and ethical criteria into the decision process itself. It is the method of policy formation that is subject to moral critique, and if it is found to be adequate, then the moral justification of a particular decision consists in having been derived through valid procedures. The democratic perspective requires a high level of citizen participation in decisionmaking that is not controlled by federal agencies with a disproportionate amount of power. It also requires a relationship of trust between agencies and the public insofar as environmental protection is concerned.

The organizational and personal perspectives have been studied less than other perspectives, but are nevertheless relevant. The organizational perspective perceives technology from the point of view of affected and affecting organizations.[7] People with an organizational perspective are cognizant of parochial priorities and interests that are distinctive to his or her organizations, and tend to reinterpret information about technology in a way favorable to organizational goals. The most subtle and elusive perspective is the personal, which sees the world through the eyes of the individual, often in an intuitive manner. Technology is primarily evaluated in a way which relates individuals to the technology and its impacts.

Linstone *et al.* describe how perspectives on assessments such as nuclear waste depend on various assumptions which people have about the world and the questions they ask.[7] The researchers examine different modes of thought and paradigms for assessing decisions about technology. These include: (a) problem-solving, where an assumption exists that there is a solution to the problem; (b) cost-benefit analysis and related techniques, which search for an "optimal" solution; (c) reductionism, which assumes that subdividing and simplifying complex systems will lead to better understanding; (d) use of data and various models, which contain different assumptions about the nature of reality and hence lead to different modes of inquiry and conclusions; (e) quantitative and qualitative analysis, which defines the relationship and importance of measurables and immeasurables; (f) importance of the individual, which defines the role of the individual in the aggregrate view of things; (g) perception of time, which defines the time horizons in which different people or organizations make assessments about the future.

The differences in these modes of inquiry and paradigms are then used to classify similarities and differences between perspectives concerning, say, nuclear waste technology. Traits studied include Weltanschauung, characteristics of each perspective (e.g. product vs. process, rational vs. intuition, efficiency vs. creativity, analysis vs. experience, objective vs. subjective, etc.), preferred system of inquiry for problem-solving, and concepts of time used for assessments. Application of the different perspectives to assessments of technology such as nuclear waste can narrow the gap between models and reality in decisionmaking and therefore reduce controversy about public policy issues.

However, most assessments about nuclear waste reflect the technical perspective to the neglect of other perspectives discussed.[5,7] Accordingly, such assessments do not reflect the full benefit which could be gained by comparison with other perspectives. More importantly, few comparisions between different perspectives include consideration of an "ethical" perspective. For example, Shrader-Frechette documents how environmental assessments of nuclear power reflect a narrow technical and economic focus to the exclusion of important value-laden issues requiring ethical analysis.[11] We are not aware that any assessments have been made about nuclear waste disposal under NWPAA that include a comparison of ethical with other perspectives.

An ethical perspective is based upon the fact that many people believe decisions and actions should be predicated upon sound moral principles. Environmental ethicists have identified several criteria on which decisions about high-level nuclear waste storage need to be based in order for them to be more ethical and, hence, less controversial. These include principles of moral reasoning, normative ethics, and forms of rationality appropriate for environmentally-ethical decisionmaking.

The goal of moral reasoning is to develop the interest in and skills necessary for thinking carefully about questions of right and wrong, good and bad, justice and injustice, duty and obligation. As stated in Regan, requirements that should be met to make an ideal moral judgment might include the following: (1) Conceptual clarity, (2) Valid information, (3) Rationality, (4) Impartiality, and (5) Use of valid moral principles.[12]

Philosophers engaged in normative ethics attempt to go beyond the aforementioned principles of moral reasoning; they attempt to determine what moral principles are valid. While it is beyond the scope of this paper to discuss in detail theories of normative ethics, several criteria inherent in such theories include: (a) environmental compatibility, (b) utilitarianism, (c) distributive justice, (d) concepts of freedom, (e) citizen participation in decisionmaking, and (f) decentralized decisionmaking. Excellent discussions of normative ethics and environmental problems are found in Regan[12] and Attfield.[13]

## 2. *Congress and Nuclear Waste Policymaking*

Congress has played a major policy role on nuclear waste disposal, in funding the implementation of policy, and in overseeing policy implementation by the DOE and other federal agencies. Several criteria need to be applied to assess the role of Congress in the Yucca Mountain siting decision.

One important criteria for assessing Congressional actions is that of political legitimacy, which is a major ethical issue in the policy process. Political legitimacy usually refers to decisionmaking that is constitutional and acceptable to relevant political actors. These may be the general public, regulated groups or other actors (e.g. environmental groups or public utilities), legislators, and administrative officials. The focus is on procedural criteria that can lead to an agreed upon definition of the public interest, such as whether adequate opportunity is given for articulation of the issues, arguments by supporters and opponents of the policy, public involvement, interaction among policy actors, and consideration of technical information.

Applied to the Yucca Mountain siting decision, the question of political legitimacy allows consideration of important questions such as: (a) whether and to what extent pertinent scientific information (and uncertainty) was used, (b) whether states such as Nevada were given sufficient opportunity to express their concerns, and (c) whether the decisionmaking process itself was sufficiently open to allow a full airing of policy arguments.

Political legitimacy needs to be evaluated within different contexts of rationality to more fully assess Congressional decisions about nuclear waste siting.[14] Rationality is required for making good public policy decisions and moral judgments. Rationality is the ability to recognize the connection between different ideas, and to recognize that if some statements are true, then some other statements must be true while others must be false. It is in logic that rules are set forth that specify which statements follow from others, and it is because of this that a person who is rational often is said to be logical. To reach an ideal moral judgment, one must not only strive to make a judgment against a background of information and conceptual clarity, but must also explore how beliefs and facts are logically related to other things that are believed or not believed.[12]

Rationality is emphasized as a necessary trait to make ethically informed decisions. However, several forms of rationality exist which can serve as a basis for evaluation of the political legitimacy of Congressional decisions about nuclear waste disposal. It is important to understand the different forms of rationality and to make them explicit so that we can discern whether one form of rationality should have precedence over others.

Caldwell[14] and Bartlett[15] present an excellent discussion of different forms of rationality used in policy formulation and decisionmaking. Substantial rationality applies to individual decisions. Such rationality takes into account the possibilities and limitations of a given situation and reorganizes it so as to produce, increase, or preserve some good according to the goals of the particular individual. Functional rationality is characteristic of organizations that are structured to produce, increase, or preserve some good in a consistent and dependable fashion. Principles of order underlie both substantial and functional rationality. This implies that decisions are made according to principles and from organized structures which embody principles of order. Substantial and functional rationality therefore entail more than technical information, the efficient achievement of a single goal, or economic efficiency; the maximum achievement of a plurality of goals is a desired outcome.

Technological rationality refers to the systematic application of large-scale technology to most levels of human activity, including governmental and economic policies which have growth as their central aim. Technological rationality emphasizes uniformity, efficiency, impersonality, and centralized decisionmaking. Economic rationality views humans, as opposed to nature, as the basic unit of rational analysis; it also emphasizes the material welfare of humans and their mastery over nature. Economic rationality is applicable to tangible and commensurable values, but often disregards important ecosystem components with little economic value. In addition, economic rationality focuses on short-term instead of long-term benefits.

Social rationality is based on standards and principles other than efficiency, such as interpersonal relations, independence and freedom, and social action. Legal rationality refers to rationality appropriate to the fundamental rules of a society, the rationality of preventing disputes and providing solutions through a system of rules that are clear, consistent, detailed, and technical. Such rationality informs people/agencies about what resources are available to them, what persons/agencies can count on to perform actions, and what actions each person/agency must perform. Political rationality refers to decisionmaking structures in terms of order of discussion and decision. It reflects adequate provision for gathering and checking information, adequate provision for inventing and checking suggestions, and adequate procedures for combining suggestions into a decision. Lastly, ecological rationality may be thought of as pertaining to living systems which includes the relationships among human and nonhuman living systems and their environments in a holistic manner. Ecological rationality also stresses long-term benefits over short-term gains. Such rationality draws extensively from the science of ecology. However, the foundations for ecological reasoning include ethical, religious, literary, and experiential foundations as well as the scientific.[16]

Practical consequences occur if different forms of rationality are not made explicit by decisionmakers in the decisionmaking process and if they are not fully understood by them. Rationality is an important concept in policy-making, yet many decisions are controversial because they are based on different forms of rationality. For example, economic and legal rationality often conflict with ecological rationality. Fundamentally, environmental ethics is concerned with whether and on what bases ecological rationality is said to have precedence over other forms of rationality in environmental decisionmaking.

## CONCLUSION

Decisions about nuclear waste disposal are made within a context of scientific, ethical, and political uncertainty. Scientific uncertainty exists about suitability of geological sites, engineering design of repositories, and geohydrologic modelling. Ethical uncertainty exists, for example, concerning how to spatially and temporally distribute burdens created by nuclear waste disposal. There is no consensus on what perspectives about technology or decisionmaking frameworks should apply to nuclear waste disposal, and none fits the policy problems precisely. This creates uncertainty about public policy, which means that decisionmakers are, to an extent, feeling their way as they attempt to resolve a novel kind of public goods problem. The fact that most decisionmaking perspectives are imperfectly applied to nuclear waste disposal means that substantive environmental goals, uncertainty, and the use of power have a relatively more important role to play in decisions and therefore require additional study and public discourse. Although the most obvious characteristic of the different decisionmaking perspectives is that they often conflict with each other, it is through their interaction and conflict resolution that they lead to insights about the assessment of nuclear waste disposal that will not emerge otherwise.

In closing, we ask whether consideration of a perspective based upon environmental ethics can really be counted on to help guide environmental scientists and policy-makers in decisionmaking? It seems doubtful that ethical precepts can, at this time, provide decisive guidance to the environmental conscience where large, complex, multiple interest issues like nuclear waste disposal are involved. Hargrove, on the other hand, draws a hopeful conclusion from the dilemma by stating that ethics can help environmental professionals by assuring that facts and other input to decisions are brought into the open to influence policy makers.[17] The results, Hargrove believes, will be not that decisions are easier to make but that they will be made in a more honest, ethical, and straightforward manner than typically is the case and that the environmental scientist will have played a proper role in the process.

**References**

1. J. Lemons and C. Malone, "America's high-level nuclear waste repository: A case study of environmental science and public policy" *Int. J. Environmental Studies* (in press, 1989).
2. B. B. Clary and M. E. Kraft, "Environmental assessment, science, and policy failure: The politics of nuclear waste disposal" In: *Policy Through Impact Assessment* (ed. R. V. Barlett). In press.
3. State of Nevada, *A Role of Environmental Compliance for the State of Nevada During Site Characterization of the Proposed High-Level Nuclear Waste Repository Site at Yucca Mountain, Nevada,* NWPO-TR-008-88 (State of Nevada, Agency for Nuclear Projects, Carson City, NV, 1988).
4. R. H. Bryan, "The politics and promises of nuclear waste disposal: The view from Nevada" *Environment* **29**(8), 14–17, 32–38 (1987).
5. D. A. Bella, C. D. Mosher and S. N. Calvo, "Technocracy and trust: Nuclear waste controversy" *J. Professional Issues in Engineering* **114**, 27–39 (1988).

6. US General Accounting Office, *Nuclear Health and Safety, Dealing with Problems in the Nuclear* Defense Complex Expected to Cost Over $100 Billion, GAO/RCED-88-197BR (Washington, DC, 1988).
7. H. A. Linstone, A. Meltsner, M. Adelson, A. Mysior, L. Umbdenstock, B. Clary, D. Wagner and J. Schuman, "The multiple perspective concept with applications to technology assessment and other decision areas" *Technology Forecasting and Social Change* **20**, 275–325 (1981).
8. P. Thompson, "Uncertainty arguments in environmental issues" *Environmental Ethics* **8**, 59–76 (1986).
9. W. D. Ruchleshaus, "Science, risk, and public perception" *Science* **221**, 1026–1028 (1983).
10. R. A. Watson, *Goals for Nuclear Waste Management, NUREG-0412* (US Nuclear Regulatory Commission, Washington, DC, 1978).
11. K. S. Shrader-Frechette, "Environmental impact assessment and the fallacy of unfinished business" *Environmental Ethics* **4**, 37–47 (1982).
12. T. Regan (ed.), *Earthbound* (Random House, NY, 1984).
13. R. Attfield, *The Ethics of Environmental Concern* (Columbia University Press, NY, 1983).
14. L. K. Caldwell, "The contextual basis for environmental decisionmaking: Assumptions are predeterminants of choice" *The Environmental Professional* 9, 302–308 (1987).
15. R. V. Barlett, "Rationality and the logic of the National Environmental Policy Act" *The Environmental Professional* **8**, 105–111.
16. I. G. Barbour, *Technology, Environmental and Human Values* (Praeger, NY, 1980).
17. E. C. Hargrove, "The value of environmental ethics" *The Environmental Professional* **9**, 289–294.

# ATTACHMENT D

# STATE OF NEVADA PERSPECTIVE ON ENVIRONMENTAL PROGRAM PLANNING FOR THE YUCCA MOUNTAIN PROJECT

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**Abstract.** The state of Nevada is authorized by the Nuclear Waste Policy Act, as amended, to review the U.S. Department of Energy (DOE) program for siting a nuclear waste repository at Yucca Mountain, Nevada. This paper reports on the results and status of the State's environmental review program and concludes that the DOE program is deficient because it fails to include: (1) comprehensive baseline studies prior to site disturbance, (2) identification of impact avoidance criteria to guide monitoring of all components of the environment while site evaluation is being carried out, (3) assessment of cumulative impacts throughout the Yucca Mountain Project, and (4) direction under the aegis of defined resource management objectives. An alternative program developed by Nevada is presented that embodies principles of environmental resource management and other concepts reflective of accepted standards of environmental practice.

## INTRODUCTION

This paper presents an approach to environmental program planning for the proposed national high-level nuclear waste (HLW) repository at Yucca Mountain, Nevada. The approach is proposed as an alternative to the environmental program identified as part of the U.S. Department of Energy (DOE) Civilian Radioactive Waste Management Program (CRWMP) (Parker *et al.*, 1990). The approach proposed here would address environmental issues effectively and better serve the substance of the National Environmental Policy Act of 1969 (NEPA) than does the DOE's program. This paper presents a framework for accomplishing that objective based on the pursuit of such a program at Yucca Mountain by the state of Nevada.

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## BACKGROUND AND PURPOSE

Since 1976, the Department of Energy (DOE) has conducted preliminary technical suitability studies related to nominating a site for the HLW repository at Yucca Mountain, located about 176 kilometers (110 miles) northwest of Las Vegas, Nevada, adjacent to the Nevada Test Site (NTS). The DOE's mission was formally defined by the Nuclear Waste Policy Act of 1982 (NWPA). The NWPA identified an objective of developing mined geologic repositories for permanent deposition of commercial HLW and established a process of site selection that was to include comprehensive investigations by the DOE of site technical suitability, and protection of public health, safety, and the environment.

The history of the DOE's progress in the program is well documented. Briefly stated, the DOE first carried out preliminary technical investigations at nine potentially acceptable sites with different geologic materials and climatic conditions. In 1986, the DOE narrowed the candidates to three sites in the western United States (Washington, Texas, and Nevada), amid controversy regarding the basis of its decision (Carter, 1987). In 1987, Congress, bending to pressure to keep momentum in the slow-moving and expensive program, passed the Nuclear Waste Policy Amendments Act (NWPAA) that established only one site for site characterization—Yucca Mountain, Nevada (Carter, 1989).

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The selection of Yucca Mountain has been opposed in Nevada, both on the political basis of the selection as well as on technical, environmental, and other issues. In regard to the technical issues, the State argues that Yucca Mountain will prove unsuitable for a repository because of recognized hazards posed by potential earthquakes, volcanism, and groundwater intrusion that would compromise significantly the integrity of the repository during the 10,000 years for which the DOE must demonstrate that the waste will be isolated from the environment. Geotechnical problems with Yucca Mountain as a suitable repository site are a primary focus of Nevada's opposition to the HLW repository (Malone, 1990a and b). From an environmental perspective, the DOE Yucca Mountain Project will cause further unnecessary environmental damage. The State's review of the DOE's environmental program concluded that it is poorly conceived and weakly structured, thereby lacking the safeguards needed to minimize environmental damage. For further discussion of these issues see Cooper (1989), Loux (1989), and Power (1989). Some of the State's concerns were subsequently confirmed by the review of the Nuclear Waste Technical Review Board (NWTRB, 1990).

The DOE has been criticized in the past for not planning and carrying out a credible environmental program for site characterization at Yucca Mountain based on comprehensive, site-specific, baseline information and systematic, integrated impact analyses in accordance with the NEPA (Clary and Kraft, 1988 and 1989; Malone, 1990c). Unfortunately, the State has seen little improvement in environmental program planning at the DOE for the Yucca Mountain Project.

In a report to Congress on November 29, 1989, the DOE presented plans for restructuring the CRWMP, as it had concluded that the program cannot be effectively executed in its current form and must be restructured in order to develop a technically sound and integrated radioactive waste management system (U.S. DOE, 1989a). Environmental issues were not addressed specifically in that report; however, the significant deficiencies with regard to them warrant correction in a restructured program. For this reason, a review of significant aspects of the DOE's environmental program at Yucca Mountain is presented below. Malone (1989 and 1990c) has presented detailed discussions of the program elsewhere.

### Overview of the DOE Environmental Program at Yucca Mountain

The DOE environmental program for site-characterization activities at Yucca Mountain (U.S. DOE, 1988a) consists of documents that include an overview of the environmental program (U.S. DOE, 1988b), and various reports that address plans for environmental monitoring and mitigation to be conducted during site characterization (U.S. DOE, 1988c), regulatory requirements that apply to site characterization (U.S. DOE, 1988d), reclamation (U.S. DOE, 1989b and 1990a), and field activities for acquiring environmental information to support monitoring, mitigation, compliance, and reclamation during the course of site characterization (*e.g.*, U.S. DOE, 1988e and 1990b). All documents and plans, except those addressing the field activities, are of a procedural nature, and the environmental program overview (U.S. DOE, 1988b) does not provide a comprehensive and integrated perspective on planned field investigations at Yucca Mountain. The DOE has pressed the State to issue environmental permits to initiate site characterization, even though it has failed to complete planning of all parts of its environmental program.

The DOE's failure to address environmental concerns in a systematic manner stems from its use of the 1986 statutory environmental assessment (EA), issued as the foundation of the program (U.S. DOE, 1986). The EA presented the DOE's conclusion that there would be no significant environmental impacts of site characterization. With few exceptions, the environmental data used for the EA were regional in nature, as opposed to being derived from site-specific studies; detailed comprehensive environmental investigations at Yucca Mountain remain to be carried out. Rather than incorporating a pre-site characterization environmental baseline program into the repository program, the DOE (1988b) used the results of the EA (U.S. DOE, 1986) to limit the scope of its subsequent environmental investigations to data collection that will serve the purpose of effecting "mitigation" of the impacts of the proposed site characterization activities and repository development.

If Yucca Mountain proves to be a suitable site, the DOE must prepare an environmental impact statement (EIS) prior to repository construction. The environmental studies for the repository EIS will be planned and implemented after site characterization has commenced and adverse impacts from those activities are incurred. As a result, the baseline for the EIS will not reflect cumulative impacts from past land disturbance at Yucca Mountain (*i.e.*, effects of the DOE's extensive activities from 1976-1986 related to nominating Yucca Mountain as a repository site), and as a consequence of extensive renewed siting activities during site characterization for eight or more years. There will be no comprehensive study of environmental conditions as they exist now, and no basis for restoring the site to its original condition, as required by the NWPA, as revised.

Beyond the issue of environmental impact documentation under the NEPA or the NWPA, concern remains over whether environmental objectives are being served adequately by the DOE's Yucca Mountain Project. This question addresses issues at the heart of the NEPA as the nation's comprehensive policy on the environment (Lemons *et al.*, 1989). The foundations of the problem are the DOE's focus on the procedural rather than the substantive requirements of the NEPA, and the failure of the DOE to establish meaningful environmental objectives in the program. In the Site Characterization Plan (U.S. DOE, 1988a), the response to environmental issues concerning repository construction and operation was put off until EIS scoping in October 1997 (U.S. DOE, 1989a). The

DOE has no comprehensive environmental management program based on defined goals and implementation plans for managing the environment and resources of Yucca Mountain, or for the repository program which extends disturbances into resource areas and jurisdictions far beyond the NTS. The ongoing studies to "mitigate" impacts lack direction and integration, because environmental goals have never been identified.

The DOE must realize that while it has a mandate of the NWPA to fulfill, it also must be a responsible manager of the lands under its jurisdiction, ensuring that environmental goals are observed and that they are not made subservient to repository development goals. The DOE has a poor record of environmental management on many of its sites, including the Nevada Test Site, and now must undertake extremely costly clean-up programs (U.S. DOE, 1989d).

In the absence of defined environmental objectives, a comprehensive environmental baseline, and an integrated environmental management program, the DOE will find it difficult to assess impacts in a meaningful manner and develop approaches to impact minimization and comprehensive mitigation. This shortcoming is revealed by the DOE's failure to identify meaningful significance criteria for avoiding environmental impacts, including those that assuredly could affect federally-listed rare and endangered species. The DOE, having predetermined a finding of no significant impact in the 1986 EA, refuses to officially recognize the possibility that significant impacts could result from its siting and site-characterization activities, and therefore has not identified avoidance criteria that can be objectively reviewed and applied.

Because the DOE has embarked on an environmental program that serves the objective of repository development, its approach has been to make promises about impact control without an integrated approach to either recognizing or averting impacts. The DOE's ongoing environmental field studies are intended to assist the DOE in conducting geotechnical studies at sites regardless of the sensitivities of the landscape and resources in which they occur. For example, during an April, 1990, field inspection by the NWTRB, the DOE was asked to identify the avoidance criteria by which geotechnical studies (including substantial surface disturbance) could be moved so as to prevent impacts on local populations of the threatened desert tortoise (*Gopherus agassizii*) and their habitat. The DOE staff could not provide such criteria. Moreover, DOE staff stated that they could not identify which geotechnical studies could be moved so as to avoid or minimize impacts. The DOE also intends to construct major facilities, such as for the proposed exploratory shaft, within the floodplains of large drainage courses. The hazards of drill pad wash-out and contamination of subsurface environments with surface runoff and the impacts to the ecology of the washes have been ignored in such siting decisions. From such site-characterization plans, it appears that the DOE program does not have a functional and effective means of integrating environmental impact avoidance considerations into its activity planning process. Also, it appears that the DOE intends to site and conduct all studies proposed for site characterization without regard to the impacts on sensitive environmental resources that would result.

In its 1990 report, the NWTRB cited significant deficiencies in the Yucca Mountain environmental program, but did not specify how the DOE might remedy those shortcomings (NWTRB, 1990). If the intended substance of the NEPA is to be realized in the CRWMP, a new approach is needed.

### Basis for a Restructured Environmental Program

In late 1986, Nevada began planning its own environmental program based on concepts of resource management, cumulative impact assessment, and protection of ecological integrity, *i.e.*, the principles that are embodied by the NEPA and concepts of sound environmental impact analysis. The State's environmental program is directed (1) to establish an independent baseline investigation in order (2) to identify environmental management objectives, (3) to specify impact significance criteria that can be used for monitoring the DOE's activities and the resultant effects on the environment, and (4) to prepare approaches to restoration. In accordance with the NWPA and the NWPAA, the state of Nevada is entitled to carry out oversight activities for the DOE repository siting program at Yucca Mountain. Funding is provided through grants to the State authorized by Congress from the Nuclear Waste Fund, administered by the DOE.

The state of Nevada has prepared reports that: (1) point to the need for environmental oversight of the DOE project, (2) describe the concepts of reasonable and responsible environmental planning, and (3) outline a study program for compensating for the shortcomings of the DOE's program. The documents include plans for environmental field studies that finally were implemented in 1989, but later terminated when funding to the State was severely curtailed. Much remains to be done to complete the environmental program conceived by the State, but the preliminary results are sufficient to formulate the framework of a more environmentally-sensitive approach to site characterization than that pursued by the DOE.

## ENVIRONMENTAL MANAGEMENT AND ITS APPLICATION AT YUCCA MOUNTAIN

### Environmental Protection as a Fundamental Objective

Nevada believes that the DOE's site-characterization program, if properly conducted, will confirm the already existing evidence that Yucca Mountain is unsuitable for a HLW repository. Therefore, further study, and its attendant environmental disturbance, will result in unnecessary environmental impact. Nonetheless, as the DOE intends to pursue site-characterization, its environmental program should be designed not only to serve repository development goals, but also to provide environmental review of the program independent of those goals. The alternative approach developed by the state of Nevada embraces the concept of environmental management involving identification of environmental sensitivities, evaluation of potential site-characterization impacts and their significance in advance, avoidance of impacts to the extent practical, and mitigation of impacts *via* best management practices and site restoration.

The fundamental goal of environmental management at Yucca Mountain should be to protect the environment consistent with the resource value of the site. The primary principles of the alternative environmental management strategy are discussed below. This strategy is consistent with sound principles of environmental planning, assessment, and management (Jain *et al.*, 1982; Beanlands and Duinker, 1984; Murthy, 1988; Bartlett, 1986; Westman, 1985).

### Identify Environmental Sensitivities and Constraints Prior to Further Disturbances

At present, the resource values at Yucca Mountain and vicinity remain unknown. The alternative approach implies an understanding of environmental conditions upon which an evaluation of resources can be made. A management plan then can be developed that minimizes impacts to sensitive and key components of the environment and maximizes the potential for reclamation or restoration of the environment. As the fundamental purpose of environmental management should be to maintain the integrity of the environment at Yucca Mountain while site-characterization activities are being carried out, it is necessary to evaluate Yucca Mountain's resources and environmental sensitivities, and from those identify and implement management objectives.

The first step must be to identify sensitive components of the environment and the constraints which they pose to site characterization and to reclamation. Such constraints must be observed in siting specific proposed activities. Based on known sensitive resources, it would be possible to identify potential impacts that should be avoided and conditions that may impede mitigation and reclamation. At Yucca Mountain, the environment is too little known at this time to designate key or sensitive components and to develop a sound management plan. The generic, regional information available and studies conducted for the state of Nevada suggest that the site is part of a unique ecosystem containing sensitive biota (ESA, 1990). Additionally, there are potentially significant physical environmental connections between Yucca Mountain and other unique environmental resources in the vicinity that remain undefined.

### Evaluate Cumulative Impacts

Because the DOE repository siting and development program at Yucca Mountain has been, and will continue to be, accomplished in stages over several decades from the 1970s through about 2010 or later (U.S. DOE, 1986, 1988a, and 1989a), it is essential that an environmental management strategy include analysis of incremental and cumulative impacts. This is necessary for reclamation purposes, and also as a means for helping prevent changes in the environment of the site that could affect its fundamental integrity. No consideration has been given by the DOE to past impacts and it has fallen on the state of Nevada to characterize the disturbances (Winsor and Ulland, 1989; Winsor and Rousseau, 1990). The DOE's past and ongoing investigations also have focused on about a 78-square kilometer (30-square mile) area at the repository site where disturbances are concentrated. However, the DOE's proposed site-characterization studies and their impacts potentially extend over areas distant from Yucca Mountain.

For the alternative approach, cumulative impacts would be given sufficient study to ensure that a comprehensive assessment of all components and phases of the program are evaluated, and that all sites of disturbance are analyzed specifically and in combination with other sites. This means that, in contrast to the existing plan, each site-characterization activity would be planned carefully in advance and include a complete description of the activity, its precise location, its scheduling, elements that may lead to environmental alteration or hazards, and proposed means to reduce environmental impact.

### Plan Site Characterization to Avoid Impacts

The DOE has not identified impact significance criteria, because the environmental sensitivities were not defined by the suspect findings of the statutory EA, and it has fragmented each environmental program element so that significant impact cannot be recognized. A reordering of priorities is needed such that site-characterization activities are planned to avoid impacts to all aspects of the environment to the extent practical, as required by the NWPA. In the alternative environmental management program, impact avoidance is given a priority position in environmental management. Avoidance is the preferred choice wherever and whenever environmental sensitivities are rated high. For example, in the case of the desert tortoise, the point of impact avoidance is to protect the individuals of a designated sensitive species and the integrity of their local habitat. An avoidance of impacts to the sensitive elements of the environment implies that impact significance criteria are identified in advance of any activity that could disturb the environment so that avoidance can be planned. Such criteria should incorporate means to identify both incremental and cumulative impacts in spatial and temporal contexts. In the case of the tortoise, criteria for determining whether a site-characterization activity should or should not be moved to avoid impacts to local populations of tortoise and their habitat should be identified.

The identification of site-specific criteria for impact avoidance is the only reasonable approach to protecting the environment from unnecessary damage. It is also the only way in which independent reviewers, such as the State, the U.S.Fish and Wildlife Service, or the National Park Service can determine whether the DOE is making an effective effort to protect the environment and significant species such as the desert tortoise and desert pupfish (*Cyprinodon diabolis*). Criteria must be established for each element of the environment. The key environmental issue areas requiring such criteria are presented later in this paper.

### Plan and Implement Mitigation and Reclamation To Preserve Ecological Integrity

In place of impact avoidance, the DOE has placed considerable emphasis on mitigation and an assumed ability to reclaim the site (U.S. DOE, 1988b). This emphasis is grounded in an optimism for reclamation success that is not shared by many experts familiar with the sensitivities of the desert environment, the extreme limitations which it imposes on mitigation efforts, and the state of the art in reclamation techniques (NAS, 1974; Box, 1976; Allen, 1988). There is scant evidence in the literature to support the DOE's claims to mitigate impacts to insignificance or to achieve its objective of establishing effective site reclamation.

The proposed management strategy must include a program for mitigation, reclamation, and site restoration in order to meet the requirements of the NWPA and NWPAA. While avoidance of impacts based on known sensitivities to disturbance is preferred, this goal cannot always be achieved. Thus, it is essential that either mitigation or reclamation and restoration measures be well-planned. Which course to pursue depends on the sensitivity and importance of the resource to be protected and the severity and extent of the impacts involved. The ultimate consequences of the impact to preservation of environmental integrity is the factor upon which decisions must rest relative to mitigation, reclamation, and restoration.

Mitigation and reclamation planning must begin with a recognition of the limited opportunity for success given the state of the art in these areas. Those limitations are based on the dearth of information about desert ecosystems in general, and at Yucca Mountain specifically, physical environment constraints (especially the limited availability of water), and the potentially high costs that may be associated with mitigation and reclamation. Those limitations provide the basis for a substantial research effort, one that is likely to require detailed onsite studies of natural conditions of vegetation, soil, hydrology, and other factors, and direct experimentation with reclamation techniques over a long period.

After some basic information is gathered about methods likely to achieve success, site-specific objectives for reclamation or restoration can be identified and plans formulated for achieving them. It is important to define realistic reclamation objectives in advance of surface disturbing activities, because these may guide the course, nature, and timing of the activities creating the disturbances.

### Develop an Environmental Management Plan

The HLW program is necessarily complex, encompasses activities in a large geographic area with a variety of biophysical environments, and is extended over a long period. Additionally, the Yucca Mountain Project will continue to extend impacts into jurisdictional areas beyond the DOE's purview. A program with these qualities demands guidance under the auspices of a defined and integrated management plan. Currently, the DOE Environmental Program is an effort lacking specific environmental management objectives for the resources and land units. The Yucca Mountain Project should be guided not solely by the DOE's mission to develop a repository, but also by its stewardship mission to carry out responsible management of the NTS and to conform with land management objectives for the adjacent areas of U.S. Bureau of Land Management and U.S. Air Force land, as well as the more distant areas which potentially could be affected by the Yucca Mountain Project, *e.g.*, Death Valley National Monument.

For the alternative approach, the environmental program would be oriented to establishing specific objectives for the lands and resources that could be affected by the project, and credible means to attain them. The objectives and guidelines for implementation would be defined by the sensitivities of the resources in both their local contexts and in regard to the broader considerations of their status. The environmental management plan should serve as the aegis under which decisions about activities that may alter the environment can be made rationally and with purpose.

To prepare specific objectives and implement policies or land management guidelines, it will be necessary to synthesize a vast quantity of information about all aspects of the environment. The demand exists for information management systems capable of handling the volume and complexity of the information. The approach proposed here incorporates the concept of a centralized, controlled, environmental database readily accessible to many potential users (including all interested parties). The database includes both spatially-defined information, as well as the textual and tabular data collected over time regarding environmental variables, evaluations of environmental sensitivities, impact models, and plans for and records of disturbance activities, mitigation, reclamation, and regulatory-compliance monitoring. Remote sensing imagery interpretation for monitoring environmental change and the use of sophisticated computers of the type known as a Geographic Information System provide a primary means to accomplish the marshalling and use of large volumes of primary data from which to make cumulative impact assessments, develop environmental management plans, and assist decisionmaking about activities that potentially could cause significant environmental impacts (Winsor and Rousseau, 1990).

## NEVADA'S ENVIRONMENTAL PROGRAM

The Nuclear Waste Project Office (NWPO) environmental program mission was defined after detailed evaluation of the Yucca Mountain Project found the structure, plans, and goals of the DOE's CRWMP falling short of sound environmental practice (NWPO, 1987; ESA and RCI, 1989).

The environmental program was formally set in motion in 1988. The program established eight primary goals (NWPO, 1987; ESA and RCI, 1989):

1. identify environmental management objectives and lay out a program to achieve them;

2. undertake studies to establish a baseline of environmental information at Yucca Mountain before further environmental disruption occurs;

3. use the environmental baseline to assess the impacts of the DOE's past disturbances and proposed site characterization;

4. use the preceding impact analysis to evaluate the efficacy of the preliminary impact analyses reported by the DOE in the statutory EA (U.S. DOE, 1986);

5. identify and assess federal, state, and local regulatory environmental requirements;

6. determine the scope of reclamation measures needed;

7. develop environmental monitoring and impact mitigation plans; and

8. incorporate environmental studies during site characterization or adjust the monitoring program to accommodate information needs for the EIS and the siting guidelines, once more is known about the repository design.

### Management Objectives and Study Plans

The state of Nevada's primary goal is to protect the ecological integrity and biological diversity of the Yucca Mountain area to the extent practicable and commensurate with its ecological and environmental values. The immediate objective is to avoid significantly altering the natural ecosystem, and thereby compromising its environmental integrity, so that any unique characteristics and resources endemic to the area can be studied before they are altered by further impacts from site characterization. The overall principles of environmental resource management discussed previously are the framework of the program. The primary precepts of this strategy are as follows:

1) Avoidance of impact should be the primary goal; impacts that are unnecessary or which would seriously compromise attainment of environmental objectives should be prevented.

2) Mitigation implemented prior to and during disturbance to eliminate and reduce impact should be the second goal. If impacts cannot be avoided, mitigation should be identified clearly in advance of the impact. Mitigation should be viewed broadly in concept, but measures should be identified with a high degree of specificity, so as to include application of specific techniques to a given site, preparation for reclamation techniques, off-site considerations and compensation.

3) Reclamation should be regarded as a follow-up to unavoidable disturbance and impact. Reclamation should be regarded as an integrated program directed to attainment of resource management objectives. It also must be regarded as an ongoing program: initiated prior to disturbance—at which time specific reclamation needs and plans are defined, implemented immediately after impact occurs, applied continuously and monitored for success, and adapted to changes in information on potentially successful techniques.

The objectives and strategy require refinement. Too little information has been collected about the Yucca Mountain area to achieve definition of specific environmental objectives. General objectives have been identified using the regional-based information about the vegetation, wildlife, soils, hydrology and water quality, climate and air quality, noise and aesthetic environment, and cultural resources of the area (ESA and RCI, 1989). Additionally, means to identify impacts have been described using indicators of direct and indirect impacts. The refinement of the environmental management plan requires information collection in an integrated study design. A study plan has been prepared that guides the overall effort required to achieve the objectives, as well as the eight goals of the environmental program previously identified (ESA, 1989a). Investigations conducted in 1988-1989 for the State have provided the basis for some refinement of objectives keyed to observed conditions at Yucca Mountain.

### Environmental Baseline of Yucca Mountain

A primary objective of the environmental program is to assess the full complement of impacts of the DOE's past siting and proposed site-characterization activities with a view toward cumulative impact assessment. To achieve this goal, it is necessary to obtain baseline information relative to: (1) the fundamental character of the resources, (2) the amount of disturbance that has occurred to date, and (3) the sensitivities of the resources to impacts. Because information of these types is critical to the completion of the other tasks, its collection has occupied the greatest portion of the work program to date. Enough information has been obtained through literature review, interpretation of remote sensing imagery, and some field investigations in the Yucca Mountain area to obtain a preliminary understanding of the environment and the sensitivities involved. Summarized here are results of studies on biota, soils, extent of existing disturbed areas, and reclamation. The plans were laid for other environmental investigations in the field. These included studies of erosion, climatology, air quality, hydrology, water quality, noise, cultural resources, and aesthetics. Because of funding limitations, these baseline studies were curtailed, but will be resumed at a later time, if possible.

**Vegetation.** The distribution of regional vegetation was described and mapped at the climax series level for most of a 155-square kilometer (60-square mile) area centered on Yucca Mountain. The mapping and analysis were accomplished in phases, using interpretation of remote sensing imagery, including low-altitude, large scale color stereo-paired aerial photography from 1988, high-altitude satellite spectral imagery from the American Landsat 5 Thematic Mapper satellite, and panchromatic imagery from the French SPOT satellite (Winsor and Rousseau, 1990). Onsite verification studies were conducted in two areas to which the State's environmental team was permitted access. Fifty-one permanent field sampling sites were established that represented the diversity of vegetation types in the Yucca Mountain area. Quantitative data on perennial vegetation were collected in the field (because of a persistent drought over the last few years, the growth of annuals was insufficient to warrant detailed data collection for them), and used to characterize and distinguish at least eight climax series types and 24 series-association sub-types (ESA, 1990). These findings, which are a significant refinement of previous work performed by the DOE, (O'Farrell and Collins, 1984), suggest that substantial biological diversity exists in the immediate vicinity of Yucca Mountain. The State's team also collected important information linking the vegetation types to important biophysical relationships. Such information will prove useful in carrying out sensitivity analysis, impact assessment, and reclamation planning. Two protected species considered to be of special status, the black wooly-pod (*Astragalus funereus*) and the Mojave fish-hook cactus (*Sclerocactus polyancistrus*), are known to occur in the area of Yucca Mountain.

The DOE did not conduct detailed vegetation studies at Yucca Mountain for the statutory EA (U.S. DOE, 1986); rather, it provided only small-scale mapping and characterization of five plant associations based on nine transects. The DOE relied heavily on the regional data on vegetation of the NTS for purposes of impact assessment. The State's team found that use of regional vegetation data is not well-suited for impact assessments. Similarities of the vegetation of Yucca Mountain and other parts of the NTS do not extend beyond the biome level of a vegetation classification system. The biome is too coarse a classification for identifying meaningful ecological units for impact assessment, reclamation planning, and resource management purposes. The State's large-scale mapping and more extensive primary data collection for identifying the plant associations (24, as compared to the DOE's five associations in the EA) offer far greater utility for identification of ecological relationships (such as connections to biophysical controls, identification of keystone and critical-link species, indices of biodiversity, and relationships to foodwebs and habitat requirements of wildlife), as well as for assessment of sensitivities to disturbance.

The generic, regional information available and studies conducted for the state of Nevada suggest that the site is part of a unique ecosystem limited in extent by virtue of its location within a transitional desert ecotone: its soils are of volcanic origin, as opposed to sedimentary, like most of the surrounding area, *i.e.*, the Mojave Desert to the south, or the Great Basin to the north (Beatley, 1980; Collins *et al.*, 1981; Mitchell, 1984; ESA, 1990). Additionally, the field investigations confirm the fact that much of the area remains in near-pristine condition, a situation unusual in most of southern Nevada.

**Wildlife.** The State's wildlife investigations have focused on: (1) identification of the terrestrial wildlife of the Yucca Mountain area, (2) assessments of the status of the desert tortoise and its habitat at Yucca Mountain, and (3) identification of the sensitivities and issues potentially affecting the unique ecological areas at nearby Ash Meadows and Devil's Hole.

The Yucca Mountain wildlife investigations to date include field studies of mammals, reptiles, and amphibians. The field studies indicate the presence of small rodents typical of the Mojave and Great Basin biomes. A richer fauna is considered to be present potentially, but the severe drought appears to have affected wildlife use of the area and reduced the endemic population at the time the studies were conducted.

The desert tortoise is a species of special concern that occurs at Yucca Mountain. It has been a candidate species for some time, and in 1989 was listed as threatened in Nevada and California. It is also a state-protected species in this area.

Field investigations of the tortoise were conducted on the portion of the NTS at the base of Yucca Mountain in late summer 1989 (Karl, 1989). The investigations included first reconnaissance surveys followed by studies on 23 strip transects to assess the distribution, habitat associations, and relative abundance of tortoises. Observations of tortoise and sign were used to yield a rough estimate of tortoise abundance at about 3 to 19 individuals per square kilometer (10 to 50 per square mile). The highest densities appear to occur on alluvial fans, many of which are areas in which the most intensive disturbance from DOE site characterization is anticipated to occur (U.S. DOE, 1988a). The data are preliminary, but are indicative of tortoise populations greater than those reported by the DOE at less than seven tortoises per square kilometer (20 per square mile) (U.S. DOE, 1986 and 1989c) and of higher density on the alluvial fans. Both the difference in tortoise abundance and distribution of estimates among the DOE's reports and the State's survey are potentially significant for impact analysis of disturbances associated with site characterization. Preliminary assessments were made of habitat quality, most of which is considered to be fair.

Little actually is known about the tortoise in the Yucca Mountain area (Berry, 1984; Karl 1981, 1983, and 1989). Although the DOE has, to date, considered impacts to the tortoise to be insignificant, there are numerous unanswered questions regarding the local populations. Key issues to be resolved include potential fragmentation of the endemic populations and their habitat. Cumulative impacts must be considered in the context of the widespread decline of the tortoise throughout much of the Mojave Desert (because of disease and other factors) and in southern Nevada in particular. There is a potential for the loss of possibly significant habitat; habitat relationships and quality remain as yet undefined and unstudied at Yucca Mountain. The sensitivity of the population and the habitat to alteration is an important consideration because the Yucca Mountain population is at the edge of the natural range of the species and presumably at the margin of its environmental tolerance. The concern is that even small changes in the environment may result in large impacts on the population. Tolerances to, and recovery rates from, natural and human-induced environmental perturbations remain unknown. Little is known about the vitality of the population—if it is growing, stable, or declining, and whether the respiratory disease that has destroyed a large portion of the tortoise population west of the Colorado River is present in the Yucca Mountain population.

There is little evidence to support the assumptions inherent in the DOE's mitigation plan (U.S. DOE, 1988c and 1989c) that tortoises can be relocated easily without inducing significant adverse effects on both the relocatees and the individuals in the relocation site. The State's desert tortoise studies, like those of the other environmental factors, indicate that there are many more questions than answers about the environment and resources of Yucca Mountain, and that assumptions of no significant impact must be regarded as premature.

The State has also investigated potential concerns regarding the relationship of the DOE's site-characterization program to the extremely sensitive resources and environment at Ash Meadows and Devil's Hole. Ash Meadows, located 40 kilometers (25 miles) south of Yucca Mountain, is a 57,500 hectare (23,000 acre) oasis of enormous biological importance. It supports more species of endemic animals and plants than any area of similar size in the United States, including at least 12 federally-listed endangered and threatened species (Hendrickson and Kubly, 1984). More than 30 springs and seeps create habitat for at least 30 animals and plants found nowhere else on earth. Devil's Hole, located near Ash Meadows, is the site of the most restricted habitat of perhaps any vertebrate in the world, the Devil's Hole pupfish. Both areas are protected, currently managed primarily by the U.S. National Park Service.

Ash Meadows and Devil's Hole are supported almost entirely by groundwater. The springs are the discharge from a groundwater basin to the north and northeast that likely includes Yucca Mountain. A potential exists for DOE activities at Yucca Mountain to affect the hydrological conditions at Ash Meadows and Devil's Hole, either through the release of contaminants or by alteration of groundwater flows. Even minor alterations of water level in Devil's Hole could destroy the entire fragile ecosystem. The DOE has yet to demonstrate that its site-characterization activities will not result in significant, irreversible, adverse impacts on Ash Meadows and Devil's Hole. A challenge to this effect has been made by the National Park Service (Williams, 1988) and must be resolved by the DOE. There is a clear need for the establishment of specific impact criteria that can form the basis of monitoring groundwater quantity and quality and defining feasible approaches to prevention of impact.

**Soils.** An evaluation of soils was omitted from the DOE's statutory EA (U.S. DOE, 1986), a fundamental oversight given the important relationship that soils bear to vegetation, wildlife, and hydrology in the desert. A draft study plan for soils has just been prepared by the DOE (U.S. DOE, 1990b); these studies would be undertaken after the initiation of site characterization. The State has initiated a soils investigation so that information can be provided to understand better biophysical relationships, estimate impacts, and plan for reclamation before the DOE's siting activities irreparably alter the site (RCI, 1989a). The soil survey included mapping of soil units and characterization of soil associations in a 1,820 hectare (4,500 acre) area of the NTS near Yucca Mountain. At least seven soil associations and 17 soil series were mapped at large scale in the area. Additionally, landforms were identified by genetic class and mapped. Both landforms and soils appear to bear significant relationships to vegetation in the area, and will form important controls in reclamation planning. Primary characteristics of the soils useful for impact assessment and reclamation planning were analyzed as part of the studies.

### The DOE's Past Disturbances and Proposed Activities

Since 1976, DOE preliminary investigations for the repository have caused widespread disturbances of the landscape. Those disturbances have not been identified accurately by the DOE to date (U.S. DOE, 1988a). In order to obtain a better understanding of the status of the environment at Yucca Mountain, to predict future impacts, and to plan for reclamation, as required by the NWPA, the State undertook an investigation of the extent of past disturbance on and near Yucca Mountain. The investigation was accomplished largely through mapping, using interpretation of large scale stereo-paired recent photography, historic photography, and remote sensing Landsat and SPOT imagery. The results of this investigation have been published elsewhere (ESA, 1989b; Winsor and Ulland, 1989; Winsor and Rousseau, 1990).

Disturbances were categorized by 24 activity types with associated disturbance characteristics. The disturbances were mapped and tagged with an identification number and type. A total of 258 hectares (638 acres) of disturbance was measured. Assuming similar disturbance characteristics of planned site-characterization activities, an additional total 211 hectares (522 acres) would be disturbed. The disturbances vary greatly in character, from total vegetation and soil removal down to bedrock, to lesser disturbances that probably will undergo natural revegetation over time. The disturbance assessment provided further indication of the extremely slow process of natural recovery of disturbance in the desert.

### Reclamation Needs, Strategies, and Practices

The DOE must reclaim the site if it decides not to construct the repository or, in the event of repository development, to reclaim the site at the time of facility closure. Restoration of disturbed land in arid environments is highly constrained by the special limitations of the harsh climate, particularly low and variable precipitation, wind erosion of topsoil, and the need for establishment of critical soil microorganisms (Allen, 1989). Although proposed activities for site characterization and repository development are the types of disturbances typically associated with mining, successful reclamation of the site will not be achieved easily. The DOE has given scant attention to the critical limitations of the Yucca Mountain environment in site restoration and has provided minimal information about the scope or goals of its reclamation program, the types of reclamation practices it intends to employ, schedules, or other pertinent information (U.S. DOE, 1989b, 1990a). Accordingly, the State has undertaken an investigation of the overall potential and strategy for reclamation that incorporates the concept of application of best management practices (ESA, 1989a; ESA and RCI, 1989). The strategy is intended to identify objectives of reclamation, appropriate levels of effort, and guidance for establishing specific reclamation plans. That strategy is based on the recognition that local site variability has produced numerous plant communities and soil conditions, each with different potential for revegetation (ESA, 1990). Each disturbance of the vegetation and soil will have to be considered independently when formulating reclamation prescriptions. No single approach can be applied to the entire Yucca Mountain site and area. Additionally, reclamation performance standards necessarily may vary over the site in accordance with site-specific reclamation potential (RCI, 1989b).

RCI (1989b) found that previous reclamation work has been done only outside the Yucca Mountain area. Studies of native shrub species' adaptability have occurred primarily in southern California and Arizona. Species adaptability recommendations, other than for native shrubs, are derived from seeding guides and are based more on species characteristics than on actual field trials. Little or no soils information on previous study sites has been documented, and the studies of soil stabilization, site preparation, mulching, and fertilization conducted mostly at mining sites in southern California are site-specific case studies. Therefore, it is difficult to extrapolate results of the past out-of-area studies of reclamation to specific sites at Yucca Mountain. Additionally, many reclamation studies reported in the literature were of short term and conducted at an applied level of research with little understanding of why a response occurred. As a result, the reported reclamation recommendations were based on trial-and-error approaches with little understanding of the underlying mechanisms that would allow extrapolation to other sites like Yucca Mountain. Scientific research of desert soil and vegetation interrelationships is in its infancy. It appears that much of the desert vegetation is distributed in "fertile islands" related to sensitive vegetation/soil interdependencies. An understanding of these interrelationships and sensitivities is critical to establishing elements in reclamation requirements, such as the important work on reestablishment of mycorrhizal fungi in the soil to improve reestablishment of some desert shrubs (*e.g.*, Allen, 1989).

The disturbance assessments reported earlier were used to estimate the potential costs of reclamation of the past disturbances. Field inspections were made to assess the scope and anticipated problems for planning reclamation efforts. The cost estimates range from five million to 23 million dollars, depending on the level of effort and goals for reclamation of the site (ESA and RCI, 1989). Reclamation costs for proposed site-characterization activities are not known, because many of the DOE's plans are not fully conceived or sited. Much potential damage from site characterization could be avoided by a better-planned program in which impact avoidance is given higher priority. Where environmental disturbance is necessary, many established best management practices can be used to minimize soil and vegetation damage, promote reclamation, and thereby reduce reclamation needs. For example, many fertile islands can be left intact without compromising the intended grading design, and track equipment could be used on many roads instead of blading, so as to reduce damage to the vegetation and to maintain an indigenous onsite seed source for revegetation. By such practices, revegetation can be promoted by both natural processes, in conjunction with supplemental planting.

The State's objective for reclamation is to encourage reestablishment of the ecological integrity of the site at conditions approximating those before the DOE initiated its studies for nominating Yucca Mountain as a repository site. The strategy is based on the integration of reclamation considerations into all activity phases including the periods prior to disturbance, during the disturbance activity, and following abandonment of a specific site. Reclamation should be oriented to development of sound and integrated planning and implementation. Overall and site-specific reclamation objectives should be defined in advance of disturbance activities and specific practices; responsibilities and schedules should be identified for each phase of reclamation activity. A monitoring program also is a critical element of the State's reclamation strategy.

## FUTURE PROGRAM DIRECTIONS

The concept of the environmental management program envisioned by the State and summarized in this paper can be realized if efforts are continued in a number of key areas discussed below. Continued primary data collection in a field-based program is essential to other aspects of environmental management planning. The State's environmental team was able to conduct only limited baseline studies in the field. The baseline studies of vegetation, wildlife, special status species, and soils should be continued and expanded onto Yucca Mountain and into the surrounding region (RCI, 1989a; ESA, 1990). Seasonal investigations of terrestrial ecology are needed to understand better biophysical relationships and sensitivities of the environment to disturbances. The baseline studies should be expanded over several years to capture a broader range in environmental conditions: the 1989 field studies were conducted in the third year of a drought.

Studies of the desert tortoise require considerable expansion in scope and geography, and should be conducted over extended periods (Karl, 1989). As noted, there are many questions that need to be resolved before the DOE undertakes a program of tortoise relocation and habitat destruction in conjunction with site characterization. Studies of vegetation must be integrated into the habitat quality evaluations for tortoise impact assessments.

The baseline studies must also be expanded to encompass the full range of environmental factors presented in the State's Environmental Studies Plan (ESA, 1989a). Studies postponed due to funding limitations should be initiated, including climatology, air quality, hydrology, erosion, water quality, noise, cultural resources, and visual/aesthetics. These studies are needed because: (1) impacts of site characterization are anticipated to affect the resources in question, (2) they are critical to understanding biophysical relationships of the Yucca Mountain ecosystem, and (3) they are not being addressed adequately by the DOE (NWPO, 1987 and 1988; Winsor and Ulland, 1989; Malone, 1990c). Integration of the findings of sophisticated hydrological models are needed to assess the potential for significant effects of site characterization at Ash Meadows and Devil's Hole. Also of great importance are the proposed studies for establishing reclamation procedures (RCI, 1989b).

In conjunction with the baseline studies, a complete evaluation of environmental sensitivities is required. Preliminary assessments of sensitivities have been established, at least at the level of identifying key environmental concerns and generic sources of impacts from human disturbances. More comprehensive assessments are needed of biophysical relationships, environmental responses to disturbance stimuli, and constraints posed by the natural environment of Yucca Mountain. These are needed both in a site-specific context as well as for general and cumulative matrices. Analyses of these types set the stage for definition of useful impact significance criteria.

The State's objective in impact assessment is to establish meaningful impact analyses using predetermined impact significance criteria. To achieve this, further investigation in two areas is required. First, impact models must be constructed to predict the effects of each disturbance type associated with a site-characterization activity. These should be based on observed, and preferably measured, effects of past disturbances at Yucca Mountain and generic effects of new planned activities by the DOE. The models should incorporate both direct and indirect effects that can be used to define thresholds of significance. Second, impact indicators must be identified in advance of disturbance activities so that impacts can be recognized through monitoring efforts. Preliminary identification of impact indicators has been made using generic criteria (ESA and RCI, 1989); these require refinement and integration into the impact models.

Continued investigations of best management practices as applied to the specific environment of Yucca Mountain are needed. The preliminary work previously described indicates that much information is lacking about reclamation practices and their potential for success. Most literature on reclamation in desert environments indicates that soil reestablishment and revegetation are extremely slow processes under natural conditions, and that proactive reclamation is a labor intensive and expensive process that often has met with limited success (RCI, 1989b). For these reasons, further research is needed regarding which reclamation practices are likely to succeed at Yucca Mountain. Active tests of reclamation techniques are needed in the Yucca Mountain environment. Similarly, further information is required regarding other mitigation measures and their potential for success at Yucca Mountain, *e.g.*, dust control, noise and vibration control, and cultural resource recovery requirements.

In its independent role, the State intends to monitor fully all DOE activities during site characterization. A full monitoring program consistent with the objectives, approaches, and constraints recognized by Duinker (1989) should include use of remote sensing methods and field studies to detect environmental change, pre-disturbance site assessments, ongoing measurements of environmental effects of disturbance-generating activities, ongoing monitoring of mitigation and reclamation efforts, and compliance monitoring. The development of an integrated, centralized database is essential for this purpose, particularly use of a Geographic Information System (Winsor and Rousseau, 1990).

## CONCLUSIONS

Nevada questions the necessity of further environmental disturbance at Yucca Mountain and has significant concerns about the environment that are not being addressed effectively by the DOE. The deficiencies in the DOE environmental program will undermine the credibility and success of the EIS that must be prepared for repository construction. Additionally, those deficiencies will pose potentially critical limitations to the reclamation program that ultimately must be pursued at Yucca Mountain. Even more important to national nuclear waste policy, shortcomings in the DOE environmental program jeopardize the efficacy of the repository program by calling into question the soundness of fundamental analyses of the ability of a geologic repository at Yucca Mountain to perform as intended and protect the environment for at least 10,000 years. The DOE must recognize the Yucca Mountain Project for the unique, first-ever effort that it is, and not approach repository siting as a routine construction project.

Another important issue raised by the NWPA, NWPAA, and the choice of Yucca Mountain as the sole site for consideration for a geologic repository involves reclamation potential. National policy rightly calls for reclamation of a site following environmental disturbance as a result of characterization and repository development. Yet in the case of the Yucca Mountain site, where harsh desert conditions prevail, it is questionable that the environment is sufficiently permissive for reclamation goals to be met. This is due to the lack of effective site reclamation methodologies for arid regions like those of the Transition Desert (Wallace *et al.*, 1980; RCI, 1989b). Because of this, the wisdom of pursuing repository siting in an area where reclamation goals are unlikely to be achieved must be called into question. For this reason, the proposed restructuring of the national nuclear waste repository program (U.S. DOE, 1989a) must include consideration of the reclamation issue and the need for considering alternative siting measures more in line with meeting reclamation goals than likely can be attained at the Yucca Mountain site. This is another instance where environmental limitations and the lack of adequate scientific knowledge and technical methodologies to overcome them must be considered in establishing national policies such as those embodied in the NWPA and the NWPAA (Malone, 1990a and 1990b). At the very least, a reordering of priorities is needed for the Yucca Mountain Project, such that impact avoidance is given a higher degree of importance in planning and conducting site characterization.

The DOE's proposed restructuring of the CRWMP presents an opportunity for effecting a significant alteration in its approach to environmental analysis and resource management at Yucca Mountain (U.S. DOE, 1989a). It is time that the DOE develop an environmental management program that is in line with current concepts of environmental planning and management for federal lands. In recent years, some federal agencies with stewardship responsibility for publicly-owned lands have made significant strides in developing environmental management plans with clearly drawn objectives for resource management, by implementing plans and policies, and by establishing protocols for minimizing adverse impacts to the environment. It is hoped that the DOE will rethink carefully its strategy about environmental management for the CRWMP and incorporate an environmental ethic that responds to the substance of the NEPA as the nation's comprehensive policy on environmental quality. The alternative environmental management program proposed here offers the framework for this long-needed fresh approach to the environment for the nuclear waste repository project at Yucca Mountain.

## REFERENCES


Allen, E.B. 1988. The Reconstruction of Disturbed Arid Lands: A Ecological Approach. Westview Press, Inc., Boulder, CO.

Allen, E.B. 1989. The Restoration of Disturbed Arid Landscap with Special Reference to Mycorrhizal Fungi. *Journal of Ar Environments* 17: 279-286.

Bartlett, R.V. 1986. Rationality and the Logic of the Nation Environmental Policy Act. *The Environmental Professional* 105-111.

Beanlands, G.E., and P.N. Duinker. 1984. An Ecological Fram work for Environmental Impact Assessment. *Journal of Env ronmental Management* 18: 267-277.

Beatley, J.C. 1980. Fluctuations and Stability in Climax Shrub ar Woodland Vegetation of the Mojave, Great Basin, and Transiti Deserts of Southern Nevada. *Israel Journal of Botany* 28: 14 168.

Berry, K. 1984. The Status of the Desert Tortoise (*Gopherus agassiz* in the United States. Order No. 11310-0083-81. Report to th U.S. Fish and Wildlife Service from the Desert Tortoise Counc Portland, OR.

Box, T.W. 1976. The Significance and Responsibility of Rehabil tating Drastically Disturbed Lands. In *Reclamation of Drast cally Disturbed Lands*. F.W. Schaller and P. Sutton, eds. Amer can Society of Agronomy, Crop Science Society of America, Sc Science Society of America, Madison, WI. pp. 1-10.

Carter, L.J. 1987. *Nuclear Imperatives and Public Trust: Dealin with Radioactive Waste*. Resources for the Future, Washingto DC.

Carter, L.J. 1989. Nuclear Waste Policy and Politics. *Forum fo Applied Research and Public Policy* 4 (3): 5-18.

Clary, B.B., and M.E. Kraft. 1988. Impact Assessment and Polic Failure: The Nuclear Waste Policy Act of 1982. *Policy Studie Review* 8: 105-115.

Clary, B.B., and M.E. Kraft. 1989. Environmental Assessmen Science, and Policy Failure: The Politics of Nuclear Wast Disposal. In *Policy Through Impact Assessment: Institutiona ized Analysis as a Policy Strategy*, R.V. Bartlett, ed. Greenwoo Press, New York, pp. 51-62.

Collins, E., T.P. O'Farrell, and W.A. Rhoads. 1981. Annotate Bibliography for Biological Overview for the Nevada Nucle Waste Storage Investigations, Nevada Test Site, Nye County Nevada. EGG 1183-2419. EG&G Energy Measurements, Sant Barbara Operations, Goleta, CA.

Cooper, B.S. 1989. Focus Shifts from Capitol to Nevada. *Forum fo Applied Research and Public Policy* 4 (3): 26-28.

Duinker, P.N. 1989. Ecological Effects Monitoring in Environmen tal Impact Assessment: What Can It Accomplish? *Environmenta Management* 13: 797-805.

(ESA) Environmental Science Associates, Inc. 1989a. Nevad Environmental Studies Program. San Francisco, CA.

(ESA) Environmental Science Associates, Inc. 1989b. Impact As sistance Report: Inventory of Past DOE Land Disturbance, Yucc Mountain, Nevada, and Estimated General Reclamation Costs San Francisco.

(ESA) Environmental Science Associates, Inc. 1990. Vegetatio Studies at Yucca Mountain, Nye County, Nevada. San Francisc

(ESA and RCI) Environmental Science Associates, Inc., and Re source Concepts, Inc. 1989. Environmental Management Ob jectives, Impact Potential and Reclamation Planning for DOE Site Characterization at Yucca Mountain, Nevada. San Francisco

Hendrickson, D.A., and D.M. Kubly. 1984. Desert Waters: Past Present, and Future. *The Nature Conservancy News* 34 (5): 6-24

Jain, R.K., L.V. Urban, and G.S. Stacey. 1981. *Environmental Impact Analysis: A New Dimension in Decision Making*. Van Nostrand Reinhold Co., New York.

Karl, A. 1981. The Distribution and Relative Densities of the Desert Tortoise, *Gopherus agassizii*, in Lincoln and Nye Counties, Nevada. U.S. Department of the Interior, Bureau of Land Management, Contract No. YA-512-CT9-90.

Karl, A. 1983. The Distribution, Relative Densities and Habitat Associations of the Desert Tortoise, *Gopherus agassizii*, in Nevada. M.S. Thesis. California State University, Northridge. 111pp.

Karl, A. 1989. Yucca Mountain Project: Investigations of Desert Tortoise Abundance and Distribution on the Focused Baseline Study Area, Fall 1989 Field Studies. Prepared for Environmental Science Associates, Inc. San Francisco.

Lemons, J., C. Malone, and B. Piasecki. 1989. America's High Level Nuclear Waste Repository: A Case Study of Environmental Science and Public Policy. *International Journal of Environmental Studies* 34: 25-42.

Loux, R.R. 1989. A View on Siting Issue from Nevada. *Forum for Applied Research and Public Policy* 4 (3): 29-31.

Malone, C.R. 1989. Environmental Review and Regulation for Siting a Nuclear Waste Repository at Yucca Mountain, Nevada. *Environmental Impact Assessment Review* 9: 77-95

Malone, C.R. 1990a. The Yucca Mountain Project: Storage Problems of High-Level Radioactive Wastes. *Environmental Science and Technology* 23: 1452-1453.

Malone, C.R. 1990b. Geologic and Hydrologic Issues Related to Siting a Repository for High-Level Nuclear Waste at Yucca Mountain, Nevada, U.S.A. *Journal of Environmental Management* 30: 381-396.

Malone, C.R. 1990c. Environmental Planning for Siting a High-Level Nuclear Waste Repository at Yucca Mountain, Nevada. *Environmental Management* 14: 25-32.

Mitchell, D.L. 1984. Evaluation of Habitat Restoration Needs at Yucca Mountain, Nevada Test Site, Nye County, Nevada. EGG 10282-2030. EG&G Energy Measurements, Santa Barbara Operations, Goleta, CA.

Murthy, D.S. 1988. *National Environmental Policy Act (NEPA) Policy*. CRC Press, Boca Raton, FL.

(NAS) National Academy of Sciences. 1974. *Rehabilitation of Western Coal Lands*. J.B. Lippincott, Cambridge, MA.

(NWPO) Nuclear Waste Project Office. 1987. Environmental Program Planning for the Proposed High-Level Nuclear Waste Repository at Yucca Mountain, Nevada. NWPO-TR-001-87. State of Nevada, Agency for Nuclear Projects. Carson City.

(NWPO) Nuclear Waste Project Office. 1988. A Role in Environmental Compliance for the State of Nevada During Site Characterization of the Proposed High-Level Nuclear Waste Repository at Yucca Mountain, Nevada. NWPO-TR-008-88. State of Nevada, Agency for Nuclear Projects. Carson City.

(NWTRB) Nuclear Waste Technical Review Board. 1990. First Report to the U.S. Congress and the U.S. Secretary of Energy. Washington, DC.

O'Farrell, T.P., and E. Collins. 1984. 1983 Biotic Studies of Yucca Mountain, Nevada Test Site, Nye County, Nevada. EGG 10282-2031s764-R. EG&G Energy Measurements, Santa Barbara, CA.

Parker, G.J., J.R. Krummel, K.E. LaGory, G.J. Marmer, and S.P. Goel. 1990. The Environmental Protection Program for Site Characterization at Yucca Mountain, Nevada. *The Environmental Professional* 12: 186-196.

Power, M.S. 1989. Politics and Science in Siting Battle. *Forum for Applied Research and Public Policy* 4 (3): 19-25.

(RCI) Resource Concepts, Inc. 1989a. Soil Survey of Yucca Mountain Study Area, Nye County Nevada. Prepared by Bruce Kenny, registered soil scientist. Carson City, NV.

(RCI) Resource Concepts, Inc. 1989b. Review of Revegetation Practices Appropriate for Reclamation of the Proposed Nuclear Waste Repository at Yucca Mountain, Nevada. Carson City, NV.

(U.S. DOE) U.S. Department of Energy. 1986. Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada. DOE/RW-0073. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1988a. Site Characterization Plan: Yucca Mountain Site, Nevada Research and Development Area, Nevada. DOE/RW-0199. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1988b. Environmental Program Overview. DOE/RW-0207. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1988c. Environmental Monitoring and Mitigation Plan for Site Characterization. DOE/RW-0208. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1988d. Environmental Regulatory Compliance Plan for Site Characterization. DOE/RW-0209. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1988e. Environmental Field Activity Plan for Terrestrial Ecosystems. DOE/NV-10576-14. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1989a. Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program. DOE/RW-0247, November 29. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1989b. Draft Reclamation Program Plan for Site Characterization. DOE/RW-0244. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1989c. Biological Assessment of the Effects of Site Characterization Activities on the Endangered Desert Tortoise. Las Vegas. October.

(U.S. DOE) U.S. Department of Energy. 1989d. Environmental Restoration and Waste Management: Five-Year Plan. DOE/S-0070. Washington DC.

(U.S. DOE) U.S. Department of Energy. 1990a. Draft Reclamation Feasibility Plan. DOE/YMP-90-10. Nevada Operations Office/Yucca Mountain Project Office. Las Vegas.

(U.S. DOE) U.S. Department of Energy. 1990b. Draft Environmental Field Activity Plan for Soils. DOE/YMP-90-11. Nevada Operations Office/Yucca Mountain Project Office. Las Vegas.

Wallace, A., E. Romney, and R. Hunter. 1980. The Challenge of a Desert: Revegetation on Disturbed Desert Lands. In *Soil-Plant-Animal Relationships Bearing on Revegetation and Land Reclamation in Nevada Deserts. Great Basin Naturalist Memoirs No. 4*. Brigham Young University, Provo, UT, pp. 216-55.

Westman, W.E. 1985. *Ecology, Impact Assessment, and Environmental Planning*. John Wiley and Sons, New York.

Williams, O.R. 1988. Protest to U.S. DOE Water Rights Application No. 52338 with the Nevada State Engineer. U.S. National Park Service, Fort Collins, CO. December 30.

Winsor, M.F., and D. Rousseau. 1990. Applications of a Geographic Information System and Remote Sensing in Assessing Superficial Environmental Impacts of Siting and Site Characterization for a Proposed High Level Nuclear Waste Repository at Yucca Mountain, Nevada. In *Proceedings, The Scientific Challenges of NEPA: Future Directions Based on 20 Years of Experience, Ninth Oak Ridge National Laboratory Life Sciences Symposium, Knoxville, Tennessee, October 24-27, 1989* (in press).

Winsor, M.F., and L. Ulland. 1989. An Evaluation of Environmental Effects of the DOE HLW Repository Siting and Characterization Program at Yucca Mountain, Nevada. In *Proceedings, Waste Management '89* 1: 559-564.

## ATTACHMENT E

# Implications of Environmental Program Planning for Siting a Nuclear Waste Repository at Yucca Mountain, Nevada, USA

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ABSTRACT / The US Department of Energy (DOE) plans to conduct site characterization studies at Yucca Mountain, Nevada, to determine if the location is a suitable site for a nuclear waste repository. In lieu of traditional environmental review in accordance with the National Environmental Policy Act of 1969, the DOE is relying on an environmental assessment (EA) mandated by the Nuclear Waste Policy Act of 1982 as the cornerstone of its environmental program for the Yucca Mountain Project. Because of statutory restrictions, the EA is not based on comprehensive baseline information. Neither does it address fundamentals of environmental analysis such as ecological integrity and assessment of cumulative impacts. Consequently, the present environmental program for Yucca Mountain reflects decisions made without complete information and integrated environmental review. The shortcomings of the program risk compromising the natural integrity of Yucca Mountain and invalidating future assessment of the ability of a nuclear waste repository located at the site to protect the environment. Significant improvements are needed in the repository siting program before it can serve as a model of how society can evaluate the long-term environmental consequences of advanced technologies, as has been suggested.

Disposal of highly radioactive waste from nuclear power plants and production of nuclear weapons in deep geologic repositories in the United States is mandated by the Nuclear Waste Policy Act of 1982 (NWPA). The NWPA directed the US Department of Energy (DOE) to conduct geologic and hydrologic site characterization studies at three candidate sites to establish the suitability of the sites for location of a repository. Difficulties encountered by the DOE in implementing environmental provisions of the NWPA resulted in a failure of the national nuclear waste policy (Clary and Kraft 1988, Lemons and others 1989) and led to passage of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA). The NWPAA reformulated national policy and mandated that the DOE consider only the Yucca Mountain site in southwestern Nevada as a potential location for a repository. [Favorable qualities of the Yucca Mountain site have been discussed by the DOE (US DOE 1986).] The amendment of NWPA thus presents an opportunity for the DOE to modify its approach to repository siting to bring about a more successful nuclear waste disposal program than was the case prior to 1987. Clary and Kraft (1988) point out that whether or not this occurs depends on DOE's capacity to learn from experience and to devise appropriate strategies. Procedural aspects of the post-1987 environmental policy for the repository siting project at Yucca Mountain have been described (Lemons and Malone 1989, Malone 1989), thereby setting the stage for a review and analysis of the substance of the post-1987 DOE environmental program.

KEY WORDS: Environmental analysis; Repository siting; Yucca Mountain

An important issue related to the success of the Yucca Mountain environmental program is the suggestion that the high-level nuclear waste issue may serve as a model for how society deals with the consequences of new technologies that have the potential for threatening the environment for thousands of years (National Board for Spent Nuclear Fuel 1988). This issue compliments recent discussion regarding how society can avert environmental problems that have the potential for threatening the future (DeYoung and Kaplan 1988). The Yucca Mountain Project is relevant in this context because a nuclear waste repository must be demonstrated capable of isolating radionuclides from the environment for at least 10,000 years (US Environmental Protection Agency 1985, Egan and Clark 1989). Assessing whether or not a sealed and abandoned geologic repository will protect the environment for thousands of years is a complex problem beyond the scope of this article. The issue is steeped in uncertainty and subjectivity that must be addressed by performance assessment methodologies that have yet to be developed and that will be based more on probabilistic approaches than on deterministic ones (Lieberman and Lee 1986, Buxton 1989). However, the impacts of geologic and hydrologic site characterization activities cannot be separated easily from the long-term environmental behavior of a repository system because information on the natural setting gathered during the siting phase ultimately will be used to assess the long-term environmental fate of radionuclides. The efficacy of repository performance assessment could depend on the cumulative impacts resulting from activities carried out in the course of detailed site characterization, i.e., determining the suitability of the site for a repository. Thus, in the context of a nuclear waste repository, the concept of performance assessment largely is analogous to the environmental concept of cumulative impact assessment that is a fundamental cornerstone of US environmental policy (Westman 1985, Bartlett 1986, Caldwell 1988). These issues are addressed below by reviewing the substance of the DOE environmental program plans for site characterization of Yucca Mountain in the context of some current views on environmental impact analysis.

## DOE Environmental Program from 1982 to 1987

In order to analyze and evaluate the current DOE environmental program for siting a nuclear waste repository at Yucca Mountain, it is necessary to understand the program since the enactment of the NWPA in early 1983. This departure point is significant because NWPA contains provisions that exempt repository siting activities from preparing an environmental impact statement pursuant to compliance with the National Environmental Policy Act (NEPA) of 1969. This issue is seen as the root of the procedural difficulties with the Yucca Mountain environmental program (Lemons and Malone 1989, Malone 1989). As documented by Clary and Kraft (1988), the DOE prepared environmental assessments (EAs) for potential repository sites as directed by NWPA. However, the resulting poor technical quality of the documents was the underlying cause for the policy failure of NWPA and the passage of NWPAA in 1987. To determine whether the current approach being taken by the DOE for the Yucca Mountain Project stands to achieve the outcome desired by NWPAA (Clary and Kraft 1988), it is helpful to review the statutory EA for the Yucca Mountain site (US DOE 1986).

In accordance with the NWPA, the Yucca Mountain statutory EA (US DOE 1986) was prepared based on available regional information. No new studies were undertaken to provide comprehensive, site-specific environmental insights. Another limitation was that only preliminary descriptions of the proposed site characterization activities at Yucca Mountain were available for preparation of the NWPA statutory EA. When the document was issued, the DOE (US DOE 1986) stated that as a result of the lack of complete information on baseline environmental conditions at the site and on the proposed action, the results should be considered preliminary. An indication of the extent of uncertainty that characterized the NWPA statutory EA for the Yucca Mountain site can be gained from Table 1 by comparing the description of the proposed action used for impact analysis with the site characterization activities currently planned. For example, the statutory EA stated that there are to be 20 drill holes, whereas the current plans (US DOE 1988d) reveal that up to 400 holes may be drilled or cored. Additional shortcomings of the NWPA statutory EA from the perspective of environmental analysis include the following:

1. No mention was made of environmental impacts associated with disturbance to soils, and no ecological information existed with respect to soils at Yucca Mountain.
2. There were no data on air quality and meteorological conditions at the site.
3. No groundwater quality information was presented.
4. No consideration was given to impacts from noise.
5. No information existed on visual resources and potential impacts from the repository program.
6. Without any basis in empiricism or deterministic analysis, the EA concluded there would be no significant environmental impacts from site characterization.
7. Without any regulatory analysis, the EA concluded that all applicable environmental requirements can be met during site characterization.

Clearly the NWPA statutory EA for the Yucca Mountain site was not suited for purposes of rigorous environmental review, evaluation, and planning in the traditional sense of NEPA (Lemons and Malone 1989, Malone 1989). Clary and Kraft (1988) concluded that the failure of the DOE to carry out systematic and objective surveys and impact analyses, to adopt credible methodologies and analytical procedures, and to defend the findings of minimal environmental consequences resulted in the DOE not achieving its goals under the NWPA. The roots of this failure have been attributed to the NEPA exemptions granted by the NWPA to repository siting activities and the prohibition on acquisition of complete information on environmental conditions at sites like Yucca Mountain (Lemons and Malone 1989, Malone 1989). As a consequence, the DOE did not carry out environmental impact analysis in accordance with traditional NEPA standards and guidelines. In light of the complex, controversial nature of the nuclear waste issue, this

Table 1. Surface-disturbing siting activities for the Yucca Mountain Project

| Activity | Described in EA (DOE 1986) | Carried out before 1987 (DOE 1988d) | Planned for after 1987 (DOE 1988d) |
|---|---|---|---|
| Drill holes (N) | 20 | 216 | 350–400 |
| Trenches (N) | Unspecified | 64 | 25–30 |
| Hydraulic pavements (N) | Not included | 6 | 2 |
| Seismic surveys (km) | 80 | Unknown | 150–240 |
| Infiltration plots and ponds (N) | Not included | Unknown | 87 |
| Exploratory shaft facilities (ha) | 8 | 8 | 13 |
| Access roads (km) | 160 | 190 | 40–50 |
| Area disturbed (ha) | 280–320 | 370 | 200–320 |

shortcoming must be viewed as a major error in decision making and policy that NEPA was meant to avoid.

In addition to understanding the background to the statutory EA, it is useful to consider the environmental regulatory requirements that apply to repository site characterization activities at Yucca Mountain. The planned activities are to be carried out over a period of five to seven years and will be in addition to similar activities that were conducted prior to 1986 when siting was halted pending preparation of site characterization plans (Table 1). In large part the regulatory requirements that apply to the Yucca Mountain Project (Malone 1989) set the framework for the DOE environmental program. The most notable of the environmental requirements are those contained in NWPA (Table 2) that have been at the root of decisions made by DOE with respect to environmental review for site characterization. As a consequence of the partial NEPA exemptions, it is DOE policy that the NWPA statutory EAs were program-specific decision documents that bear no relation to the requirements of the NEPA. Because an environmental impact statement is not required for site characterization, the DOE has no plans for evaluating impacts that could occur as a result of site characterization and errors reflected in the NWPA statutory EA for Yucca Mountain risk being perpetuated during site characterization. Federal and state environmental regulations that apply to the project also influence the environmental program, but none of these require comprehensive environmental analysis (Malone 1989). For the most part the federal and state compliance requirements are similar to those that apply to all major construction activities on federally owned land.

## DOE Environmental Program for Yucca Mountain since 1987

Following passage of the NWPAA in 1987, the DOE issued an Environmental Program Overview (US DOE 1988a) that describes environmental planning for site characterization activities at Yucca Mountain. The program overview describes the purpose of other documents that, when completed, will comprise composite plans for protecting the environment at Yucca Mountain during site characterization (Table 3). All the plans are based on the findings and conclusions of the NWPA statutory EA (US DOE 1986) and are predicated on the assumption that the EA provides a sound basis for continued environmental program planning. As discussed in the preceding section, the adequacy of the statutory EA is fundamental to the post-1987 DOE environmental program. The components of the DOE environmental program plan for site characterization activities are discussed below, followed by a critique of the success with which the Environmental Program Overview (US DOE 1988a) illustrates that the documents reflect comprehensive, integrated environmental program planning for the Yucca Mountain Project.

Table 2. Environmental provisions of the Nuclear Waste Policy Act for repository site characterization

| Section | Requirement |
|---|---|
| 112 (a) and (b) | Recommendation of candidate site for consideration as a repository site requires preparation of a statutory environmental assessment (EA) based on information available at the time. |
| 112 (e) and 113 (d) | Siting activities are exempt from preparation of an EIS pursuant to NEPA. |
| 113 (a), (b), and (c) | Subsequent to site recommendation, geologic and hydrologic siting studies are to be carried out at Yucca Mountain in a manner that minimizes the significant adverse environmental impacts that are to be identified in a second EA (separate from the Section 112 EA) submitted as part of the plans for siting studies. The plans also are to include reclamation of the Yucca Mountain site and mitigation of significant adverse impacts. |

Table 3. Documents described in the environmental program overview (DOE 1988c) as comprising the environmental program plans for site characterization at Yucca Mountain

| Title | Reference |
|---|---|
| Environmental Monitoring and Mitigation Plan | US DOE 1988a |
| Environmental Regulatory Compliance Plan | US DOE 1988b |
| Reclamation Program Plan | In preparation |
| Reclamation Feasibility Plan | In preparation |
| Reclamation Implementation Plan | In preparation |
| Environmental Field Activity Plans for: | |
| Aesthetics | Unscheduled |
| Air quality | US DOE 1988f |
| Archeology | US DOE 1988g |
| Noise | Unscheduled |
| Soils | Unscheduled |
| Ecosystems | US DOE 1988e |
| Water resources | In preparation |

## Monitoring, Mitigation, Reclamation, and Regulatory Compliance

An Environmental Monitoring and Mitigation Plan (US DOE 1988a) addresses monitoring and mitigating significant adverse impacts from future site characterization activities and was prepared to assure that site characterization would be conducted in a manner that minimizes environmental impacts. The plan is not comprehensive and fails to address all components of the environment because the NWPA statutory EA was used to identify potential impacts to be minimized and mitigated during site characterization (US DOE 1988a,b). Thus, if a potential impact is not identified in the statutory EA, it is not addressed in the monitoring and mitigation plan. For example, terrestrial ecosystems are to be surveyed principally where site characterization activities will result directly in site disturbance and not across the entire study site. There will be no comprehensive studies associated with impact monitoring and mitigation prior to site characterization. No monitoring will be conducted for soils, noise, and aesthetics because the statutory EA concluded that no impacts will occur in those components of the environment. Monitoring for air pollutants from site characterization will cover only particulate matter, and no other emissions resulting from site characterization will be measured. There will be no attempt to address cumulative impacts of any kind, and the only form of mitigation to be considered is subsequent alteration of an ongoing activity if impacts are detected. In the DOE's view, the concept of cumulative impacts from past and planned activities and the need to consider direct mitigation measures are ideas restricted to NEPA and do not apply to the Yucca Mountain Project (US DOE 1988b). Thus, the scope of the plan for monitoring and mitigation is narrowly restricted to the context of the NWPA and the statutory EA with no consideration of a broad perspective on environmental review.

Following the monitoring and mitigation plan, the DOE issued a plan for complying with environmental requirements other than those derived directly from the NWPA. The Environmental Regulatory Compliance Plan (US DOE 1988c) is a procedural document that implements the DOE internal orders requiring that operations be carried out in an environmentally sound manner as defined by statutes and regulations. This reflects how DOE equates environmental protection with regulatory compliance. Such a policy would be more credible if NEPA were complied with in its entirity during repository siting, but this is not to be the case. Aside from the specific exemptions granted by the NWPA that remain applicable to site characterization at Yucca Mountain, there is no indication in the regulatory compliance plan (US DOE 1988c) of how the requirements that address planning, decision making, and other aspects of NEPA may be met. Other than the limitations imposed on NEPA, the compliance plan adequately identifies the range of non-NWPA and environmental requirements likely to apply to the Yucca Mountain Project. How compliance will be achieved is not addressed, and although the plan mentions that a compliance auditing program will be developed, there is no discussion of its substance.

The DOE is preparing three separate plans for reclamation activities at Yucca Mountain (Table 3) pursuant to the requirements of NWPA. The first of the documents is to be a Reclamation Program Plan meant to discuss the requirements that mandate reclamation. The second document will be a Reclamation Feasibility Plan describing field studies for developing reclamation practices for the Yucca Mountain site. The third document will be a Reclamation Implementation Plan that discusses how the results of the feasibility plan will be implemented. A notable feature of these plans is that they will include plans for floristic studies of the Yucca Mountain ecosystem (US DOE 1988a) that will be apart from the ecological investigations to be carried out on soils and on fauna. As a consequence, no single plan exists for comprehensive ecological studies.

## Environmental Field Activities

Field studies and analyses needed to provide data and information for the Environmental Monitoring and Mitigation Plan, the Environmental Regulatory Compliance Plan, and the uncompleted reclamation plans are to be described by DOE in a set of Environmental Field Activity Plans (Table 3). Each individual disciplinary field activity plan is to be developed to reflect only the studies needed to meet environmental requirements as they arise in a stepwise manner during the course of the Yucca Mountain Project. Thus, as a need for field information arises, a new activity plan will be prepared or an existing one amended to reflect the studies required. This approach precludes DOE ever achieving the comprehensive planning and integration that typically characterize sound and effective environmental analysis. As a result of the piecemeal manner in which the field plans are being prepared, it is not possible to obtain a perspective on the overall studies that are to comprise the DOE environmental program for the Yucca Mountain Project. The difficulties inherent in the approach are apparent from the following observations.

1. The Environmental Field Activity Plan for Terresterial Ecosystems (US DOE 1988e) describes preconstruction surveys needed at Yucca Mountain to assure that no protected species or habitat is present. These surveys will focus on the desert tortoise (*Gopherus agassizii*) because that species is a candidate for protection under the Endangered Species Act. Following completion of site characterization, DOE will conduct postconstruction surveys to determine the need for impact mitigation and reclamation. As noted above, the ecosystems field plan contains no floristic studies as these are to be included among the reclamation plans. Neither does the plan contain studies or analyses of ecosystem-level parameters such as productivity, nutrient cycling, and ecological integrity.

2. The Environmental Field Activity Plan for Air Quality (US DOE 1988f) addresses monitoring of particulate matter to determine if regulatory exceedences will occur during site characterization. No other criteria pollutants are to be monitored with respect to site characterization activities, and no dispersion modeling is planned. Meteorological monitoring (US DOE 1985) is a program separate from the environmental program and is not addressed in the air quality plan.

3. A comprehensive survey of Yucca Mountain for archeological sites was conducted in 1982 prior to passage of NWPA and was reported in the NWPA statutory EA (US DOE 1986). The archeological resources data base constitutes the only source of comprehensive site-specific environmental information available for Yucca Mountain. Locations of archeological sites are known and an archeological field activity plan (US DOE 1988g) contains plans for recovery of artifacts where site characterization will directly disturb them. All the measures required by federal archeological resources protection laws and regulations are addressed by the field plan.

4. A field plan for water resources is being prepared for purposes of environmental regulatory compliance and monitoring. The initial omission by the DOE of such a plan was on the basis that the NWPA statutory EA found no potential impacts to water resources as a result of site characterization activities at Yucca Mountain. However, DOE (US DOE 1988c) subsequently learned that field studies were needed for purposes of regulatory compliance.

5. No field plans are available for soils, noise, and aesthetics. As the DOE contends that no regulatory requirements exist for soils, noise, and aesthetics during repository siting, field plans will not be prepared for analysis of impacts from site characterization. Monitoring for these aspects of the environment as part of the Environmental Monitoring and Mitigation Plan (US DOE 1988b) was omitted because the NWPA statutory EA concluded that adverse impacts would no result from site characterization activities.

### Environmental Program Overview

The Environmental Program Overview for site characterization activities at Yucca Mountain (US DOE 1988a) describes the procedural purpose of the individual plans that comprise the DOE environmental program (Table 3). The document does not discuss the substance of each plan and thus does not provide an integrated view of the scientific nature of the DOE environmental program. There is no component of the plan that accomplishes a substantive, as opposed to a procedural, overview and illustrates that the program reflects a comprehensive approach to planning for environmental protection. The absence of complete environmental baseline information precludes accomplishing a sound analysis of impacts that could result from site characterization and renders all planning based on the NWPA statutory EA subject to uncertainty. The lack of complete information on conditions at the site will not be remedied because the true baseline will never be known. The decision to monitor impacts primarily where the NWPA statutory EA predicted them means that unmonitored components of the environment could be impacted and never detected.

## Discussion and Conclusions

Environmental protection programs are based increasingly on concepts of cumulative impacts, biological diversity, environmental integrity, and resources conservation (Stakhiv 1988, Westman 1985, Jordan and others 1988. Office of Technological Assessment 1987). This is not the case with the Yucca Mountain repository siting project. Given the inadequacies of the environmental planning effort, it is unlikely that the DOE can carry out a credible and effective program of impact analysis and environmental protection during site characterization at Yucca Mountain. There is some reason to believe that prior to repository construction at Yucca Mountain, a more comprehensive and integrated approach to DOE's environmental program could be developed. This possibility exists because of the requirements that performance assessment studies be carried out before authorization of repository construction in order to demonstrate the ability of the environment's natural setting to safely contain nuclear wastes for at least 10,000 years (US Environmental Protection Agency 1984, Egan and Clark 1989). Performance assessment must address the sustained integrity of the site's natural setting and confirm that cumulative impacts of radionuclides from a repository will not threaten the quality of the environment (Lieberman and Lee 1986, Buxton 1989). However, the assessment ultimately could be flawed because of DOE's current policy of not performing comprehensive, integrated siting studies and not analyzing cumulative impacts as a result of site characterization.

A sound environmental program plan for Yucca Mountain must provide for acquisition of comprehensive information on the site. This means that baseline conditions should be described before site characterization proceeds. It will not be sufficient for studies to be carried out after site characterization has been initiated, as the US DOE (1988a,b) plans to do. The lack of complete environmental baseline information for the Yucca Mountain site coupled with the DOE decision to monitor impacts primarily where the NWPA statutory EA predicted them means that unmonitored components of the environment could be impacted and never detected. This is important with respect to the need for impact mitigation and site reclamation. The consequences that environmental impacts that are not remediated could have to the preservation of the site's natural integrity are a critical factor in light of the performance assessment requirements (US Environmental Protection Agency 1985, Egan and Clark, 1989). It is essential that geologic and hydrologic characterization not compromise the fundamental nature of the environment. To do so would impose uncertainty on the ability of the site to perform as intended and protect future environmental systems from serious radiological impact. To this end it seems that auditing of predicted impacts as discussed by Canter (1985) is needed at Yucca Mountain.

A major weakness in the post-1987 DOE environmental program for Yucca Mountain was inevitable when the decision was made to accept the statutory EA (US DOE 1986) mandated by the NWPA as the basis for subsequent planning. The alternative would have been to follow the intent of the NWPA, set the statutory EA aside once it had served the decision-making purpose intended by NWPA, and prepare another assessment based on comprehensive, empirically derived information as an intrinsic component of site characterization. In choosing not to follow such a course, the DOE has not benefited from the experience of the failed 1982 policy (Cleary and Craft 1988) and, as a result, the absence of appropriate environmental analysis continues to trouble the repository siting project. Continuing to pursue the environmental policy eminating from NWPA in 1982, already proven to be faulty, will only result in another failure of the high-level nuclear waste repository program. The reason for the DOE reliance on the NWPA statutory EA is unclear but may be based on legal considerations and an unwillingness to suggest that the document was inadequate by undertaking another analysis based on comprehensive environmental information and complete plans for site characterization (Malone 1989).

If an alternative to the present course of environmental program planning for the Yucca Mountain Project were to be developed, it could adopt an approach that holds promise for accommodating the complexities inherent in repository performance studies where uncertainty is a significant consideration (Buxton 1989). In this respect recent developments in expert systems technology (Lein 1989) offer a unique approach to complex environmental assessment and merit consideration. The computer-based expert systems approach is well suited to accommodating the multifaceted considerations inherent to environmental performance assessment. Interdisciplinary knowledge can be encoded to provide solutions to specialized problems that transcend traditional, formalized environmental analysis. An especially appealing aspect of the systems approach is that it provides for the screening and evaluation of alternative considerations, such as siting activities and engineering designs, before adverse consequences occur (Lein 1989). If adopted by the DOE, expert systems methodology could provide the framework for an enlightened approach to environmental planning and performance assessment for the Yucca Mountain site that is consistent with the complexity and significance of the nuclear waste disposal issue and program in the United States.

A fundamental lesson to be learned from the experiences that led to and that are following from the

NWPA policy failure is that in matters of critical environmental concern over high-risk technologies like nuclear energy and disposal of nuclear waste the environmental rationality embodied within NEPA (Bartlett 1986) should not be set aside for an expedient politically based rationality. The environmental rationale that is the cornerstone of NEPA and upon which the precepts of sound environmental impact analysis are based (Bartlett 1986, Caldwell 1988) will serve society well when faced with making decisions in the face of uncertainties that carry unknown risks to the environmental systems of future generations. The concepts of environmental integrity (Westman 1985) and cumulative impact analysis (Stakhiv 1988) are essential to the task of assessing the performance of an environmental system in which a repository is to be developed for isolating nuclear wastes for thousands of years. In this sense the emerging methodology of performance assessment for a repository system stands to benefit from adopting the precepts of sound environmental planning and management founded on preserving the integrity of environmental systems and analysis of cumulative impacts disturbuted over time. Only if performance assessment is conceptually sound and does not compromise basic precepts of environmental protection and analysis like those embodied in NEPA can it ever offer society a potential means of addressing the long-term consequences of scientific and technological development on future environmental systems and generations. In this respect, how society deals with the issue of nuclear waste could be a turning point in addressing the consequences of far-reaching actions on future environmental systems and generations (National Board on Spent Nuclear Fuel 1988; DeYoung and Kaplan 1988). The US nuclear repository program as now reflected by the DOE Yucca Mountain Project shows little promise of contributing to the resolution of this problem.

## Literature Cited

Bartlett, R. V. 1986. Rationality and the logic of the National Environmental Policy Act. *The Environmental Professional* 8:105–111.

Buxton, B. E. 1989. Geostatistical, sensitivity, and uncertainty methods for ground-water flow and radionuclide transport modeling. Battelle Press, Columbus, Ohio. 670 pp.

Caldwell, L. K. 1988. Environmental impact analysis (EIA): Origins, evolution, and future directions. *Policy Studies Review* 8:75–83.

Canter, L. W. 1985. Impact prediction auditing. *The Environmental Professional* 7:255–264.

Clary, B. B., and M. E. Kraft. 1988. Impact assessment and policy failure: The Nuclear Waste Policy Act of 1982. *Policy Studies Review* 8:105–115.

DeYoung, R., and S. Kaplan. 1988. On averting the tragedy of the commons. *Environmental Management* 12:273–283.

Egan, D., and R. Clark. 1989. Amended environmental radiation protection standards for management and disposal of spent nuclear fuel, high-level, and transuranic radioactive wastes. 40 CFR Part 191: Working draft I. June 2. US Environmental Protection Agency, Washington, DC. 32 pp.

Jordan, W. R., III, R. L. Peters II, and E. B. Allen. 1988. Ecological restoration as a strategy for conserving biological diversity. *Environmental Management* 12:55–72.

Lein, J. K. 1989. An expert system approach to environmental impact assessment. *International Journal of Environmental Studies* 33:13–27.

Lemons, J., and C. Malone. 1989. Siting America's geologic repository for high-level nuclear waste: Implications for environmental policy. *Environmental Management* 13:435–441.

Lemons, J., C. Malone, and B. Piasecki. 1989. America's high-level nuclear waste repository: A case study of environmental science and public policy. *International Journal of Environmental Studies* 34:25–42.

Lieberman, J. A., and W. W. L. Lee. 1986. Mathematical modeling of waste respository performance: A peer review. Pages 749–758 *in* H. C. Burkholder (ed.), High-level nuclear waste disposal. Battelle Press, Columbus, Ohio.

Malone, C. R. 1989. Environmental review and regulation for siting a nuclear waste repository at Yucca Mountain, Nevada. *Environmental Impact Assessment Review* 9:77–95.

National Board on Spent Nuclear Fuel. 1988. Ethical aspects of nuclear waste. Report 29. SKN, Stockholm, Sweden. 23 pp.

Office of Technology Assessment. 1987. Technologies to maintain biological diversity. US Government Printing Office, Washington, DC. 334 pp.

Stakhiv, E. Z. 1988. An evaluation paradigm for cumulative impact analysis. *Environmental Management* 12:725–748.

US DOE (Department of Energy). 1984. Nuclear Waste Policy Act of 1982: General guidelines for the recommendation of sites for the nuclear waste repositories (final siting guidelines), 10 CFR Part 960. *Federal Register* 49:47714–47770.

US DOE (Department of Energy). 1985. Meteorological monitoring plan. DOE/NVO 10270-5. US Department of Energy, Las Vegas, Nevada. 54 pp.

US DOE (Department of Energy). 1986. Environmental assessment: Yucca Mountain Site, Nevada research and development area, Nevada. DOE/RW-0073. US Department of Energy, Washington, DC. 902 pp.

US DOE (Department of Energy). 1988a. Environmental monitoring and mitigation plan for site characterization. DOE/RW-0208. US Department of Energy, Washington, DC. 104 pp.

US DOE (Department of Energy). 1988b. Environmental regulatory compliance plan for site characterization. DOE/RW-0209. US Department of Energy. Washington, DC. 139 pp.

US DOE (Department of Energy). 1988c. Environmental program overview. DOE/RW-0207. US Department of Energy, Washington, DC. 50 pp.

US DOE (Department of Energy). 1988d. Site characterization plan. DOE/RW-0199. US Department of Energy, Washington, DC. 6331 pp.

US DOE (Department of Energy). 1988e. Environmental field activity plan for terrestrial ecosystems. DOE/NV-10576-14. US Department of Energy, Las Vegas, Nevada. 109 pp.

US DOE (Department of Energy). 1988f. Environmental field activity plan for air quality. DOE/NV-10576-13. US Department of Energy, Las Vegas, Nevada. 46 pp.

US DOE (Department of Energy). 1988g. Environmental field activity plan for cultural resources: Archaeological component. DOE/NV-10576-16. US Department of Energy, Las Vegas, Nevada. 81 pp.

US DOE (Environmental Protection Agency). 1985. Environmental standards for the management and disposal of spent nuclear fuel, high-level, and transuranic radioactive wastes, 40 CFR Part 191. *Federal Register* 50:38066–38089 (Remanded July 17, 1987, US Court of Appeals, First Circuit).

Westman, W. E. 1985. Ecology, impact assessment, and environmental planning. John Wiley & Sons, New York. 532 pp.

**ATTACHMENT F**

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# ECOLOGY, ETHICS, AND PROFESSIONAL ENVIRONMENTAL PRACTICE: THE YUCCA MOUNTAIN, NEVADA, PROJECT AS A CASE STUDY

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**Abstract.** The U.S. Department of Energy (DOE) is proposing to develop a geologic repository for disposing of high-level nuclear waste at Yucca Mountain, Nevada. In this commentary, the ecology program for the DOE's Yucca Mountain Project is discussed from the perspective of state-of-the-art ecosystem analysis, environmental ethics, and standards of professional practice. Specifically at issue is the need by the Yucca Mountain ecology program to adopt an ecosystem approach that encompasses the current strategy based on population biology and community ecology alone. The premise here is that an ecosystem approach is essential for assessing the long-term potential environmental impacts at Yucca Mountain in light of the thermal effects expected to be associated with heat from radioactive decay.

## INTRODUCTION

The resolution of environmental issues, both short-term and long-term, involves a proper synthesis of environmental information with principles of ethics and values (Lemons, 1987; Shrader-Frechette, 1993; Golley, 1994). In some cases this does not happen, a frequent reason being that environmental science and management often are not practiced holistically in an integrated and interdisciplinary sense as advocated by environmental professionals such as Cairns and Crawford (1991) and Dorney and Dorney (1989). Some environmental professionals do not comprehend holistic approaches to environmental protection or for other reasons do not practice their profession in a manner that integrates principles of interdisciplinary environmental science and ethics adequately.

My commentary discusses such a case from the perspective of the ecosystem approach (e.g., Allen and Hoekstra, 1992; Golley, 1993; Slocombe, 1993b; Grumbine, 1994a) and comments on issues of methodological value judgment, environmental ethics, and standards of professional environmental practice. From this perspective, I suggest how concepts of ecosystem analysis combined with sound principles of ethics and professional practice can contribute to the resolution of some controversial environmental issues.

The case study at hand is the U.S. Department of Energy (DOE) project to dispose of high-level nuclear waste in a deep geologic repository at Yucca Mountain, Nevada. The Yucca Mountain Project previously has been used by Lemons (1995) and Shrader-Frechette (1993, 1994) to illustrate clashes between ethics and methodological value judgment. In the present commentary, I use the Yucca Mountain ecology program as an example of how environmental decisions need to be based on an understanding of the capabilities for human actions to pose a threat to long-term environmental quality (e.g., Peters and Lovejoy, 1992). In cases involving potential consequences to long-term ecosystem integrity (Woodley et al., 1993), it is prudent for decisions to be made in a manner that poses the least threat to the environment for future generations. Extremely long-lived radioactive and associated hazardous waste threatens environmental quality for as long as 10 million years (Kirchner, 1990). Therefore, decisions made now about such wastes could deprive future generations of options and choices that are rightfully theirs to make (Baldwin, 1985). From this standpoint logically fall questions about ecology and environmental ethics with respect to the Yucca Mountain Project.

It should be noted at the outset that the concern I express here is not over the loss of a small amount of desert ecosystem. Instead, my concern involves the greater potential environmental consequences that could follow from the sacrifice of the ecosystem atop a high-level nuclear waste repository at Yucca Mountain (Figure 1). Thus, it is not explicitly the principle of maintaining ecosystem integrity and biodiversity that is at issue but rather what might result from failing to use ecosystem analysis to assess the potential consequences. This in turn leads to issues of ethics and professional practice and some of the challenges faced by the environmental profession in terms of applying the best scientific concepts and practices available for preserving the environment for future generations.

## THE YUCCA MOUNTAIN CASE

The purpose of the Yucca Mountain Project along with other information relevant to my commentary is shown in Table 1.

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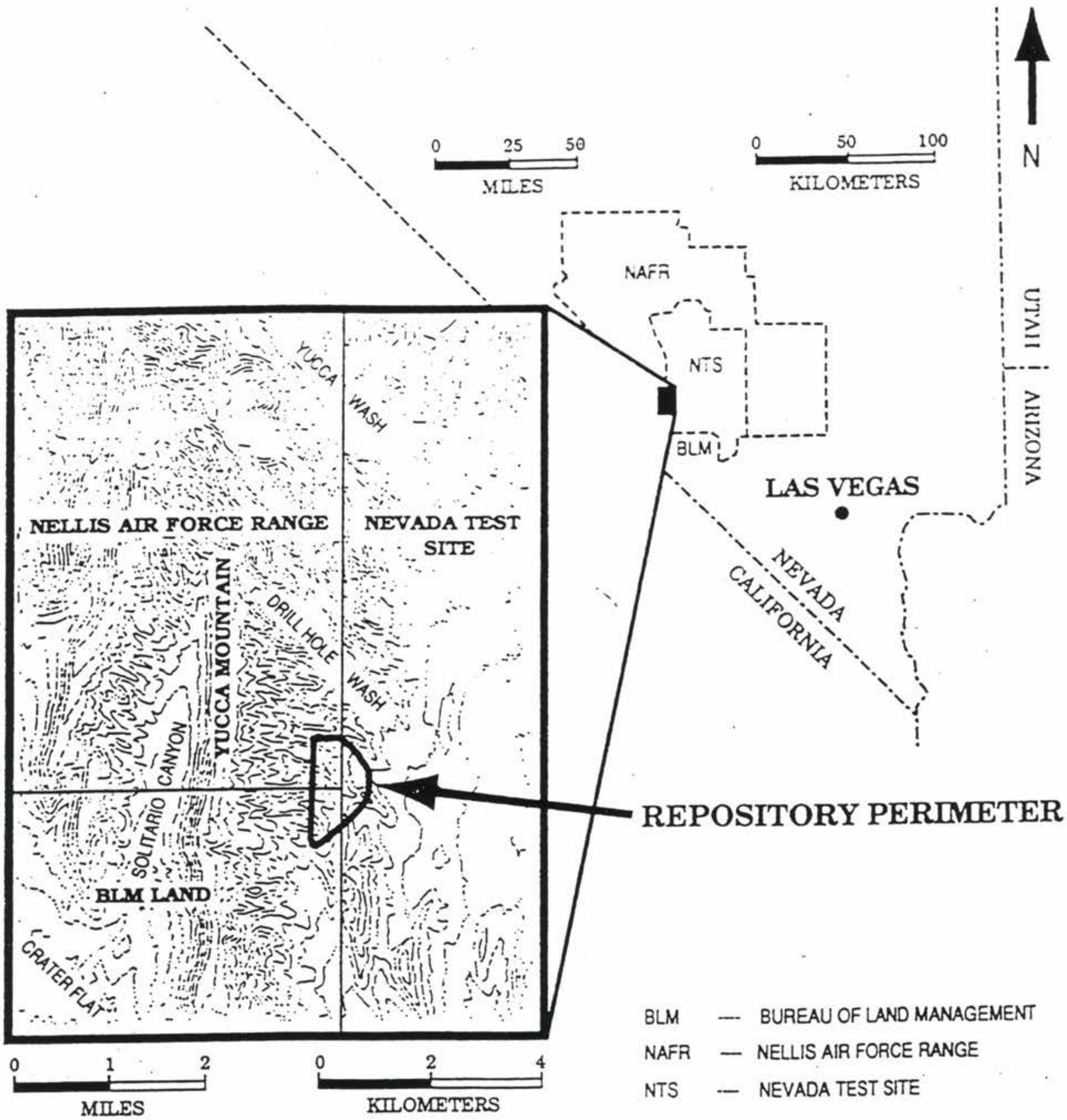
Figure 1. Map of the U.S. DOE Yucca Mountain Project Site Showing the Perimeter of the Proposed Geologic Repository for Disposing of Nuclear Waste




Regulations require that the repository must isolate nuclear waste from the environment for a minimum of 10,000 years (Lemons et al., 1989; Malone, 1989; Shrader-Frechette, 1993). This is because there will be large amounts of long-lasting radioactive contaminants such as plutonium-239 (Kirchner, 1990), which has a half-life of 24,390 years. As noted, Kirchner demonstrated that nuclear waste inside a deep geologic repository would be hazardous for as long as 10 million years. He suggested that a waste containment period of 10,000 years is far too short, a matter that remains open for

**Table 1. Important Features of the Yucca Mountain Repository Project**

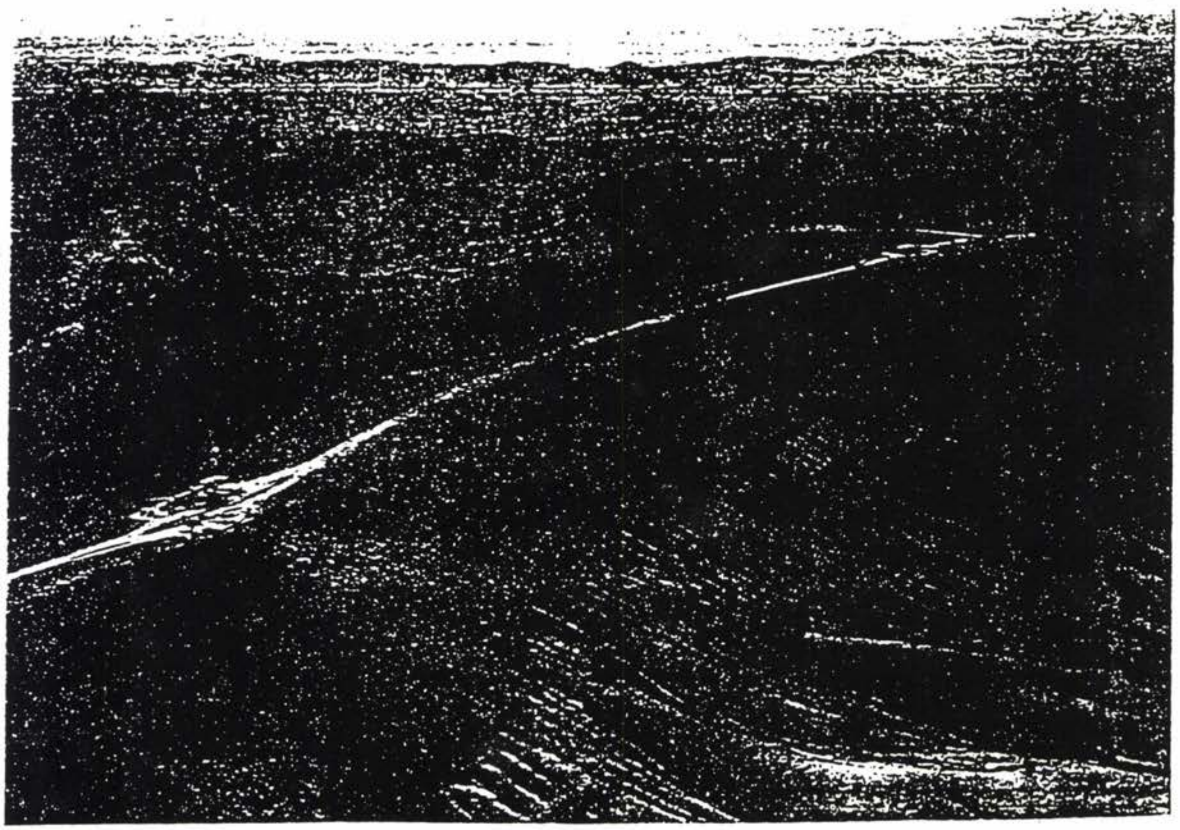
| | |
|---|---|
| Purpose: | Confinement of 70 kmt of commercial and military high-level nuclear waste for >10,000 years |
| Total Cost: | $35-$50 Billion |
| Schedule: | Opens 2010<br>Is Sealed 2150 |
| Depth: | 350 m below the surface<br>225 m above the groundwater table |
| Repository Temperature: | 300°C to >100°C for >10,000 years |

reconsideration regarding the Yucca Mountain Project. For long-term isolation of nuclear waste to be achieved requires that a site must not experience significant climatic, geologic, hydrologic, or other environmental perturbation that would compromise a repository's integrity.

As would be expected in any attempt to forecast long-term environmental conditions at Yucca Mountain, many uncertainties exist regarding assurances of containment of radioactive waste (Malone, 1990a; Shrader-Frechette, 1993). The need for the very best scientific insight on this issue recently was emphasized by the work of Bowman and Venneri (1995). The investigators predict that under plausible long-term conditions likely to occur at Yucca Mountain, highly radioactive waste emplaced in a geologic repository at the site could result in nuclear criticality and explosion that would release radioactive material into the surrounding environment and the global atmosphere. A peer review process

**Figure 2. A Portion of the Potential Thermal Impact Zone at the Yucca Mountain Site**

Shows part of the 7 km² potential thermal impact zone atop and on either side of the north/south-running ridgetop in the foreground (north is to the left of the photograph).



within the DOE complex attempted to disprove the findings but failed (Benjamin, 1994; Bowman, 1995).

A principal matter of concern at Yucca Mountain is the heat that will occur within a repository as a result of radioactive decay. This is estimated to cause peak temperatures around 300°C at the repository walls that would remain above 100°C for over 10,000 years (Buscheck and Nitao, 1993; Buscheck et al., 1993). The hydrothermal scenario for such a "hot" repository is poorly understood with respect to the associated environmental consequences. Hydrothermal process modeling by Buscheck and others suggests that temperatures within the top 7 m at Yucca Mountain can be expected to rise by an average of 2°-13°C. This is consistent with the 6°C rise allowed by the DOE (1988b) for temperature increases at the ground surface.

The repository-driven hydrothermal regime being studied is anticipated (Buscheck, 1994b) to influence the surface environment beginning about 200 years after the repository is filled in 2050. Peak effects would occur at the surface of Yucca Mountain after another 400 to 800 years and would remain in effect for at least 10,000 years or longer. These effects would occur over an area 3 km in diameter (7 $km^2$) (Buscheck and Nitao, 1993), designated here as "the surface thermal impact zone." This is comparable to the 10 $km^2$ disturbed area allowed by the DOE (1988b). The potential impact zone is partially shown in Figure 2. The investigators have yet to conduct field studies relative to thermally induced changes near the surface at Yucca Mountain (Buscheck, 1994a).

The issue of repository-induced thermal impacts at Yucca Mountain is more than a scientific curiosity. An environment altered by subterranean heat at Yucca Mountain could influence the ecosystem and in turn the hydrologic balance and groundwater regime above a repository. Because groundwater is considered to be the most important factor affecting a repository's performance (by corroding waste canisters and transporting radionuclides), long-term interactions between the nuclear waste and the underground setting should not be ignored (Malone, 1989-90, 1990c; Fehringer, 1994; Lemons and Malone, 1994; NWTRB, 1994).

The problem would arise from increases in environmental temperature and therefore is similar to questions posed by elevated soil temperatures associated with global warming (e.g., Peters and Lovejoy, 1992). Accordingly, it is logical to consider whether or not understanding the issue of repository-induced ecosystem impacts would be responsive to the application of the holistic ecosystem approach as some are doing in the case of global warming and the environmental implications to ecosystem integrity and biodiversity (Van Cleve et al., 1990; Field et al., 1992; Harte et al., 1992, 1995; Peterjohn et al., 1993, 1994; Harte and Shaw, in press).

It might be expected that in complying with the requirements of the National Environmental Policy Act (NEPA) at Yucca Mountain, the DOE would adopt a systematic ecosystem approach for environmental impact assessment (EIA). Such approaches are available (e.g., Beanlands and Duinker, 1984; Duinker and Baskerville, 1986; Westman, 1987; Cairns and Crawford, 1991; Golley, 1993), but the DOE (1988a, 1992) continues to pursue an approach based alone on population biology and community ecology and lacking integration with abiotic environmental sciences such as hydrology, geology, and climatology (Winsor and Malone, 1990; Malone, 1990b; Lemons and Malone, 1994; NWTRB, 1994). The DOE approach is seen here as being contrary to principles of environmental ethics and standards of professional environmental practice. To understand this, it is instructive to consider some key issues of ethics and professional practice before turning attention to the Yucca Mountain Project and applied ecosystem science.

## ETHICS AND STANDARDS FOR PROFESSIONAL ENVIRONMENTAL PRACTICE

As noted in the introduction above, environmental professionals should conduct their practice cognizant that the synthesis of authentic facts and values consistent with interdisciplinary concepts is a professional responsibility. Some professional codes of ethics and standards of professional practice recognize this (e.g., Shrader-Frechette, 1994; ACEC, 1995; ESA, 1995; Lemons, 1995; NAEP, 1995; NDEP, 1995). For example, Table 2 lists some fundamental principles of ethics and standards of practice adopted by environmental professional organizations such as the National Association of Environmental Professionals (NAEP).

The principles listed in Table 2 set the scene for this case study of ecosystem science, ethics, and standards of professional practice using the Yucca Mountain Project ecology program (DOE, 1986, 1988a, 1992, 1994b). Specifically, the approach taken involves using principles of ethics and standards of environmental practice to question the absence within the DOE ecology program of an interdisciplinary ecosystem-based approach to EIA.

My first premise is that the Yucca Mountain ecology program is not being conducted consistent with environmental codes of ethics and sound professional practice. A second premise is that this fault has adverse consequences for both the nuclear waste repository program and the long-term environment. The principal fundamental feature of the Yucca Mountain ecology program on which these premises are based is the program's failure to apply the ecosystem approach advocated by Schulze and Zwolfer (1987), Westman (1987), Golley (1993, 1994), and others in accordance with interdisciplinary, integrated environmental management as set forth by Savory (1988), Cairns and Crawford (1991), Allen and Hoekstra (1992), and Golley (1993, 1994).

**Table 2. Fundamental Principles of Ethics, Standards of Practice, and Guidance for Environmental Professionals Relevant to the Yucca Mountain Case and This Commentary**

- Environmental professionals must conduct themselves in a manner consistent with the principles of environmental ethics and objectivity.
- Environmental professionals must accept only assignments for which they are qualified, and they must alert clients when another professional's expertise will be required for an assignment.
- Environmental professionals must incorporate the best principles of the environmental sciences for reducing environmental harm and enhancing environmental quality. This includes recognizing that environmental management and practice involve the interdisciplinary consideration of all environmental factors (biotic, abiotic, natural, and cultural). Thus, environmental professionals must recognize and foster the participation of other professionals in interdisciplinary teams for performing environmental impact assessment.
- Environmental professionals must support their findings and advice to clients with authentic data, analyses, and plans based on objective procedures. If uncertainties remain in important environmental insights and advice presented to clients, the uncertainties must be acknowledged. If subjective judgment is used to advise a client where authentic data are unavailable, that fact must be acknowledged, and the judgmental procedures followed must be made clear.
- Environmental professionals must determine that all project activities are consistent with the intent of and comply with all applicable laws, regulations, and standards, especially the National Environmental Policy Act.
- Environmental professionals must seek common, adequate, and sound technical grounds for communication with and respect for the contributions of other professionals in developing and executing policies, plans, activities, and projects.
- Environmental professionals must encourage development of their profession and participate in maintaining its integrity and competence.

Source: ACEC (1995), ESA (1995), NAEP (1995), and NDEP (1995).

I support these premises first by turning to issues of ecosystem science regarding the Yucca Mountain Project. Second, I explain the potential adverse consequences of the Yucca Mountain ecology program as it now stands. Third, I show how the ecosystem approach could be applied to correct the asserted shortcomings that are of concern within the DOE's nuclear waste repository project.

## ECOSYSTEM SCIENCE AND THE YUCCA MOUNTAIN PROJECT

In this section, the existing ecology at Yucca Mountain is summarized. Following that, fundamental principles of the holistic ecosystem approach to addressing environmental problems are discussed. This serves as a basis for subsequently understanding why comprehending the holistic ecosystem and assessing its long-term future as opposed to studying the present biotic structure alone is consistent with the environmental challenges posed by a high-level nuclear waste repository.

### The Yucca Mountain Ecology Program

The Yucca Mountain site (Figure 1) is located within a narrow biotic zone (2-5 km wide) where the Mojave Desert and the Great Basin Desert meet. The vegetation of this transitional desert ecotone was described by Beatley (1975), but prior to the interest in the Yucca Mountain site as a location for a nuclear waste repository, little environmental information existed regarding the area.

Following passage of the Nuclear Waste Policy Act of 1982 that set forth the repository project, an environmental assessment was issued for the Yucca Mountain site (DOE, 1986). Ecological information for the assessment was based on biological surveys focused primarily on four principal plant communities recognized at Yucca Mountain. Live trapping of small mammals was carried out to determine species composition and relative abundance. Preliminary surveys were conducted for the presence of the desert tortoise (*Gopherus agassizii*), a species later designated as threatened under the Endangered Species Act. In all, the biological surveys at Yucca Mountain prior to 1986 were meant to identify protected biota. Ecosystem analysis was not attempted for the DOE's 1986 environmental assessment.

Additional ecology field activities were initiated by the DOE at Yucca Mountain in 1990 and continue to the present (DOE, 1988a, 1992, 1994b; Parker et al., 1990). The activities include studies of the population biology of the desert tortoise and the community ecology of vegetation and small mammals. No special consideration is being given to the ecology of the 7 $km^2$ hydrothermal impact zone atop the site shown in Figure 2.

While the issue of the long-term ecosystem integrity at Yucca Mountain is a formidable one, it is likely to be no more problematic than the requirement to predict climatic, geologic, and hydrologic conditions over a period of 10,000 years. Without such information, it is doubtful if sufficient insight into the potential for environmental feedbacks to influence repository integrity and nuclear waste isolation will be available for the ultimate decision to proceed with developing a repository. This decision is anticipated to be made by the DOE in the late 1990s.

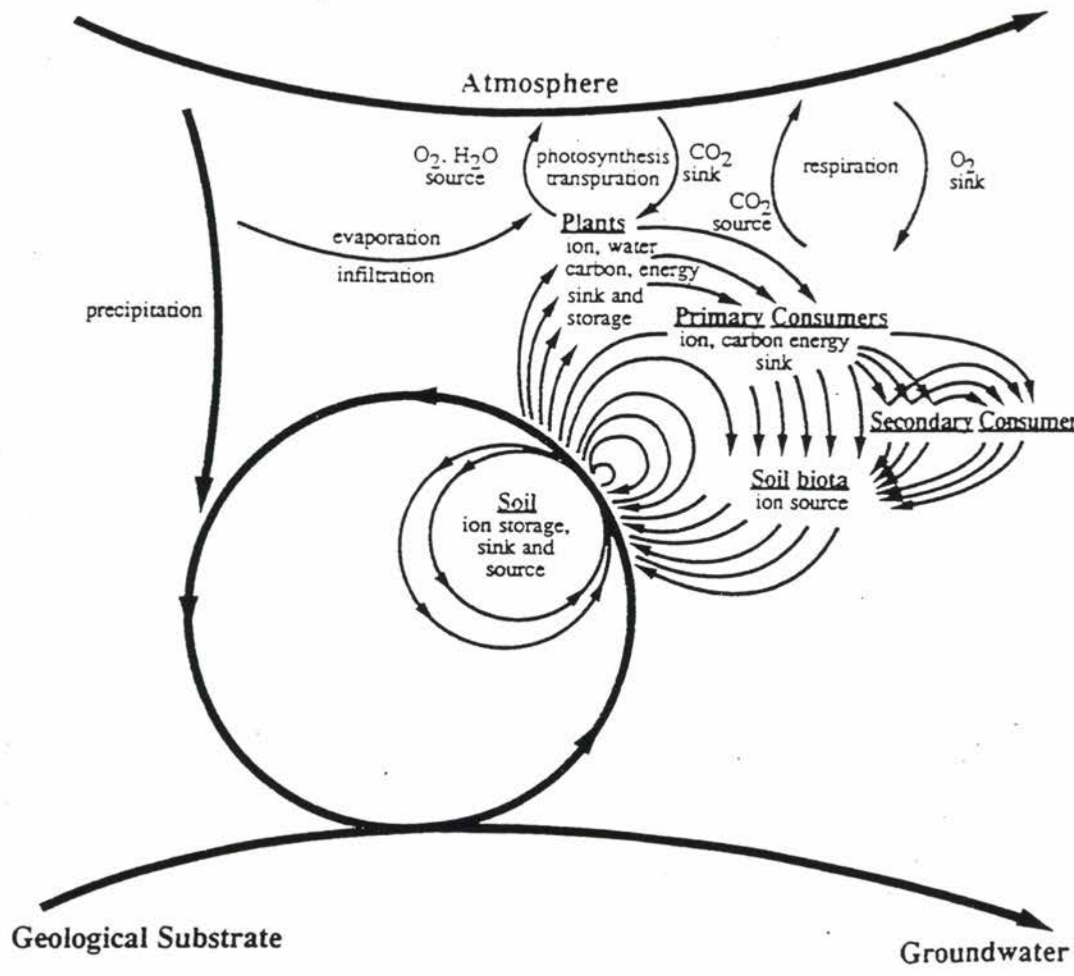
The following section of this commentary discusses the fundamentals of ecosystem analysis in the context of the Yucca Mountain Project and suggests that an ecosystem approach, as opposed to one based only on the lower hierarchies of population biology and community ecology, is both necessary and practical.

### The Ecosystem Approach

Here the term "ecosystem" means the integrated, process-functional system discussed by McIntosh (1985) and elaborated on by others (e.g., Schulze and Zwolfer, 1987; Allen and Hoekstra, 1992; Golley, 1993). Ecosystems include the interacting complexes of the biotic and abiotic environment and are viewed as open systems that are dependent on the abiotic environment. Additionally, ecosystems exhibit organization and self-regulation where the biotic components influence the abiotic environment. This two-way interaction involves numerous feedback mechanisms, as suggested by Figure 3.

The process-functional concept of ecosystems is more realistic than one that focuses on biotic structure alone. Thus, insights into ecosystems and their integrity can be seen more effectively in terms of dynamic process-oriented transformations of materials and energy rather than as things, i.e., biota, in a place at a given time (Woodley et al., 1993; Harte et al., 1995).

Figure 3. Conceptual Configuration of an Integrated Process-Function Ecosystem




Source: After Schulze and Zwolfer, 1987, with permission of the publisher

In most ecosystems, plants occupy a key position because of their autotrophy. Sometimes animals can dominate an ecosystem and in such cases are designated as "keystone species" (Mills et al., 1993). An example of this is the role played by burrowing rodents in some arid and semiarid ecotones (Brown and Heske, 1990) similar to the Yucca Mountain site where the dissemination of seeds of annual grasses and forbs depends on the rodents. If something happens to the rodents, the nature of the ecosystem changes. With respect to Yucca Mountain, the role that rodents play and the effects that elevated subsurface temperatures could have on them are unknown. This is an example of the myriad of ecological phenomena that can be overlooked in the absence of an ecosystem approach to EIA.

### Ecosystem Perturbation

Over long periods of time, natural ecosystems characteristically maintain themselves in equilibrium with respect to functional processes. If a perturbation occurs, such as global warming (e.g., Peters and Lovejoy, 1992; Peterjohn et al., 1994; Harte, 1994), this balance will be upset, and processes throughout the ecosystem will be altered in an effort by the system to achieve a new equilibrium. If a functional steady-state condition is not reached, the ecosystem will become progressively dysfunctional, and if the situation persists long enough, the ecosystem will break down (Rapport et al., 1985; Costanza et al., 1992). This will result in the environment being altered to an extent that the ecosystem will be unable to recover. Such a situation likely would result from increased underground temperatures above a nuclear waste repository at Yucca Mountain (Harte, 1994; Tausch et al., 1994).

**Figure 4. Postulated Temperature Timeline at Yucca Mountain Under a Regime of Global Warming and Subsurface Heat from a Hot Nuclear Waste Repository (not drawn to scale)**

| | |
|---|---|
| 8,000 years | Global warming abates |
| 3,000 years | Peak subsurface temperature is maintained |
| 700 years | Peak subsurface temperature is reached |
| 300 years | Subsurface (6-7 m) temperature increases |
| 150 years | Air temperature increases 2°C; additional ecosystem stress occurs |
| 70 years | Ecosystem stress occurs |
| 50 years | Air temperature increases another 1°C |
| 0 years | Air temperature has increased 1°C |

Source: Peters (1992), Peters and Lovejoy (1992), Buscheck and Nitao (1993), Buscheck (1994a, 1994b), Harte (1994), Harte et al. (1995)

At Yucca Mountain, some of the future environmental changes likely to occur are shown in Figure 4, based on Peters (1992), Peters and Lovejoy (1992), Buscheck and Nitao (1993), Buscheck (1994a, 1994b), Harte (1994), and Harte et al. (1995). The timeline shows that while subsurface temperatures at the Yucca Mountain site would be increasing, atmospheric temperature associated with global warming also might be increasing. There is no understanding of the environmental interactions of these two perturbations because such a dual temperature change, both above and below the ground surface, has never been addressed. However, Whitford (1992) and West et al. (1994) have shown how critical the three-way relationships among climate, soil, and vegetation are to the functional integrity of desert ecosystem processes such as maintaining nutrient and water budgets. Understanding such matters in the context of the long-term environment at Yucca Mountain is important (Lemons and Malone, 1991; Ferhenger, 1994; Harte, 1994; NWTRB, 1994).

A difficulty in environmental science has been predicting what will happen in the future to disturbed ecosystems (e.g., Rapport et al., 1985; Westman, 1987; Costanza et al., 1992; Harte et al., 1992). Central to that is the concept of scale, which pertains to both time and space (Allen and Hoekstra, 1992). The issue of the future ecosystem at Yucca Mountain under a regime of elevated subterranean temperature is large-scale with respect to the time period involved and small-scale with respect to the areal space that may be affected. Size is not the principal critical characteristic with respect to a thermally altered ecosystem at Yucca Mountain. Rather, the most important aspect of the problem is the long-term capability of the environment at the site to sustain ecosystem integrity. Traditional discussions of ecosystem response to perturbations such as temperature change generally have not considered the complexity of feedback mechanisms associated with functional processes and with maintaining ecosystem integrity (Mooney, 1991; Field et al., 1992; Woodley et al., 1993). Why this is essential to to the Yucca Mountain case and how it could be accomplished by the ecosystem approach are addressed in the next two sections of this paper.

## POTENTIAL LONG-TERM ENVIRONMENTAL IMPACTS AT YUCCA MOUNTAIN

A reasonable question to ask is why the Yucca Mountain Project should invest in an ecosystem approach when only a relatively small (7 km$^2$) thermal impact area at the site would be likely to experience long-term impacts from a nuclear waste repository. In other words, with such a vast extent of arid lands in the vicinity of the site, how could the loss of such a small area be significant? In response to this question, it is necessary to consider what is likely to happen at Yucca Mountain during the thousands of years after a geologic repository is completed, filled with waste, and permanently sealed. To facilitate this, some rational assumptions about the affected area of concern must be considered before proceeding to a scenario for the potential consequences.

Although scientific uncertainty abounds in the Yucca Mountain Project, Buscheck (1994a, 1994b) and Buscheck and Nitao (1993) believe that heat from radioactive decay in a repository beneath Yucca Mountain will reach the surface and will cause increased soil temperatures for up to 10,000 years. During the time that subterranean temperatures are increasing, atmospheric temperature above the surface also may be rising due to global warming (Peters and Lovejoy, 1992). Most climatologists believe that changing climatic conditions will cause global temperatures to increase by 3° ± 1.5°C (Peters, 1992). This is expected to hold as well for the Great Basin region (Giorgi et al., 1992; Murphy and Weiss, 1992) where Yucca Mountain is located.

Whitford (1992) and West et al. (1994), for example, have shown how critical interactions among the atmosphere, soil, and vegetation are to desert ecosystems and how changes in one component of the ecosystem will induce responses in the other components. Noble (1993) has shown that ecotones, such as the Yucca Mountain site, can be expected to respond to climate change before other areas do. Under the regime of global warming, the vegetation of the northern Mojave Desert, now occurring in the valley floors and on the slopes of Yucca Mountain (Beatley, 1975; DOE, 1986; Malone, 1991), would be expected to move to the summit of the ridge (Murphy and Weiss, 1992; Woodward, 1992; Tausch et al., 1993). Such shifts in dominant vegetation as a consequence of climate warming were suggested by Harte et al. (1995) and subsequently demonstrated (Harte and Shaw, in press). Unanswered in the case of Yucca Mountain is whether or not the vegetation that now inhabits the valleys and slopes at the site would remain or be replaced by species from even hotter environments like those currently occurring in the Death Valley region 60 km south of Yucca Mountain.

A 7 $km^2$ thermally affected area at Yucca Mountain could be significantly altered so that it would constitute a disturbed and dysfunctional area inhabited only by invaders like tumbleweed (*Salsola kali*) and red bromegrass (*Bromus rubens*). At best, the affected area would adapt into a semiautonomous system of its own with different structural and functional attributes from its initial condition and the surrounding ecosystem (Tausch et al., 1994). Discerning the nature of the existing ecosystem and projecting its integrity far into the future are the issues that face the Yucca Mountain ecology program.

In light of the uncertainty involved, and lacking information to the contrary, it must be assumed that a reasonable worst-case situation could occur at Yucca Mountain. The postulated scenario depicted in Figure 5 was constructed from existing information and professional views (Bull, 1991, 1993; Peters and Lovejoy, 1992; Buscheck and Nitao, 1993; Buscheck et al., 1993; Tausch et al., 1993, 1994; Buscheck, 1994a, 1994b; Harte, 1994; Harte et al., 1995; Harte and Shaw, in press). Reflected in the scenario is knowledge that at Yucca Mountain a likely route for radioactive waste to reach the environment is via the groundwater aquifer that lies 225 m beneath the repository horizon. Subterranean heat at Yucca Mountain is expected to drive groundwater in the unsaturated zone above the repository to the surface in the form of water vapor. During the winter this is likely to result in greater than normal fog above the repository and consequently increased precipitation. In the summer, despite the potential for water vapor to have a slight cooling effect, the water would evaporate rapidly because of normal aridity enhanced by increased ambient temperatures from global warming. Very few, if any, higher plant species might be expected to survive these conditions, and eventually such an ecosystem likely would

**Figure 5. Model for an Environmental Response at Yucca Mountain from a Hot Nuclear Waste Repository**

Subsurface temperature and local climate are altered.

↓

Vegetation is reduced and winter precipitation is increased.

↓

Runoff and infiltration increase.

↓

Erosion and bedrock exposure increase.

↓

Vegetation is eliminated.

↓

Erosion and infiltration are maximized.

↓

**Would the performance of a repository be influenced?**

Source: Bull (1991, 1993), Peters and Lovejoy (1992), Buscheck and Nitao (1993), Buscheck et al. (1993), Buscheck (1994a, 1994b), Harte (1994), and Tausch et al. (1994).

become dysfunctional and barren of both vegetative cover and soil (Bull. 1991. 1993; Peters and Lovejoy. 1992; Tausch et al.. 1993. 1994).

Land forms exist today that are similar to what could occur in the future at Yucca Mountain (Bull. 1991. 1993). Under such conditions, both erosion and infiltration would accelerate, and greater amounts of water would move downward toward the repository horizon, altering the geohydrology of the site (Buscheck and Nitao. 1993; Buscheck. 1994a). This response would be intensified by heat-induced upwelling of the repository overburden, which would enhance the naturally occurring fractures in the rock overburden and further increase the rate of water infiltration to the repository horizon (Buscheck. 1994a).

Following from this scenario is the question of whether or not such environmental impacts would affect the performance of a repository. It fits with what is known about the Yucca Mountain environment that accelerated movement of precipitation toward a repository and into the aquifer beneath it would result from removal of the vegetation and soil above the repository. The consequences of this perturbed environment on the ability of a geologic repository at Yucca Mountain to isolate radionuclides for at least 10,000 years is not being addressed by the Yucca Mountain Project (Dixon. 1994. 1995; Fehringer. 1994; NWTRB. 1994). In view of the theory that water in a repository could result in a nuclear disaster (Benjamin. 1994; Bowman. 1995; Bowman and Venner. 1995), it is contingent under NEPA regulations (40 CFR 1502.22[a]) regarding "reasonably foreseeable" impacts for the DOE to assess such a scenario. To do so based on the concept of ecosystem-based environmental analysis would be consistent with the state of the art of ecosystem science. This assertion is discussed in the next section.

## A RESOURCE-BASED APPROACH FOR ADDRESSING THE YUCCA MOUNTAIN CASE

Approaches to applied ecosystem research suitable for the Yucca Mountain case have emerged recently from the issue of global warming and questions about long-term future environmental conditions and ecosystems. Notable in this respect is the resource-based approach of Field et al. (1992). This approach to ecosystem analysis addresses the functional responses of natural settings to alterations in environmental forcing factors that drive an ecosystem like those involved with climate change (e.g., $CO_2$, temperature, moisture).

### The Conceptual Framework

Field et al. (1992) demonstrated that the effects of increased temperature and $CO_2$ and changes in soil moisture on terrestrial ecosystems can be analyzed in terms of the resources required by organisms for growth. These resources include, among other things, light, oxygen, $CO_2$, water, nutrients, and carbon compounds. Results of experimental studies of the responses of ecosystems to changes in soil fertility, water availability, or temperature provide a starting point for assessing the impact on ecosystem integrity likely to result from long-term changes in environmental conditions.

The resource-based approach addresses a broad range of ecosystem types and complements the unified concept of ecosystem (Allen and Hoekstra. 1992), both of which together respond to the call by Mooney (1991) for new ecosystem-based strategies for addressing phenomena like changes in climate and ambient temperature. Others are using similar approaches for field research regarding ecosystem responses to changing environmental conditions such as temperature (e.g., Van Cleve et al.. 1990; Peterjohn et al.. 1993. 1994; Harte et al. 1995; Harte and Shaw, in press), and their methods have been judged appropriate for the Yucca Mountain case (Fehringer. 1994; Harte. 1994; NWTRB. 1994; Tausch et al.. 1994). For example, experimental studies of ecosystem perturbation by artificially raising subterranean temperatures to simulate nuclear waste impacts to the surface environment could be performed to provide the data needed under the resource-based approach (Fehringer. 1994; Harte. 1994; NWTRB, 1994). Once the direction and magnitude of the ecosystem responses are sufficiently understood quantitatively, ecosystem network modeling, such as advocated by Allen and Hoekstra (1992) and applied by others (e.g., Peters and Lovejoy. 1992), can be used to predict the long-term potential of the Yucca Mountain ecosystem.

### What the Yucca Mountain Ecology Program Should Be Doing

The worst-case scenario at Yucca Mountain (Figure 5) is, according to NEPA regulations (40 CFR 1502.22[a]), reasonably foreseeable. The NEPA regulations further state (40 CFR 1502.22) with respect to "incomplete or unavailable information" needed to dispel concern about a reasonably foreseeable impact that the information must appear in a NEPA environmental impact statement (EIS) unless obtaining the data would involve "exorbitant" costs (Fogleman. 1990; Bartlett and Malone, 1993; Cox at al.. 1993). Thus, to avoid having to assume the worst-case scenario in the EIS for the Yucca Mountain Project, the DOE needs a restructured, reoriented ecological program that would provide information dispelling the scenario and its potential consequences.

The ecology program for the Yucca Mountain Project should begin with an analysis of the present ecosystem at the site, conduct experimental temperature studies, understand the responses of ecosystem processes to dual forces of temperature increases, and forecast the long-term consequences to the repository environment. To accomplish this requires recognizing concepts like ecosystem integrity, ecological feedback, and nonequilibrium ecology as well as ecosystem processes like nutrient, heat, and water budgets (Winsor and Malone, 1990; Cairns and Crawford, 1991; Allen and Hoekstra, 1992; Field et al., 1992; Hornbeck and Swank 1992; Slocombe, 1993b; Harte et al. 1995). Additionally functional processes and system components that are critica to ecosystem integrity at Yucca Mountain should be identified through experiments on heat perturbation. Finally, the Yucca Mountain ecology program should use process-based simulation modeling for impact assessment based on likely alterations of ecosystem processes (Winsor and Malone, 1990; Allen and Hoekstra, 1992). The fundamentals of such an ecosystem approach to EIA and forecasting were set forth by Beanlands and Duinker (1984), Duinker and Baskerville (1986), and Westman (1987).

With regard to field studies on ecosystem responses to alterations in subterranean temperatures, experimental heat perturbations induced by tunnel-installed electric heating cables (Peterjohn et al., 1993, 1994; Harte, 1994) or piped geothermal water (Tausch et al., 1994) would be practical. Buscheck et al. (1993) have proposed *in situ* heater tests on rocks from the repository horizon at Yucca Mountain to confirm their thermal models. Such studies would provide insight to the possibility of homeostatic temperature feedback by water vapor moving upward from a repository (Buscheck 1994a, 1994b). It is not practical to conduct long-term realistic studies of the effects of a nuclear waste repository. However, studies of five years' duration would provide insights to potential long-term environmental consequences at Yucca Mountain.

This course of study, applied in conjunction with methods involving watershed ecosystem analysis (Hornbeck and Swank, 1992), has been recommended for the Yucca Mountain Project by a group of White House-appointed reviewers (Fehringer, 1994; NWTRB, 1994) as well as by others (Winsor and Malone, 1990; Lemons and Malone, 1991, 1994; Field, 1994; Harte, 1994). However, the recommendations are considered impractical and unnecessary by the DOE (Dixon, 1994) as well as by the community ecologists and population biologists responsible for the Yucca Mountain ecology program (O'Farrell, 1994). The DOE believes that the schedule for the EIS for a repository is too critical to allow for the costs and time delays involved with the ecosystem approach for EIA at Yucca Mountain (Dixon, 1994).

## ETHICS, PROFESSIONAL PRACTICE, AND YUCCA MOUNTAIN

In comparing the actions of the Yucca Mountain ecology program with the ethical principles and standards of sound practice for environmental professionals given in Table 2, the following points emerge.

- The Yucca Mountain ecology program is not being pursued in a manner consistent with the principles of environmental ethics.

- The population biologists and community ecologists involved with the program have stepped outside their expertise with respect to advising the DOE that the Yucca Mountain ecology program does not need to be based on ecosystem analysis. Moreover, the advice given by the environmental professionals is biased toward the DOE view that it is untimely for the repository project schedule to implement an ecosystem approach. This policy appears to be based on undocumented subjective judgment alone and not to be supported by facts and analyses consistent with scientific objectivity.

- The Yucca Mountain Project is inconsistent with the intent of NEPA regarding interdisciplinary approaches to EIA and does not recognize the principles of holistic environmental management.

- The environmental professionals engaged in the Yucca Mountain ecology program have discounted the importance of scientific uncertainty in their assessment of the plausibility of a worst-case environmental scenario that could jeopardize the acceptable performance of a geologic repository at Yucca Mountain.

- The failure of the Yucca Mountain ecology program to be integrated with other environmental programs such as climate forecasting, hydrogeology, and hydrothermal studies in the Yucca Mountain Project is inconsistent with an interdisciplinary approach to environmental impact analysis.

- The personnel involved with the DOE ecology program have not heeded the advice of outside expert reviewers such as the White House-appointed NWTRB with respect to the Yucca Mountain ecology program and have not sought the counsel of appropriate outside environmental experts.

- The preceding points are inconsistent with fostering the environmental profession and preserving its integrity by virtue of competent practice.

Considering the nature and significance of the Yucca Mountain Project, especially regarding the environmental quality of future generations, it is reasonable to hold the project to high standards of environmental ethics and professional practice. This particularly is the case regarding incorporation of the best principles of environmental science in an effort to resolve the issue of the worst-case scenario (Figure 5) and the risks of widespread radioactive contamination that would result from an explosion in a repository for high-level nuclear waste at Yucca Mountain (Benjamin, 1994; Bowman, 1995; Bowman and Venneri, 1995).

My commentary contends that the Yucca Mountain Project stands to benefit from the application of principles of environmental ethics, appropriate expertise, and sound professional environmental practice. These ideals are encouraged by professional organizations like the NAEP. If the environmental managers of the Yucca Mountain Project were members of an association with an adequate code of ethics and standards of practice, they could be called upon by the association to explain the ecology program in light of comments like those expressed herein. Unfortunately, this is not the case.

The final section of my commentary addresses the role of professional organizations like the NAEP regarding such matters.

## ECOSYSTEM MANAGEMENT, ENVIRONMENTAL ETHICS, AND THE NAEP

Advocates of integrated, interdisciplinary environmental management (e.g., Baldwin, 1985; Savory, 1988; Dorney and Dorney, 1989; Cairns and Crawford, 1991; Grumbine, 1994a, 1994b; Knight and Bates, 1995;) recognize the need for their discipline to remain abreast of modern ecosystem science and to incorporate ecosystem analysis as a matter of policy. This is occurring now in most federal landholding agencies where the approach to environmental resource management advocated here is being implemented in response to Vice President Gore's National Performance Review (GPO, 1993; GAO, 1994b). To this end, a Presidential Executive Order has been recommended (OEP, 1994; IEMTF, 1995) that would require relevant federal agencies to develop, adopt, and implement ecosystem-based management of resources, both natural and cultural (socioeconomic). Legislation was introduced in the U.S. Senate in the form of the Ecosystem Management Act of 1994 (S. 2189) to require that all federal lands, such as the Yucca Mountain site, be managed in accordance with the principles of ecosystem science.

Some agencies foresaw this action and began taking steps in that regard three years ago (e.g., FS, 1992, 1994; BLM, 1994; DOD, 1994; EPA, 1994; FWS, 1994, 1995; GAO, 1994a). The DOE took steps in this respect with a draft policy that would require all agency projects, including the Yucca Mountain Project, to be based on the principles of ecosystem management to protect the environment (DOE, 1994a). The draft policy stated that it would be based on concepts of ecosystem sustainability and biodiversity. Implementation of the policy by the DOE would have constituted a major shift in an agency currently driven by the concepts of nuclear technological sustainability and development, as opposed to ecosystem sustainability. As of July 1995 the DOE policy has not been implemented. Other federal agencies are pursuing ecosystem management policies and programs that merge natural and socioeconomic sustainability as well as biodiversity (Grumbine, 1994a, 1994b; Knight and Bates, 1995).

Thus, for the Yucca Mountain Project the DOE is proceeding with an EIS for the nuclear waste repository that overlooks ecosystem analysis and management and instead is based on population biology and community ecology alone (Dixon, 1995). In the DOE's approach, no meaningful attention is given to interactions between the biotic and abiotic aspects of the environment. This is consistent with precepts of sustainable technological development and inconsistent with approaches based on precepts of environmental ethics and sound professional practice. Others have shown that the conflict between technological development and ecosystem management is unnecessary, because reasonable ecosystem approaches for avoiding the conflict are available (e.g., Golley, 1993, 1994; Slocombe, 1993a).

The case of the Yucca Mountain Project illustrates that there remains a need for skilled and ethically motivated environmental professionals to resolve complex and portentous issues involving the environment of future generations. This does not mean to suggest that the only capable environmental professionals are ecosystem ecologists or that there are no limits to what applying the ecosystem approach can accomplish (Hilborn and Ludwig, 1993; Shrader-Frechette and McCoy, 1993, 1994). It does mean, as some professional codes of ethics support (Table 2), that cognizance of interdisciplinary concepts and practices, such as the ecosystem approach, should be encouraged, pursued, and applied wherever appropriate. In the context of the Yucca Mountain Project, it means that population biologists and community ecologists involved with the DOE ecology program are remiss if they do not appreciate and advocate an ecosystem approach to long-term EIA. Ecologists who specialize in hierarchies of lower order than the ecosystem are of course essential to the interdisciplinary ecosystem approach, as are experts in other environmental disciplines (Baldwin, 1985; Dorney and Dorney, 1989; Cairns and Crawford, 1991; Allen and Hoekstra, 1992; Grumbine, 1994a, 1994b; Knight and Bates, 1995). The point is that interdisciplinary guidance consistent with the ecosystem approach should be fundamental to activities like the Yucca Mountain ecology program.

Golley (1993, 1994) suggested that the ecosystem perspective and approach can lead to an environmental value system that influences environmental law and political agendas. Golley also pointed out that the ecosystem perspective is necessary for guiding environmental resource managers as well as for understanding long-term environmental issues. Thus, Golley views the ecosystem concept as a foundation for environmental ethics. This view anchors ecosystem-based ethics in tangible experience with nature involving authentic and factual ecosystem science and competent professional expertise, as encouraged by this commentary. Indeed, the discipline of environmental management has recognized this. For example, Baldwin (1985), Savory (1988), Dorney and Dorney (1989), Cairns and Crawford (1991), and Grumbine (1994a) have well articulated and applied the ecosystem concept to holistic resource management.

The adoption by most federal agencies of concepts such as resource management, ecological sustainability, and preservation of biodiversity based on principles of ecosystem management (GAO, 1994a; Grumbine, 1994a; Knight and Bates, 1995) is evidence that the ecosystem perspective of Golley (1993) is materializing rapidly. Some may view this transition to ecosystem-based environmental policy and practice as being as significant as the passage of NEPA was in 1969. This is because the implementation of environmental policy based on the ecosystem approach may make it possible for NEPA finally to achieve what it was envisioned to do by those involved in drafting the act, i.e., to see environmental resources and impacts assessed and managed in an interdisciplinary, holistic context with ecosystem-level science at the core of the effort. Thus, NEPA sought to give the nation an environmental ethic (Bartlett and Malone, 1993), and now the ecosystem approach advocated by Golley (1993, 1994), Slocombe (1993a, 1993b), Grumbine (1994a), and many others to environmental assessment and management offers a way of realizing and applying that ethic.

The necessity for all environmental professionals to think and practice in accordance with the exemplary principles of both ethics and standards of professional practice is recognized by professional environmental organizations like the NAEP. Such groups should, therefore, endorse and foster the application of concepts and principles of ecosystem management, especially where the science of environmental impact assessment and compliance with NEPA are concerned. The need is to transpose awareness and practice of this ecosystem-based environmental ethic to institutions like the DOE and to activities like the Yucca Mountain Project.

This issue is of course far larger than the DOE's Yucca Mountain Project, which served here to illustrate a major challenge facing environmental professionals and organizations like the NAEP. The task at hand is to take action with respect to fostering exemplary ethics and competency among all environmental professionals and to assure that interdisciplinary science and the ecosystem approach play a strong role in achieving sound and accountable environmental practice. Those who direct and govern professional environmental organizations must continue taking concrete steps to meet this challenge.

## REFERENCES


(ACEC) American Consulting Engineers Council of the United States. 1995. Code of Ethics. ACEC, Washington, DC.

Allen, T.F.H., and T.W. Hoekstra. 1992. *Toward a Unified Ecology*. Columbia University Press, New York.

Baldwin, J.H. 1985. *Environmental Planning and Management*. Westview Press, Boulder, CO.

Bartlett, R.V., and C.R. Malone, eds. 1993. Science and the National Environmental Policy Act. *The Environmental Professional* 15(1): 1-160.

Beanlands, G.E., and P.N. Duinker. 1984. An Ecological Framework for Environmental Impact Assessment. *Journal of Environmental Management* 18: 267-277.

Beatley, J.C. 1975. Climates and Vegetation Patterns Across the Mojave/Great Basin Desert Transition of Southern Nevada. *American Midland Naturalist* 93: 53-70.

Benjamin, R.W. 1994. Personal Letter to C.D. Bowman. Nuclear Physicist, Westinghouse Savannah River Company, Aiken, SC. December 20.

(BLM) U.S. Bureau of Land Management. 1994. Ecosystem Management in the BLM. From Concept to Commitment. BLM/SC/GI-94/005+1736. BLM, Washington, DC.

Bowman, C.D. 1995. Telephone interview. Nuclear Physicist, Los Alamos National Laboratory, Los Alamos, NM. March 6.

Bowman, C.D., and F. Vennen. 1995. Underground Autocatalytic Criticality from Plutonium and Other Fissile Material. LA-UR 94-4022. Los Alamos National Laboratory, Los Alamos, NM.

Brown, J.H., and E.J. Heske. 1990. Control of a Desert-Grassland Transition by a Keystone Rodent Guild. *Science* 250: 1705-1707.

Bull, W.B. 1991. *Geomorphic Responses to Climatic Change*. Oxford University Press, New York.

Bull, W.B. 1993. Telephone interview. Professor, Department of Geomorphology, University of Arizona, Tuscon, AZ. October 14.

Buscheck, T.A. 1994a. Presentation to the U.S. Nuclear Waste Technical Review Board and the U.S. Department of Energy Yucca Mountain Project. Research Scientist, Earth Sciences Department, Lawrence Livermore National Laboratory, Livermore, CA. March 22.

Buscheck, T.A. 1994b. Telephone interview. Research Scientist, Earth Sciences Department, Lawrence Livermore National Laboratory, Livermore, CA. January 13.

Buscheck, T.A., and J.J. Nitao. 1993. Repository-Heat-Driven Hydrothermal Flow at Yucca Mountain, Part I: Modeling and Analysis. *Nuclear Technology* 104: 418–448.

Buscheck, T.A., D. Wilder, and J.J. Nitao. 1993. Repository-Heat-Driven Flow at Yucca Mountain, Part II: Large-Scale *In Situ* Heater Tests. *Nuclear Technology* 104: 449–471.

Cairns, J., Jr., and T.V. Crawford, eds. 1991. *Integrated Environmental Management*. Lewis Publishers, Chelsea, MI.

Costanza, R., B.G. Norton, and B.D. Haskell, eds. 1992. *Ecosystem Health: New Goals for Environmental Management*. Island Press, Washington, DC.

Cox, D.K., T.M. Keevin, F.T. Norris, and D.J. Schaeffer. 1993. When Is a Cost Exorbitant Under NEPA? *The Environmental Professional* 15(1): 145-149.

Dixon, W.R. 1994. Environmental Program Update presented to the U.S. Nuclear Waste Technical Review Board. Assistant Manager for Environment, Science, and Health, Yucca Mountain Project Office. U.S. Department of Energy, Las Vegas, NV. March 22.

Dixon, W.R. 1995. Environmental Program Update presented to the U.S. Nuclear Waste Technical Review Board. Assistant Manager for Environment, Science, and Health, Yucca Mountain Project Office, U.S. Department of Energy, Las Vegas, NV. January 10.

(DOD) U.S. Department of Defense. 1994. Implementation of Ecosystem Management in the Department of Defense: Ecosystem Management Principles. DUSD (ES)/EQ-CO, August 8. Office of the Under Secretary for Defense, DOD, Washington, DC.

(DOE) U.S. Department of Energy. 1986. Environmental Assessment: Yucca Mountain Site, Nevada. DOE/RW-0073. DOE, Washington, DC.

(DOE) U.S. Department of Energy. 1988a. Environmental Program Overview. DOE/RW-0207. DOE, Washington, DC.

(DOE) U.S. Department of Energy. 1988b. Site Characterization Plan, Yucca Mountain Site, Nevada. DOE/RW-0199. DOE, Washington, DC.

(DOE) U.S. Department of Energy. 1992. Yucca Mountain Site Characterization Environmental Field Activity Plan for Terrestrial Ecosystems. YMP/91-41. DOE, Las Vegas, NV.

(DOE) U.S. Department of Energy. 1994a. Draft Land and Facility Use Policy and Requirements. Agency-wide memorandum, August 26. Associate Deputy Secretary for Field Management, DOE, Washington, DC.

(DOE) U.S. Department of Energy. 1994b. Site Environmental Report for Calendar Year 1993. Yucca Mountain Site. Nye County, Nevada. DOE. Las Vegas. NV.

Dorney, R., and L. Dorney. 1989. *The Professional Practice of Environmental Management*. Springer-Verlag. New York.

Duinker, P.N., and G.L. Baskerville. 1986. A Systematic Approach to Forecasting in Environmental Impact Assessment. *Journal of Environmental Management* 23: 271-290.

(EPA) U.S. Environmental Protection Agency. 1994. Report of the National Advisory Council Committee on Ecosystem Management. Office of the Administrator. EPA. Washington. DC.

(ESA) Ecological Society of America. 1995. Code of Ethics. ESA. Washington. DC.

Fehringer, D.J. 1994. U.S. Nuclear Waste Technical Review Board Comments on the Yucca Mountain Ecology Program. Letter to W. Dixon, Yucca Mountain Project Office. DOE. Las Vegas. NV. August 18.

Field, C.B. 1994. Telephone interview. Research Scientist. Department of Plant Biology. Carnegie Institute of Washington. Stanford. CA. February 23.

Field, C.B., F. Chapin III. P. Matson, and H.A. Mooney. 1992. Responses of Terrestrial Ecosystems to the Changing Atmosphere: A Resource-Based Approach. *Annual Review of Ecology and Systematics* 23: 201-235.

Fogleman, V.M. 1990. *Guide to the National Environmental Policy Act: Interpretations, Applications, and Compliance*. Quorum Books. Westport. CT.

(FS) U.S. Forest Service. 1992. Taking an Ecosystem Approach to Management. WO-WSA-3. U.S. FS. Washington. DC.

(FS) U.S. Forest Service. 1994. An Ecological Basis for Ecosystem Management. General Technical Report RM-246. U.S. FS. Fort Collins, CO.

(FWS) U.S. Fish and Wildlife Service. 1994. An Ecosystem Approach to Fish and Wildlife Conservation: An Approach to More Effectively Conserve the Nation's Biodiversity. FWS. Washington. DC.

(FWS) U.S. Fish and Wildlife Service. 1995. An Ecological Basis for Ecosystem Management: Concept Development. FWS. Washington. DC.

(GAO) U.S. General Accounting Office. 1994a. Ecosystem Management: Additional Actions Needed to Adequately Test a Promising Approach. GAO/RCED-94-111. GAO. Washington. DC.

(GAO) U.S. General Accounting Office. 1994b. Management Reform: Implementation of the National Performance Review. OCG-95-1. GAO. Washington. DC.

Giorgi, F., G.T. Bates, and S.J. Nieman. 1992. Simulation of the Arid Climate of the Southern Great Basin Using a Regional Climate Model. *Bulletin of the American Meteorological Society* 73: 1807-1822.

Golley, F.B. 1993. *A History of the Ecosystem Concept in Ecology: More Than the Sum of the Parts*. Yale University Press. New Haven. CT.

Golley, F.B. 1994. Grounding Environmental Ethics in Ecological Science. In *Ethics and Environmental Policy: Theory Meets Practice*. F. Ferre and P. Hartel. eds. University of Georgia Press. Athens. GA. pp. 9-20.

(GPO) U.S. Government Printing Office. 1993. Reinventing Environmental Management: Accompanying Report of the National Performance Review. GPO-355-681. GPO. Washington. DC.

Grumbine. R. Edward. 1994a. What Is Ecosystem Management? *Conservation Biology* 8(1): 27-38.

Grumbine. R. Edward. ed. 1994b. *Environmental Policy and Biodiversity*. Island Press. Washington. DC.

Harte. J. 1994. Presentation to the U.S. Nuclear Waste Technical Review Board and the U.S. Department of Energy Yucca Mountain Project. Research Scientist. Earth Sciences Department. Lawrence Livermore National Laboratory. Livermore. CA. March 22.

Harte. J., and R. Shaw. In Press. Shifting Dominance Within a Montane Vegetation Community: Results of a Climate-Warming Experiment. *Science* (in press).

Harte. J., M.S. Torn. and D. Jensen. 1992. The Nature and Consequences of Indirect Linkages Between Climate Change and Biological Diversity. In *Global Warming and Biological Diversity*. R.L. Peters and T.E. Lovejoy. eds. Yale University Press. New Haven. CT. pp. 325-343.

Harte. J., M.S. Torn. F. Chang. B. Feifarek. A.P. Kinzig. R. Shaw. and K. Shen. 1995. Global Warming and Soil Microclimate: Results from a Meadow-Warming Experiment. *Ecological Applications* 5(1): 132-150.

Hilborn. R., and D. Ludwig. 1993. The Limits of Applied Ecological Research. *Ecological Applications* 3(4): 550-552.

Hornbeck. J.W., and W.T. Swank. 1992. Watershed Ecosystem Analysis as a Basis for Multiple-Use Management. *Ecological Applications* 2: 238-247.

(IEMTF) Interagency Ecosystem Management Task Force. 1995. The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies. White House Office of Environmental Policy. Washington. DC.

Kirchner. G. 1990. A New Hazard Index for the Determination of Risk Potentials of Disposed Radioactive Wastes. *Journal of Environmental Radioactivity* 11: 71-95.

Knight. R.L., and S.F. Bates. eds. 1995. *A New Century for Natural Resources Management*. Island Press. Washington. DC.

Lemons. J. 1987. Environmental Science and Values. *The Environmental Professional* 9(4): 277-278.

Lemons. J. 1995. Shrader-Frechette's Schemata for Scientific Research: Implications for Environmental Professionals. *The Environmental Professional* 17(1): 72-77.

Lemons. J., and C. Malone. 1991. High-Level Nuclear Waste Disposal and Long-Term Ecological Studies at Yucca Mountain. *BioScience* 41(10): 713-718.

Lemons. J., and C. Malone. 1994. Integrated Environmental Management and Assessment of the Environmental Program at the Potential High-Level Nuclear Waste Repository at Yucca Mountain. Nevada. In *Implementing Integrated Environmental Management*. J. Cairns. Jr., T.V. Crawford. and H. Salwasser. eds. Virginia Polytechnic Institute and State University. Blacksburg. VA. pp. 41-59.

Lemons. J., C. Malone. and B. Piasecki. 1989. America's High-Level Nuclear Waste Repository: A Case Study of Environmental Science and Public Policy. *International Journal of Environmental Studies* 34(1): 25-42.

Malone. C.R. 1989. Environmental Review and Regulation for Siting a Nuclear Waste Repository at Yucca Mountain. Nevada. *Environmental Impact Assessment Review* 9(2): 77-95.

Malone. C.R. 1989-90. Environmental Performance Assessment: A Case Study of an Emerging Methodology. *Journal of Environmental Systems* 19(2): 171-184.

Malone. C.R. 1990a. Geologic and Hydrologic Issues Related to Siting a Repository for High-Level Nuclear Waste at Yucca Mountain. Nevada. USA. *Journal of Environmental Management* 30: 914-929.

Malone. C.R. 1990b. Implications of Environmental Program Planning for Siting a Nuclear Waste Repository at Yucca Mountain. Nevada. *Environmental Management* 14(1): 25-32.

Malone, C.R. 1990c. Performance Assessment and Long-Term Environmental Problems. *Project Appraisal* 5(3): 134-138.

Malone, C.R. 1991. The Potential for Restoring the Yucca Mountain Site to a Stable Ecological Condition. *The Environmental Professional* 13(3): 216-224.

McIntosh, R.P. 1985. *The Background of Ecology: Concept and Theory*. Cambridge University Press. Cambridge. England.

Mills, S.L., M.E. Soule, and D. Doak. 1993. The Keystone-Species Concept in Ecology and Conservation. *BioScience* 43(4): 219-224.

Mooney, H.A. 1991. Biological Response to Climate Change: An Agenda for Research. *Ecological Applications* 1(2): 112-117.

Murphy, D.D., and S.B. Weiss. 1992. Effects of Climate Change on Biological Diversity in Western North America: Species Losses and Mechanisms. In *Global Warming and Biological Diversity*. R.L. Peters and T.E. Lovejoy, eds. Yale University Press. New Haven. CT. pp. 355-368.

(NAEP) National Association of Environmental Professionals. 1995 Purpose and Objectives, Certified Environmental Professional (CEP) Program, Membership and Qualifications, Code of Ethics and Standards of Practice for Environmental Professionals. NAEP. Washington, DC.

(NDEP) Nevada Division of Environmental Protection. 1995. Environmental Manager Certification Program. NDEP, Carson City, NV.

Noble, I.R. 1993. A Model of the Responses of Ecotones to Climate Change. *Ecological Applications* 3(3): 396-403.

(NWTRB) U.S. Nuclear Waste Technical Review Board. 1994. Report to the U.S. Congress and the Secretary of Energy. NWTRB. Arlington, VA.

(OEP) White House Office of Environmental Policy. 1994. Ecosystem Management Initiative Overview. March 4. OEP. Washington, DC.

O'Farrell, T.P. 1994. Discussion with the U.S. Nuclear Waste Technical Review Board. Director. Yucca Mountain Environmental Study Project Office, EG&G Energy Measurements, Las Vegas, NV. March 21.

Parker, G.J., J.R. Krumell, K.E. LaGory, G.J. Marmer, and S.P. Goel. 1990. The Environmental Protection Program for Site Characterization at Yucca Mountain, Nevada. *The Environmental Professional* 12(3): 185-195.

Peterjohn, W.T., J.M. Melillo, F.P. Bowles, and P.A. Steudler. 1993. Soil Warming and Trace Gas Fluxes: Experimental Design and Preliminary Flux Results. *Oecologia* 93: 18-24.

Peterjohn, W.T., J.M. Melillo, P.A. Steudler, K. Newkirk, F. Bowles, and J.D. Aber. 1994. Responses of Trace Gas Fluxes and N Availability to Environmentally Elevated Soil Temperatures. *Ecological Applications* 4(3): 617-625.

Peters, R.L. 1992. Introduction. In *Global Warming and Biological Diversity*. R.L. Peters and T.E. Lovejoy, eds. Yale University Press, New Haven, CT. pp. 3-14.

Peters, R.L., and T.E. Lovejoy, eds. 1992. *Global Warming and Biological Diversity*. Yale University Press, New Haven, CT.

Rapport, D.J., H. Regier, and T. Hutchinson. 1985. Ecosystem Behavior Under Stress. *American Naturalist* 125(5): 617-640.

Savory, A. 1988. *Holistic Resource Management*. Island Press. Washington, DC.

Schulze, E.D., and H. Zwolfer, eds. 1987. *Potentials and Limitations of Ecosystem Analysis*. Springer-Verlag, New York.

Shrader-Frechette, K.S. 1993. *Burying Uncertainty: Risk and the Case Against Geological Disposal of Nuclear Waste*. University of California Press. Berkeley, CA.

Shrader-Frechette, K.S. 1994. *Ethics of Scientific Research*. Rowman & Littlefield Publishers, Lanham, MD.

Shrader-Frechette, K.S., and E.D. McCoy. 1993. *Method in Ecology: Strategies for Conservation Problems*. Cambridge University Press. Cambridge, England.

Shrader-Frechette, K.S., and E.D. McCoy. 1994. Ecology and Environmental Problem-Solving. *The Environmental Professional* 16(4): 342-348.

Slocombe, D.S. 1993a. Environmental Planning, Ecosystem Science, and Ecosystem Approaches for Integrating Environment and Development. *Environmental Management* 17(3): 289-303.

Slocombe, D.S. 1993b. Implementing Ecosystem-Based Management. *BioScience* 43(9): 612-622.

Tausch, R.J., P.E. Wigand, and J.W. Burkhardt. 1993. Plant Community Thresholds, Multiple Steady States, and Multiple Successional Pathways. *Journal of Range Management* 46: 439-447.

Tausch, R.J., P.E. Wigand, and J.W. Burkhardt. 1994. Personal conversation. Research Scientists, U.S. Forest Service, Desert Research Institute, and Department of Range, Wildlife, and Forestry, University of Nevada System, Reno, NV.

Van Cleve, K.W., W.C. Oechel, and J.L. Hom. 1990. Response of Black Spruce (*Picea mariana*) Ecosystems to Soil Temperature Modifications in Interior Alaska. *Canadian Journal of Forest Research* 20: 1530-1535.

West, N.E., J. Stark, D.W. Johnson, M. Abrams, J.R. Ross, D. Heggem, and S. Peck. 1994. Effects of Climate on the Edaphic Features of Arid and Semiarid Lands of Western North America. *Arid Soil Research and Rehabilitation* 8: 307-351.

Westman, W.E. 1987. *Ecological Impact Assessment and Environmental Planning*. Wiley Interscience, New York.

Whitford, W.G. 1992. Effects of Climate Change on Soil Biotic Communities and Processes. In *Global Warming and Biological Diversity*. R.L. Peters and T.E. Lovejoy, eds. Yale University Press. New Haven, CT. pp. 93-117.

Winsor, M., and C. Malone. 1990. State of Nevada Perspective on Environmental Program Planning for the Yucca Mountain Project. *The Environmental Professional* 12(3): 196-207.

Woodley, S., J.J. Kay, and G. Francis, eds. 1993. *Ecological Integrity and the Management of Ecosystems*. St. Lucie Press, Waterloo, Canada.

Woodward, F.I. 1992. A Review of the Effects of Climate on Vegetation: Ranges, Competition, and Composition. In *Global Warming and Biological Diversity*, R.L. Peters and T.E. Lovejoy, eds. Yale University Press, New Haven, CT. pp. 105-123.

**ATTACHMENT G**

<u>ENVIRONMENTAL COMMENTS ON THE EIS NOI FOR</u>

<u>THE YUCCA MOUNTAIN PROJECT</u>

## 1. Background

Choices about what knowledge to base public decisions on and how the knowledge is used influence human society. With respect to protecting the environment, the National Environmental Policy Act (NEPA) focuses on this concept and seeks to improve the use of knowledge in public affairs (**cf. "Science and the National Environmental Policy Act",** ***The Environmental Professional*** **15: 1-160, 1993**), such as disposing of nuclear waste. In the context of the U.S. Department of Energy (DOE) Yucca Mountain Project this aspect of NEPA is of paramount importance because of the many uncertainties associated with isolating nuclear waste for $10^6$ years. Fortunately, the timing for the Yucca Mountain environmental impact statement (EIS) coincides with a transition in federal environmental policy that is making the resource management process more open to stakeholder participation and collaborative decisionmaking (**"The Federal Ecosystem Management Initiative",** ***The Environmental Professional*** **18: 1-235, 1996**). This ongoing initiative stands to benefit stakeholders in the Yucca Mountain Project by making available knowledge relative to the NEPA process that otherwise might be denied, i.e., if DOE adheres to the relevant environmental policies established by the Secretary of Energy in 1994.

The seeds within DOE for the transition away from autocratic, closed environmental decisionmaking driven by the desire to make proposed projects succeed are the ***Secretarial Policy on the National Environmental Policy Act*** of June 13, 1994 and the agency's December 21, 1994, ***Land and Facility Use Policy***. The latter, issued by the Secretary of Energy and explained in ***Department of Energy - Stewards of a National Resource***, is a resource stewardship policy that invokes ecosystem management to integrate DOE's mission, economics, ecologic, social, and cultural factors. The intent is that a comprehensive resource management plan be prepared for each DOE site, which should include Yucca Mountain. Other federal agencies took steps prior to DOE's action to adopt ecosystem management in complying with the White House National Performance Review (***Creating a Government That Works Better & Costs Less***, **September 1993**) that called for agencies to adopt "a proactive approach to ensuring a sustainable economy and a sustainable environment through ecosystem management." The action steps for accomplishing this were set forth in ***The Ecosystem Approach: Healthy Ecosystems <u>and</u> Sustainable Economies***, the June 1995 report of the Interagency Ecosystem Management Task Force which participating agencies, including DOE, agreed to implement.

In the past, effective policies were lacking within DOE for creating and providing knowledge for the public and for opening the agency's environmental decionmaking process. This was despite NEPA's mandate for federal agencies (**a**) to utilize a systematic, interdisciplinary approach to protecting the environment, (**b**) to ensure the integrated use of environmental information in planning and decisionmaking, and (**c**) to initiate and use ecological information in the planning and development of resource-oriented projects. These directives are meant by NEPA to be made apparent in EISs for projects that might significantly affect the human environment, including that for both present and future generations. They are included in the ***Secretarial Policy on the National Environmental Policy Act*** of June 13, 1994.

The emergence of initiatives like ecosystem management now render it federal policy that the public be provided the knowledge envisioned and explicitely mandated by NEPA. This essentially moral framework gives direction to the links between knowledge and action that must be forged under the NEPA Section 102 mandate. This is part of the ethical dimension explicitly written into NEPA in terms of a call for results conditioned by context-specific knowledge including input from affected parties (stakeholders) and by the ethical concerns articulated in NEPA Section 101. Thus, in view of DOE's commitment to comply with the substantive spirit of NEPA and to adopt ecosystem management, it is crucial that these policies be reflected in the EIS IP and achieved by the EIS for the Yucca Mountain Project.

A policy conceptually related to ecosystem management is the November 19, 1993, ***Common Sense Initiative*** undertaken by the U.S. Environmental Protection Agency (EPA) (**cf. *NAEP News* 20(5): 10-11**). The ecosystem management initiative adopted by DOE, as well as by EPA, and the EPA's ***Common Sense Initiative*** share a recognition that ecosystems are an integrated system of air, water, land, and biota requiring holistic environmental management. They also recognize that human society, ethics, and democratic principles regarding protection of resources are rapidly moving away from the traditional adversarial relationship with federal agencies and toward opening environmental decisionmaking to stakeholders in collaboration with government.

A preview of DOE's response to the ecosystem management initiative illustrated the developing awareness within the federal government of its responsibilities to the public regarding environmental information and decisionmaking (***Ecosystem***

*Management: Federal Agency Activities*, **Congressional Research Service, 94-339 ENR, April 19, 1994**). A subsequent description of DOE's current policy regarding the ecosystem management initiative will appear early in 1996 (**"The Federal Ecosystem Management Initiative,"** ***The Environmental Professional*** **18: 1-235, 1996**). Both presentations discuss the importance of DOE's ecosystem management policy and note that NEPA "gave the nation an environmental mandate but no definite plan to achieve environmental goals. Now, the ecosystem approach offers a plan to move towards achievement of essentially the same environmental goals." Additionally, DOE views implementation of ecosystem management as part of the agency's pursuit of Environmental Total Quality Management (TQM) **(cf.** ***Applying Total Quality Management to Environmental Activities*****, Workbook for a conference sponsored for and supported by DOE, January 25-27, 1991, La Jolla, California, and,** ***Environmental TQM, Second Edition*****, McGraw-Hill, Inc., 1995**). Environmental TQM is viewed by DOE headquarters as being equivalent to ecosystem management in that both concepts seek to sustain ecosystems for supporting economic development and communities for future generations (i.e., sustainable development, cf. ***Toward Sustainable Development*****, Island Press, 1994**). This is evident in DOE's adoption of the same framework for ecosystem management to achieve sustainable development as that set forth by the White House, which is:

- Define and identify ecosystems of concern;
- Involve stakeholders to develop a shared vision of an ecosystem's desired future condition;
- Characterize the ecosystem, its holistic environmental condition, and trends for the ecosystem;
- Establish ecosystem goals;
- Develop and implement an action plan for achieving the goals;
- Monitor conditions and evaluate results; and
- Adapt management according to the new information.

The framework established by DOE's ***Land and Facility Use Policy*** should apply to the NEPA process underway for the Yucca Mountain Project. This much has been acknowledged by the project's management (**W.E. Barnes' letter of November 9, 1995, to the State of Nevada Department of Administration**). In this letter, Mr. Barnes, manager of the Yucca Mountain Project, asserts that ecosystem management is and has alway been practiced by the DOE at Yucca Mountain. Yet Mr. Barnes also asserts that the site-wide resource management plan, being prepared by the Nevada Test Site in accordance with principles of ecosystem management consistent with the Secretary's resource management policy of December 21, 1994, does not apply to the Yucca Mountain Project. Moreover, Mr. Barnes stated that there is no intention to prepare such a management plan for the project, which contradicts his assertion that the Yucca Mountain Project embodies the ecosystem management concept. (Barnes' letter responded to an August 28, 1995, inquiry from the State of Nevada Department of Administration about the consistency between the Yucca Mountain Project and both DOE headquarters policy and the Nevada Operations Office policy regarding implementing ecosystem management as set forth by the White House and adopted by DOE's own ***Land and Facility Use Policy***.)

Over the years that the Yucca Mountain Project's environmental program has been underway, the State of Nevada and the Nuclear Waste Technical Review Board have consistently faulted the program because it lacks an ecosystem approach to environmental protection (cf. ***The Environmental Professional*, Vol. 17: 271-284**). Instead, the program relies on a piecemeal, compartmentalized approach based on population biology and community ecology totally without benefit of interdisciplinary integration. This is the result of (**a**) environmental management that is unqualified in EIA and ecosystem management regarding compliance with the substantive spirit of NEPA and (**b**) support contractors who are equally unqualified with respect to the scientific as well as the ethical aspect of environmental practice. (As noted later in these comments, in the context of the Yucca Mountain Project's ongoing NEPA process, these discrepancies contradict ***40 CFR 1502.6*** and ***40 CFR 1502.24*** concerning interdisciplinary studies and scientific integrity and are therefore inconsistent with the ***Secretarial Policy on the National Environmental Policy Act*** of June 13, 1994.)

Thus, the Yucca Mountain environmental program lacks scientific integrity and credibility due in part to the absence of competent environmental professionals capable of interdisciplinary teamwork and bound to codes of environmental ethics and best standards of professional environmental practice. To its credit, the NTS environmental program, on the other hand, benefits from qualified environmental management. This accounts for the NTS's adoption of ecosystem management upon which to base resource management planning in the course of complying with NEPA on a site-wide basis, except for the portion of the site occupied by the Yucca Mountain Project. Unfortunately, the Yucca Mountain Project fails to require attention to scientific, ethical, and professional precepts in carrying out the NEPA process. This situation exists in part because of the September 1, 1994, ***Memorandum of Agreement*** between the DOE Nevada Operations Office and the Yucca Mountain Project Office that sets the two apart with respect to environmental protection, compliance decisionmaking, and the NEPA process.

As noted, the Yucca Mountain NEPA compliance program is driven by the desire to implement the project, the decision for which is already made on the part of the DOE. As a consequence of this predetermined decision, little importance is likely to be given to the EIA planning process regarding cognitive reform measures implicit in DOE's ***Secretarial Policy on the National Environmental Policy Act*** and in the ***Land and Facility Management Policy***, the latter of which explicitely embraces ecosystem management and collaborative environmental decisionmaking betweem DOE and its stakeholders. However, the preparation of the Yucca Mountain EIS IP will provide DOE the opportunity to redress this and other shortcomings of its environmental program.

The manner in which EIA and the EIS planning processes are undertaken for the Yucca Mountain Project represents a major determinant of the outcome of the NEPA process because planning for the EIS IP plays a central role in structuring and applying knowledge to carry out EIA to support environmental decisionmaking. Adequate implementation planning must assure that all practical alternatives within the project will be pursued in light of sufficient, credible scientific information for EIA and long-term environmental protection. This requires an effective interdisciplinary approach to EIA for (**a**) acquiring empirical baseline information, (**b**) empirical information about potential adverse impacts of the proposed action, (**c**) reducing EIA uncertainties through environmental risk analysis, and (**d**) developing adequate plans for monitoring, managing, and mitigating potential negative impacts up to $10^{\circ}$ years. The only manner by which the last requirement can be achieved over such a great spans of time is by strict adherence to impact avoidance (**cf. *The Environmental Professional* 12: 196-207**).

Traditionally DOE relies heavily on subjective "expert" judgement for its EIA process instead of pursuing empirical and quantitative approaches. Consequently, views regarding impacts fail to rely on systematic empirically based findings and instead are derived from personal opinion. This problem is further compounded by the absence of any formal methodology for treating subjective judgement for EIA and for maintaining a sound, defendable basis for inference and decisionmaking. Without a consistent means of guiding the application of personal opinion through the Yucca Mountain EIA process, a critical source of uncertainty and imprecision is left untreated to degrade the predictive credibility of the process and procedures that created the project's EIS, and ultimately the EIS itself. This is the flawed scenario currently being pursued for the Yucca Mountain Project.

If the DOE continues to assert, as Mr. Barnes did, that its environmental program at Yucca Mountain is based on ecosystem management without first restructuring the environmental program, in the end the EIA process will rely on subjective opinion that is neither visible nor formal to the extent that current practice and the ecosystem approach to environmental management dictate. In this case, environmental impact analysts will fail to separate objective fact from personal opinion and instead will switch between the two conditions as the need arises to falsely justify a predetermined decision to develop the project. This situation would thus repeat the mistakes evident throughout the DOE's 1986 statutory EA for the Yucca Mountain site (**DOE/RW-0073, May 1986**). Such a strategy, which the Yucca Mountain environmental program currently is repeating, will fail to convince stakeholders of DOE's good faith in carrying out EIA as well as call the credibility of the EIS into question on grounds of not conforming to the norms of sufficiency. If this scenario prevails, DOE ultimately will compound and perpetuate its lack of integrity regarding the NEPA process because there will be no direct measure to extract from the Yucca Mountain EIS for deriving a value of integrity. Thus, in the end the EIS will lack credibility and fail to achieve "full compliance with the letter and spirit of" NEPA as stipulated by the ***Secretarial Policy on the National Environmental Policy Act*** of June 13, 1994.

The complimentary policy frameworks of NEPA and of ecosystem management offer DOE an opportunity to furnish stakeholders with the knowledge needed for responsible environmental decisionmaking for the Yucca Mountain Project. Ecosystem management principles are consistent with NEPA's policy, and their implementation in the Yucca Mountain Project would provide stakeholders the basis for obtaining information necessary for social choice that more readily allows ethically based, rational decisionmaking. Thus, knowledge provided by the DOE through the NEPA process should create links between the affected public and federal resource management policy. As noted later, this is being achieved by other federal agencies in the Yucca Mountain region (e.g., the Department of Defense, Bureau of Land Management, Fish and Wildlife Service, National Park Service, and the USDA Forest Service) and by DOE itself for the NTS (**cf. *Five-Party Cooperative Agreement*, May 1994**, for federal lands surrounding the NTS, and Yucca Mountain, that includes the State of Nevada as a party). The Yucca Mountain Project stands as an exception to how public land and resources are being managed throughout southern Nevada.

Achieving NEPA's ethical policy goals for the Yucca Mountain Project will require a new environmental rationality and ethic that historically has been missing from DOE's NEPA process. Credible execution of the NEPA process rests on a recourse to competently executed science. As noted, this demands control of the process by professionals bound by codes of ethical behavior and standards of practice that assure proper weight being given to environmental factors. Fostering greater environmental sensitivity in planning and decisionmaking is essential for the Yucca Mountain Project if DOE headquarters and the Secretary wish to be taken seriously with respect to its new ecosystem-based ***Land and Facility Management Policy***.

## 2. Purpose of the Comments

Environmental documentation within the DOE routinely is prepared to justify decisions already made, and the Yucca Mountain Project is no exception to that rule. The following comments recognize that fact and discuss how this must be avoided in the course of pursuing legitimate environmental impact assessment (EIA) for the Yucca Mountain Project EIS that is consistent with the ***Secretarial Policy on the National Environmental Policy Act*** of June 13, 1994. The intent of the State of Nevada is that the issues raised here be explicitely dealt with by the DOE in its EIS implementation plan (EIS IP) for the project. If the DOE fails to do so its NEPA process for the project will be seen by the State of Nevada as another token, insufficient compliance effort that is fundamentally flawed and lacks credibility, and ignores the stakeholders in the process.

## 3. NEPA Process and Review

The national policy set forth by NEPA encourages (**a**) harmony between man and the environment, (**b**) minimizing harm to the environment, (**c**) fostering man's well being, and (**d**) enhancing knowledge about ecosystems. Included among the goals is protecting the environment for the benefit of future generations. These are important substantive objectives that an EIS for a repository at Yucca Mountain must address in the forthcoming EIS IP (***40 CFR 1500.1*** **and the** ***Secretarial Policy on the National Environmental Policy Act,*** **June 1994**). To assure that is done, the DOE should upgrade its NEPA process by incorporating valid independent peer review of the EIS IP and the draft and final EISs for the Yucca Montain Project. The issue of independent peer review of EIA and the EIS and how it will be resolved must appear in the EIS IP.

## 4. Qualified Interdisciplinary Expertise

Another important aspect of NEPA that must be evident in the EIS IP is that an EIS must be prepared by an interdisciplinary team (***40 CFR 1502.6***), not simply by a group of people with different disciplinary backgrounds. To date, the DOE has not established such a team and instead is pursuing a rigidly compartmentalized approach. The EIS IP must demonstrate how the necessary methodology, scientific accuracy, and professional integrity (***40 CFR 1502.29***) will be achieved for the Yucca Mountain Project EIS with or without an integrated approach and what expertise will be involved (***40 CFR 1502.17***).

This issue is especially important with respect to DOE's excessive reliance on contractors to fulfill its NEPA responsibilities. In the case of the Yucca Mountain Project, the DOE has minimal environmental expertise among its staff, a critical matter in terms of achieving appropriate oversight of the work performed by environmental contractors. It is interesting to note that with respect to high priority projects that "present unusually controversial or sensitive issues," such as the Yucca Mountain Project, heavy reliance on support contractors is counter to the ***Secretarial Policy on the National Environmental Policy Act*** of June 1994. Section IV. A on pages 5 and 6 of the policy states that DOE "personnel rather than contractors will be used, to the maximum extent practicable." The deficiency regarding qualified environmental management for the Yucca Mountain Project, if not corrected, will result in an EIS that consists of a perfunctory paper-compliance approach to the NEPA process and a continuing lack of a proper environmental ethic on the part of both the DOE and its contractors.

Thus, it is essential that the EIS IP confront how existing weaknesses in environmental expertise and ethics will be overcome so that scientifically and objectively sound EIA will result from the NEPA process. A part of achieving this is the aforementioned necessity of the DOE having an independent oversight review body to appraise the EIA process, including the EIS IP and the environmental documentation aspects of the Yucca Mountain Project. This is crucial if the DOE is to overcome its traditional lack of enviromental credibility and its inattention to stewardship of resources as the Secretary of Energy sought to establish with the ***Land and Facility Use Policy*** of December 21, 1994. How the Yucca Mountain Project will apply ecosystem management to integrate DOE's mission, economics, ecologic, social and cultural factors in a comprehensive resource management plan the Yucca Mountain site must appear in the EIS IP, contrary to Mr. Barnes' view (**W.E. Barnes' letter of November 9, 1995, to the State of Nevada Department of Administration**).

## 5. Council on Environmental Quality

Another means of achieving credibility and public trust is for the DOE to implement the Council on Environmental Quality (CEQ) NEPA referral process whereby the CEQ becomes involved when there is a threat of the NEPA process or its outcome being fundamentally at odds with NEPA's mandate (**cf. "Science and the National Environmental Policy Act",** ***The Environmental Professional*** **15: 1-160, 1993**). Such a threat clearly exists due to the unique timeframe that the Yucca Mountain EIS must address and NEPA's mandate regarding responsibilities to future generations. A particularly relevant part of this concern is DOE's persistent refusal to adopt an ecosystem approach to understanding the long-term consequences of a heat-disturbed ecosystem above the repository.

A related reason for the CEQ to become involved in the NEPA process is the inability of the DOE to responsibily address cumulative impacts in the timeframe of $10^3$ to $10^6$ years regarding anticipated releases of radionuclides into the groundwater environment underlaying Yucca Mountain and release carbon-14 into the atmosphere. For the DOE as an institution, cumulative impact assessment (***40 CFR 1508.7***) has always been a difficult and neglected aspect of the EIA process. In this respect the CEQ is committed to working with federal agencies to find ways to look at the issue, and how DOE will take advantage of the opportunity should be reflected in the Yucca Mountain EIS IP.

## 6. Cumulative Impacts, Connected Actions, and Segmentation

In DOE's NEPA process, cumulative impacts (***40 CFR 1508.7***) typically are ignored or brushed aside with cursory personal opinion that such effects will not occur. In the case of potential long-term radiation health impacts from the Yucca Mountain Project, the EIS IP must address cumulative effects supported by scientific data and analysis. Adequate peer review of the Yucca Mountain NEPA process should focus on assessment of cumulative impacts.

Additionally, ***40 CFR 1508.25*** states that an agency should analyze "connected actions" in one EIS. The CEQ regulations are directed at avoiding improper segmentation, wherein the significance of the environmental impacts of an action as a whole would not be evident if the action were to be broken into component parts and the impacts of those parts analyzed separately. The EIS IP for the Yucca Mountain Project must address this matter with respect to the disconnected EIA between the NTS and the repository project and the exclusion of Yucca Mountain from the regional environmental resource management plan underway for the NTS site-wide EIS. This is especially important with respect to (**a**) groundwater issues and past testing of nuclear weapons at NTS and (**b**) the ongoing environmental restoration program at the site.

7. **Truly Significant, Reasonably Foreseeable Long-Term Impacts**

With respect to NEPA's focus on cognitive reform regarding understanding ecosystems, the Yucca Mountain EIS IP must provide for the improved utlization of knowledge of ecosystems and their resources. This is because potential adverse environmental and human health consequences are associated with the "truly significant" issue ***(40 CFR 1500.1)*** of "reasonably foreseeable" long-term ($10^6$ years) impacts (***40 CFR 1502.22***) of a repository on the ecosystem above the facility and the secondary impacts of an altered ecosystem on repository performance. At sufficiently high thermal loads of nuclear waste the ecosystem is likely to experience impacts from the heat of radioactive decay. Coupled with anticipated increases in ambient temperature resulting from global climate change (warming) higher temperatures will induce ecosystem responses that are not understood for the Yucca Mountain ecosystem. The EIS IP therefore must contain provisions for understanding how increased temperatures both above and beneath the ground surface at Yucca Mountain will affect the environment (***40 CFR 1502.15 and 1508.8***) and how the environmental consequences (***40 CFR 1508.16***) will influence protection or impsct mitigation (***40 CFR 1508.20***) with respect to resources like groundwater for future generations.

Thus, in keeping with NEPA's mandate for creating knowledge about ecosystems, the DOE is challenged to understand how the ecosystem at Yucca Mountain will respond to dual sources of heat stress and how in turn altered ecosystem conditions might influence long-term repository performance. The information needed to meet the challenge of scientific integrity (***40 CFR 1502.24***) and to assess signifance (***40 CFR 1508.27***) must be empirical, quantitative, and should be made available within the period being allocated by DOE for preparing the EIS. The challenge cannot be met with DOE''s traditional application of subjective expert judgement to EIA in cases of unavailable information (40 CFR 1508.22). Plans for resolving this issue in a manner that withstands independent expert peer review must be presented in the EIS IP.

8. **Succeeding (Future) Generations**

Many EISs prepared by the DOE do little to substantively protect the environment, particularly in regards to future generation where, aside from such concerns as transportation accidents, most of the threat posed by geologic disposal of nuclear wastes lies. In the case of the Yucca Mountain Project, consideration of long-term cumulative impacts to the environment and therefore to humans poses a serious threat to NEPA compliance and is a "truly significant" issue that the NEPA process must address (***40 CFR 1500.1*** and the ***Secretarial Policy on the National Environmental Policy Act***, June 13, 1994). The undeniable knowledge that such consequencies eventually will materialize poses a fundamental conflict with NEPA's mandate that each generation be a trustee of the environment for succeeding generations. This is an issue that the EIS IP must confront and set forth the means for resolving via EIA and the NEPA process.

9. **Supplemental Information**

As noted above, the Yucca Mountain environmental program has been faulted over the years by oversight bodies for not initiating ecosystem-based studies necessary for understanding the long-term consequences that a repository might have on future generations. It probably is too late to gain quantitative empirical insight to that issue in accordance with DOE's current NEPA schedule. However, the need for such studies remains critical. Therefore, the EIS IP should present plans for obtaining the information and presenting it later in a supplemental statement (***40 CFR 1502.9(c)(1)***). Ongoing research of a related nature regarding global warming demonstrates that such studies are feasible, that significant adverse impact are reasonable foreseeable, and that the costs of acquiring such information are not exorbitant (***40 CFR 1502.22, The Environmental Professional* 15: 1-160, 1993**, and ***The Environmental Professional* 17: 271-284, 1995**).

10. **Environmental Risk Analysis**

Central to NEPA is the ability to make predictions about environmental outcomes resulting from alternative courses of action such as thermal loading scenarios for a repository at Yucca Mountain. The soundness of decisionmaking is dependent on this predictive capability. In turn, the soundness of the very long-term predictions, such as the Yucca Mountain Project faces, depends on the inclusiveness, representativeness, and explanatory power of simulation models derived from sound empirical information. Gaps in knowledge should be eliminated whereever possible. Decisionmaking, on the other hand, like that under NEPA, should be based on best practicable methodology, i.e., environmental risk aanalysis. The extent of uncertainty that can be tolerated in EIA for the Yucca Mountain Project and that is unlikely to be resolved by risk assessment must be made clear in the EIS by a methodology presented in the EIS IP.

Functional characteristics of ecosystems are important components of ecosystem health and are closely related to resource management goals. For this reason, it is important to assure the long-term protection of ecosystem function as well as ecosystem structure. The best way to assess the protection of ecosystem function is to develop models to predict effects of stress on function, to make decisions among alternatives and take preventive action based on the model's predictions. The importance of establishing methods for determining ecosystem function and resilience transcends scientific interest because methods are important to environmental risk managers as tools needed to predict impacts and protect sustained societal use of ecosystems and long-term productivity. Increased awareness of information on ecosystem function and new ways of viewing ecosystem protection will improve the decisions made under NEPA (**cf. *The Environmental Professional* 15: 1-160, 1993** and ***The Environmental Professional* 18: 1-235, 1996**).

Ecological risk assessment is a scientific process for estimating, with a known degree of certainty, human effects on the integrity of ecosystems, i.e., ecological function and resilience. At this stage of the Yucca Mountain Project there is extensive scientific uncertainty with respect to the potential threat that excessive heat associated with thermal loading would pose to the ecosystem and in turn to a nuclear waste repository at Yucca Mountain. Ecological risk analysis should be used by DOE to reduce that uncertainty and the approach to its use should be part of a long-term ecosystem studies plan presented in the EIS IP. Otherwise, the DOE must pursue the worse-case scenario for a repository at Yucca Mountain that could result from a combination of global climate change and a high thermal load (**cf. *The Environmental Professional* 17:271-284**).

The steps in this risk-approach are for the DOE to (**a**) define the end point conditions that must be protected, (**b**) characterize the environment that will exist under global warming, and (**c**) assess the hazard to the Yucca Mountain ecosystem that will result from thermal loading and threaten repository performance and the long-term health of the groundwater and future generations. The extensive uncertainty that presently exists in all three step can be reduced only by empirical scientific studies. Any effort to resolve the uncertainties by subjective opinion alone will be unsatisfactory. Thus, it is essential that DOE present study plans in the EIS IP for an ecosystem-based approach in the context of ecosystem management. This will provide a capability for resolving EIA uncertainty with respect to the thermal loading issue through the use of predictive models of long-term ecosystem outcome.

## 11. Environmental Life Cycle Assessment

In 1993 the U.S. EPA took steps to encouraged waste management activities to apply environmental life cycle assessment to environmental protection (**cf. *Life Cycle Design Guidance Manual*, EPA/600/R-92/226, January 1993, and, *Life-Cycle Assessment: Guidelines and Principles*, EPA/600/R-92/245, February 1993**). Life cycle assessment is a holistic approach that analyzes the entire system around waste disposal. Applied to the Yucca Mountain Project, it would encompass raw materials used for manufacturing nuclear waste canisters and transporting the waste to a repository, as well as reporisory construction, operation, and closure. All the downstream and upstream effects of the operation of waste disposal would be factored into EIA to provide a holistically view of the environmental consequences associated with the Yucca Mountain Project.

This departure away from DOE's present piecemeal, compartmentalized approach to the NEPA process would be a departure from evaluating nuclear waste options that look at single components of the effort in step-wise manner. Such a procedure could be initiated by integrating EIA into DOE's systems engineering program. This would permit the systems engineering analyses to address alternatives within the project that would allow the best environmental decisions to be made to the benefit of the holistic repository program. To this end, the EIS IP should present a framework for environmental life-cycle assessment that would assure environmental decisionmaking in the full long-term context of the Yucca Mountain Project.

## 12. Resource Management

As noted earlier, the White House has instructed federal agencies to adopt ecosystem management as the basis for protecting public land and resources. The DOE, while tardy in adopting the ecosystem approach for its policy of managing land and facilities, now has joined the other federal agencies in doing so. The first DOE site to take steps in this respect was the NTS where a site-wide EIS now in preparation will encompass a resource management plan founded on ecosystem management. It is unfortunate the the Yucca Mountain Project has excluded itself from this activity and vows not to initiate resource management activities (***Memorandum of Agreement Between DOE Nevada Operations Office and the Yucca Mountain Site Characterization Office*, UN-27, September 1, 1994, and, W.E. Barnes' letter of November 9, 1995, to the State of Nevada Department of Administration**). This is particularly so in view of the fact that all public land adjacent to and surrounding Yucca Mountain is being managed in accordance with ecosystem management (Figure 1) (**cf. *Five-Party***

*Cooperative Agreement*, **May 1994**).

The letter from Mr. Barnes, Manager of the Yucca Mountain Project, asserted that the project already has incorporated the principles and concepts of ecosystem management into its program. As evidence of this, Mr. Barnes refers to the ***Yucca Mountain Project Environmental Management Plan***, YMP/93-04) and the ***Yucca Mountain Project Annual Site Environmental Report*** procedure as reflecting the principles of ecosystem management and sufficing for the project's compliance with such DOE policies as the ***Secretarial Policy on the National Environmental Policy Act***, June 13, 1994 and the agency's December 21, 1994, ***Land and Facility Use Policy***. Neither of the documents cited by Barnes has been revised to reflect an ecosystem approach consistent with either of the Secretary of Energy's policies regarding such matters.

Because the Yucca Mountain Project has ignored independent expert advice about adopting an ecosystem approach to its environmental program (**cf.** ***The Environmental Professional*** **17:271-284, 1995**), the EIS IP for the project should explain its rationale for "complying" with the Secretary of Energy's directive in the ***Land and Facility Use Policy*** that, "Our (land) stewardship will be based on the principles of ecosystem management and sustainable development."

13. **Post-closure Project Monitoring**

The DOE's Yucca Mountain environmental program has conducted environmental monitoring meant to detect significant adverse impacts of site characterization activities. Because monitoring did not commence sufficiently before the environmental disturbance activities began, there is not adequate environmental baseline information reflecting natural temporal variability against which to compare the results of the site charactization effects monitoring. Moreover, the limited monitoring that has occurred is too thinly spread over the diverse transitional desert ecotone at Yucca Mountain to credibly characterize environmental conditions. Additionally, with such limited monitoring it is not possible to separate human perturbations from natural temporal environmental variability characteristic of ecosystems. Thus, observed conditions cannot be attributed to either human intervention or to wide-ranging natural differences in temporal patterns, in which case, like the Yucca Mountain Project, the monitoring data are not credible for EIA prediction.

The DOE sought to correct this situation by altering the monitoring design while at the same time curtailing environmental monitoring activities, all to no avail. Despite these shortcomings, the Yucca Mountain Project plans to base EIA for the repository EIS on a restriced amount of environmental information.

It is, therefore, essential that the EIS IP explain the rationale behind this impact assessment scheme and how the DOE perceives the information being made statistically credible in the face of its present limitations. This will provide the DOE an opportunity to address the assertions by Mr. Barnes that the field program is consistent with an ecosystem approach. Describing in the EIS IP how the environmental monitoring and the EIA activities currently underway, and defended by the DOE as being adequate, will provide the opportunity to address issues of long-term thermal impacts on the ecosystem at Yucca Mountain and the potential threat to repository performance. The EIS IP also should explain how the environmental program will compensate for the lack of process-based ecosystem simulation modeling necessary for predicting long-term impacts to the Yucca Mountain ecosystem.

14. **Policy and Guidance for the NEPA Process**

The EIS IP must list and discuss the policies and guidance (e.g., from the DOE Office of NEPA Oversight) to be followed regarding NEPA compliance for the Yucca Mountain EIS. Because of the intent of the Nuclear Regulatory Commission (NRC) to adopt DOE's EIS, the NRC's NEPA policy and guidance to be satified must be included.

Ongoing site characterization activities heavily rely on numerous requirements documents that guide the Yucca Mountain Project. The role that these and similar requirements will play in describing all phases of the proposed action (construction, operation, closure, post-closure monitoring) and carrying out EIA for NEPA compliance also must be identified and discussed in the EIS IP. The EIS IP should be clear about the role and use of this information in guiding EIA for repository project.

With respect to compliance with routine media-based environmental regulatory requirements, a statement in the EIS IP and ultimately in the EIS itself that the proposed action would be in compliance with applicable regulations, DOE Orders, and NRC licensing will not substitute for a presentation of impacts. The adage that "the whole is greater than the sum of the parts" is true with respect to ecosystem-based EIA. Thus, credible and responsible NEPA compliance requires a holistic, ecosystem approach to EIA whereas media-based environmental regulations address only restricted components of the integrated environment. The EIS IP that is to follow from comments such as these must demonstrate DOE's recognition that NEPA is the only environmental law requiring holistic, integrated environmental impact assessment. The DOE's ***Land and Facility Use Policy*** and the ***Secretarial Policy on the National Environmental Policy Act*** commit the Yucca Mountain Project to: "Full compliance with the letter and spirit of the National Environmental Policy Act (NEPA), our national charter for protection of the environment, is an essential priority for the Department of Energy, consistent with our core values." (**Secretary of Energy *National Environmental Policy Act Policy Statement*, June 13, 1994.**

# ATTACHMENT H

VIEWS ON

THE FEDERAL INITIATIVE ON ECOSYSTEM MANAGEMENT

AND THE U.S. DEPARTMENT OF ENERGY

## Introduction

In recent years, fundamental changes have been occurring in the concepts of managing environmental resources. Traditionally, resource management was undertaken to maximize yield of or to protect one or more resource components. Concepts of a holistic, intergrated environment and of a harmony between man and his environment played small roles in conventional resource management. However, this is now changing with the evolving concept of ecosystem management that strives to manage the environment consistent with principles of ecological, economic, and social sustainability and of mutual harmonious benefit among those sectors of human society. Thus, ecosystem management involves environmental management that (1) recognizes social and economic viability within functioning ecosystems, (2) is at a scale compatible with natural processes, (3) is cognizant of nature's time frames, and (4) is realized through effective partnerships among private, local, state, and federal interests.

The goal of ecosystem management is to preserve, restore, or simulate ecosystem integrity (as defined by ecosystem structure and function) consistent with maintaining socioeconomic sustainability (Grumbine 1994a, Keystone Center 1995, Slocombe 1993a and 1993b). Thus, the concept of ecosystem management recognizes human needs and the importance of developing a vision that integrates ecological and cultural factors and therefore involves a recognition of the interrelationship of a healthy economy and a healthy environment. It focuses on policies that foster both a sustainable economy and sustainable ecosystems that support biodiversity.

Ecosystem management policies and activities within the federal land management agencies, including the U.S. Department of Energy (DOE), have been described (CRS 1994). Basically, the DOE approach is said by Breed (1994) and by Pearman (1994) to be founded on maintaining the natural sustainability and biological diversity of ecosystems while support sustainable economis development and communities. This would involve a regional planning strategy that integrates stakeholder and community concerns and goals and draws on DOE's foundation of knowledge regarding ecological interactions and environmental compatibility of technology development and human use.

**The Federal Initiative**

A number of things are responsible for the ongoing fundamental changes in how environmental resources are being managed in the federal sector. In short, the two most important factors are the recent emergence of ecosystem science and the concurrent widespread realization that traditional resources management was not working. These two occurrances are well documented by Grumbine (1993b), Knight and Bates (1995), and Savory (1988).

Among the initial signs of the federal ecosystem management initiative was an extensive national workshop in 1992 sponsored by the USDA Forest Service that reflected the ecosystem approach to resources management (FS 1992). This was followed in 1994 by a notable report that documented the need for the Forest Service to alter its management procedures to formally embrace ecosystem management (FS 1994). Several other federal land management agencies followed suit in 1994 and 1995 (e.g., BLM 1994, FWS 1994 and 1995). These actions and their recent status and potential are documented in U.S. Senate (1994a), CRS (1994 and 1995), and GAO (1994).

A crucial step toward a federal ecosystem management initiative was taken by the Clinton Administration under the National Performance Review. In an accompanying report to the review, Vice President Al Gore proposed that federal stewardship of public environmental resources be founded on the concept and principles of ecosystem planning and management (Gore 1993). The Gore report called for a Presidential Executive Order by September 1994 directing federal land management agencies to implement ecosystem management. Next, the report called for a high-level Interagency Ecosystem Management Task Force to develop a number of cross-agency ecosystem management demonstration projects. The Executive Order was drafted to be issued in late 1994. However, an outcome of the 1994 congressional elections was that the anticipated Executive Order on Ecosystem Management was deferred.

In the meantime, the Interagency Ecosystem Management Task Force was established with the Director of the White House Office of Environmental Policy as the head and Assistant Secretaries from 12 departments and agencies. Representatives from the Office of Management and Budget and White House Office of Science and Technology Policy also serve on the task force. The task force formed the Interagency Ecosystem Management Working Group to assist in its work, to conduct case studies, and to develop a report on implementing an ecosystem-based approach to managing environmental resources. In turn, the working group created teams to address scientific, legal, institutional, public participation and budgetary issues relative to the federal ecosystem management initiative. At the same time, case studies of ecosystem management in practice were initiated in Southern Appalachia, Coastal

Louisiana, the Anacostia River Watershed, Prince William Sound, the Great Lakes, South Florida, and the Pacific Northwest Forests.

The report of the Interagency Ecosystem Management Working Group is to be issued in mid-1995. It will be a landmark in the federal ecosystem management initiative that will influence land and facility management in federal agencies like the DOE.

It also should be noted that in 1994 during the 103rd Congress a bill (S. 2189) was introduced by Sen. Mark Hatfield (R - Oregon) to establish the Ecosystem Management Act of 1994 (U.S. Senate 1994b). The bill would have amended the Federal Land Policy Management Act of 1976 to provide for ecosystem management. The objectives of the bill basically were consistent with the work of the Interagency Ecosystem Management Task Force and Working Group and the hoped for Executive Order on Ecosystem Management. Like the proposed Executive Order, however, the fate of the bill in the 104th Congress is uncertain. What remains certain for the present, at least, is the federal ecosystem management initiative is alive and well within the relevant federal departments and agencies.

## Ecosystem Management in the DOE

### The Rule

According to Breed (1994) the DOE comprehends and is adopting ecosystem management throughout its programs and facilities. Breed supports this position by noting two DOE Orders that promote and assure a proactive ecosystem management approach to maintaining a sustainable environment and a sustainable economy. DOE Order 5400.1(1.5a), on Environment, Safety, and Health, ensures incorporation within the agency of national environmental protection goals to advance restoring and enhancing environmental quality on DOE lands. DOE Order 4320.1B, on Land and Facility Use Management, is the basis for a broad planning perspective for addressing the regional and local conditions surrounding DOE sites and for identifying present land uses and future opportunities for performing planning analyses. Under this framework, the DOE is seeking to achieve Total Quality Environmental Management for sustaining ecosystems and for supporting economic development and communities for future generations.

In August 1994, consistent with the position expressed by Breed (1994), the DOE took steps toward revising its policy under DOE Order 4320.1B (Pearman 1994). This action involved issuance of a draft Land and Facility Use Management Policy that, when adopted and implemented, would have replaced the current site development planning policy. The stated impetus for the action was to conform DOE internal policy with the then pending Executive Order on Ecosystem Management. The policy's objectives were laudable, i.e., for DOE to manage all land and facilities as valuable national resources in accordance with the principles of ecosystem management and sustainable development. The draft policy sought to integrate mission, ecological, economic, and social factors in a comprehensive plan for each DOE site that would guide land and facility use decisions. Comprehensive plans developed for each site were to consider the site's larger regional context and be developed with stakeholder participation.

Since the draft policy emerged in August 1994 nothing more has been seen of it outside of the DOE. Inquiries have been made to DOE headquarters about the status of the policy and of the ecosystem management initiative it hearlded. None of these overtures has been responded to by the DOE. Similarly, a request was made to no avail for other information such as resource documents on "Role of Future Use in Ecosystem Management" and "Department of Energy - Stewards of a National Resource" (Walker 1995). With one exception to be discussed later, all traces of the ecosystem management initiative within the DOE seem to have disappeared with the White House decision subsequent to November 1994 not to issue its Executive Order on Ecosystem Management.

The seeming reticence of the DOE to be forthcoming with information relative to ecosystem management policy is contrary to other federal land management agencies. For example, the DOE is not participating along with other agencies in a National Policy Dialogue on Ecosystem Management being sponsored by the Keystone Center (1995). Additionally, the DOE alone has not consented to contribute a policy position paper to a special professional publication that will address such matters and activities with respect to federal ecosystem management initiative (Malone 1995). Thus, while other federal land management agencies and the White House continue to pursue ecosystem management and are forthcoming about their policies and programs, the DOE remains silent.

The Exception

The exception to this rule has been the action taken in the field by the DOE with respect to preparing an Environmental Impact Statement (EIS) for the Nevada Test Site (NTS). In its Notice of Intent for the EIS, the DOE Nevada Operations Office proposed to prepare a Resource Management Plan (RMP) for the NTS that would address ecosystems and facilities at the site in a framework of mutual sustainability (DOE 1994). Upon receiving comments from stakeholders associated with the NTS, it became apparent to the DOE that what the stakeholders envisioned as an acceptable RMP, one based on the concepts of ecosystem management, exceeded the DOE's capabilities at the time. Rather than reneging on its offer to prepare an RMP, the DOE committed to including a framework for a management plan in the EIS and to pursuing the the RMP subsequent to the EIS (DOE 1995).

What is particularly reassuring to the stakeholders in the NTS

EIS process is that the DOE has agreed to base the RMP on the principles of ecosystem management and to participate with stakeholders in the framing of the RMP as well as in its execution. Thus, other federal agencies, state and local governments, concerned citizens, and public interests will become involved in an ecosystem management approach to planning for the future management of natural resources and facilities at the NTS. This contrasts markedly with the reticence of DOE headquarters regarding agency-wide policy on ecosystem management.

The ongoing EIS process for the NTS is the first ever at a DOE site that will adopt and lead to implementing the concepts and principles of resource management planning based on ecosystem management. Perhaps this initiative will lead the way to the DOE actually realizing the otherwise seemingly hollow commitments to Total Quality Environmental Management described by Breed (1994) for a broad planning perspective that addresses regional and local conditions surrounding DOE sites. To achieve this, DOE headquarters must take steps to achieve a unified planning agenda by coordinating and integrating disparate elements of ecosystem management within the agency. While it is too late in the federal initiative on ecosystem management for the DOE to be a leader, as anticipated by Breed (1994), the agency must take steps at all of its sites for identifying present land uses and future options. This will of necessity involve efforts to achieve consensus decisionmaking with stakeholders regarding a sustainable environment that addresses ecological as well as socioeconomic components.

**REFERENCES**

Breed, B. 1994. Department of Energy. In *Ecosystem Management: Federal Agency Activities*. Congressional Research Service, Washington, DC. pp. 43-49.

(BLM) Bureau of Land Management. 1994. Ecosystem Management in the BLM: From Concept to Commitment. BLM/SC/GI-94/005+1736. BLM, Washington, DC.

(CRS) Congressional Research Service. 1994. Ecosystem Management: Federal Agency Activities. 94-339 ENR, April 19. CRS, The Library of Congress, Washington, DC.

(DOE) U.S. Department of Energy. 1994. Nevada Test Site Enivronmental Impact Statement Notice of Intent. *Federal Register* 59(153), Wednesday, August 10.

(DOE) U.S. Department of Energy. 1995. Implementation Plan for the Nevada Test Site Enivronmental Impact Statement. DOE/NV-390 UC-700, Revision 0, February. DOE, Washington, DC.

(FS) USDA Forest Service. 1992. Taking an Ecological Approach to Management. WO-WSA-3. FS, Washington, DC.

(FS) USDA Forest Service. 1994. An Ecological Basis for Ecosystem Management. GTR RM-246. FS, Fort Collins, CO.

(FWS) U.S. Fish and Wildlife Service. 1994. An Ecosystem Approach to Fish and Wildlife Conservation: An Approach to More Effectively Conserve the Nation's Biodiversity. March. FWS, Washington, DC.

(FWS) U.S. Fish and Wildlife Service. 1995. An Ecosystem Approach to Fish and Wildlife Conservation: Concept Document. February. FWS, Washington, DC.

(GAO) U.S. General Accounting Office. 1994. Ecosystem Management: Additional Actions Needed to Adequately Test a Promising Approach. GAO/RCED-94-111, GAO, Washington, DC.

Gore, A. 1993. Reinventing Environmental Management. Accompanying report of the National Performance Review. September. U.S. Government Printing Office, Washington, DC.

Grumbine, R.E. 1994a. What is Ecosystem Management? *Conservation Biology* 8: 27-38.

Grumbine, R.E. (ed.). 1994b. *Environmental Policy and Biodiversity.* Island Press, Washington, DC.

Keystone Center. 1995. Keystone National Policy Dialogue on Ecosystem Management. February 22-24. The Keystone Center, Keystone, CO.

Knight, R.L. and S.F. Bates (eds.). 1995. *A New Century for Natural Resources Management.* Island Press, Washington, DC.

Malone, C.R. (1995). The Federal Initiative on Ecosystem Management. *NAEP News* 20: in press.

Pearman, D.W., Jr. 1994. Land and Facility Use Management Policy and Requirements. August 26. U.S. Department of Energy, Washington, DC.

Savory, A. 1988. *Holistic Resource Management.* Island Press, Washington, DC.

Slocombe, D.S. 1993a. Environmental Planning, Ecosystem Science, and Ecosystem Approaches for Integrating Environment and Development. *Environmental Management.* 17: 289-303.

Slocombe, D.S. 1993b. Implementing Ecosystem-Based Management. *BioScience* 43: 612-622.

U.S. Senate. 1994a. Ecosystem Management: Status and Potential. Senate Print 103-98, December. U.S. Government Printing Office, Washington, DC.

U.S. Senate. 1994b. The Ecosystem Management Act of 1994. S. 2189. U.S. Senate, Washington, DC.

Walker, J.B. 1995. Letter to J. Glickman, U.S. Department of Energy. March 7. Nuclear Waste Project Office, Carson City, NV.

# ATTACHMENT A

# ATTACHMENT I

## ATTACHMENTS

V. Transportation of Spent Nuclear Fuel and HLW: A Systematic Basis for Planning at National, Regional, and Community Levels

W. Current Capabilities Shipments Scenario By Reactor

X. Map - DOE Truck Routes

Y. Map - DOE Rail Routes

Z. State of Nevada Comments on NRC's Reassessment of Spent Nuclear Fuel Transportation Risks/Modal Study Update

AA. RADTRAN and RISKIND Calculations

BB. RADTRAN IV Economic Analysis

CC. Summary Comments - Severe Accidents and Terrorism/Sabotage

# Integrated Weapons-Site Cleanup

*The Department of Energy is using ecosystem management to help clean up our nation's nuclear weapons sites.*

BY CHARLES R. MALONE

In 1951, the Atomic Energy Commission, forerunner to the present-day U.S. Department of Energy, was looking for a place to test its newly developing arsenal of nuclear weapons. It selected a remote tract of the Mojave Desert in southern Nevada, 50 miles (80 kilometers) northwest of Las Vegas. For the next four decades, the Nevada Test Site would serve as the nation's nuclear testing ground.

The Nevada Test Site covers 1,350 square miles (3,500 square kilometers), which is roughly the size of the state of Rhode Island. Until 1962, when aboveground testing was banned, the Atomic Energy Commission conducted about 100 aboveground nuclear tests on the site. During the next three decades, until nuclear testing was banned altogether in 1994, more than 800 underground tests were conducted on the site. Today, the site is largely used for disposing of low-level DOE wastes. The Yucca Mountain site, which is being studied as a possible respository for high-level nuclear wastes from nuclear weapons and nuclear reactors throughout the United States, straddles the test site's western perimeter.

The Nevada Test Site is one of 140 sites in DOE's nuclear weapons complex—which includes such familiar names as Savannah River, Oak Ridge, Hanford, and Idaho Falls—that are remnants of the Cold War legacy. Now that the Cold War is over, DOE has begun cleaning up the Nevada Test Site.

The Nevada Test Site contains more contaminated surface rock, soil, and groundwater than any other site in the DOE weapons complex. The amount of radioactivity in the environment from weapons testing is estimated at 300 million curies, spread over about 300 square miles (800 square kilometers). DOE's goal is to remove enough of the contamination from the soil and groundwater to make the environment safe for future use. Cleanup began in 1997 and will extend to 2007, at a cost of $1.3 billion.[1]

Future uses being considered include developing the site for producing clean-burning fuels, decontaminating low-level nuclear wastes, or training emergency workers who deal with highly destructive weapons.

### Ecosystem Management

As part of the restoration of the Nevada Test Site, DOE developed a resource management plan to ensure the long-term sustainability of the site.[2] The main goals of the plan are to

- Manage and sustain natural resources.
- Maintain native ecosystems, biota, and habitats.
- Protect undisturbed areas.
- Develop baseline environmental information needed for cleanup, land use planning, and ecosystem management.
- Site new facilities only on environmentally suitable, previously disturbed lands.
- Foster sustainable economic development.

Traditional resource management focuses on managing a single resource such as water, livestock, or timber. Wildlife management and operating reservoirs for navigation and flood control are traditional resource management approaches.

Ecosystem management, which is at the heart of DOE's resource management plan, focuses instead on managing the ecosystem as a whole, including its fauna, flora, soils, groundwater, and air. Ecosystem management recognizes that humans are a fundamental component of ecosystems; it appreciates the importance of the diversity and complexity of ecosystems; and it strives to maintain the processes that tie the physical, chemical, and biological components of the ecosystem together.[3]

As a resource tool, ecosystem management has been applied successfully in a variety of other settings.[4] In the Pacific Northwest, for example, where logging has abused forests and streams for decades, ecosystem management is being used to identify sensitive areas that should be restored, areas where logging should be banned, and areas where logging can occur, provided it balances environmental and economic objectives.

Similarly, ecosystem management has been successfully applied to livestock grazing in arid lands to help restore abused sensitive habitats and to avoid further damage.

An analogy may help to further clarify the difference between traditional resource management and ecosystem management. Think of traditional resource management as like trying to fix an automobile carburetor without even turning on the engine. Ecosystem management, on the other hand, is like making fine-tuning corrections while the engine is running. A good mechanic will listen to the engine, adjust the carburetor, and make any other changes necessary—such as replacing spark plugs—to make the engine run smoothly and quietly.

An ecosystem manager, like our good mechanic, has a holistic perspective. Rather than just looking after the trees or the wildlife or water quality, the ecosystem manager considers each of these, along with other components, as part of a greater whole; and he or she manages the whole to ensure it is operating smoothly and efficiently.

### Implementing the Model

DOE has begun inventorying natural resources at the Nevada Test Site, and it is protecting critical areas such as habitat for endangered species. Natural springs and seeps, for instance, play an especially important role in desert ecosystems and are therefore being restored to as near natural conditions as practical.

DOE is also removing soil from contaminated land and is reclaiming these disturbed sites for eventual reuse. By restoring contaminated lands and using them for further development, DOE can avoid development on ecologically valuable, undisturbed lands, which have not been contaminated.

The involvement of stakeholders—such as the state of Nevada, nearby communities, other federal land managers, and area landowners—has long been a missing element in planning for the Nevada Test Site. Applying the ecosystem management model helps correct this problem. Today, regional stakeholders are contributing to decisions about economic development and cultural, social, and long-term environmental trends that will shape the Nevada Test Site's future. While DOE is currently using ecosystem management only for the Nevada Test Site, the approach is also an appropriate tool for cleaning up other contaminated DOE lands. Ecosystem management can be used to assess environmental risks, set cleanup priorities, help determine the appropriate level of cleanup needed for various land uses, and evaluate alternative solutions for remediating contaminated land.

Some DOE managers will doubtless view ecosystem management as overly problematic, especially given the degree of intradepartmental, interagency, and stakeholder cooperation required to make ecosystem management succeed. Further complicating the application of ecosystem management is DOE's notoriously fragmented bureaucracy; coordination among its programs is contrary to prevailing, long-established DOE custom. Moreover, the attitude of openness to public and private stakeholders, which is integral for effective ecosystem management, is contrary to DOE's history of isolating itself from outsiders.

Even at the Nevada Test Site, these issues are not fully resolved. For example, the Timber Mountain Caldera National Natural Landmark on the Nevada Test Site remains off-limits to visitors even though a number of people have expressed interest in being allowed access to the area's unique geological features. Likewise, some mountainous areas on the site that support herds of desert bighorn sheep large enough for hunting are closed to the public despite efforts of the Nevada Division of Wildlife to have the areas opened for public use.

Nonetheless, progress toward incorporating outside recommendations into DOE decision making is occurring at the Nevada Test Site, and there are decided grounds for hope.

### Reversing Old Customs

Change often comes slowly and stubbornly within traditionally conservative organizations like DOE, and progress in using ecosystem management to reverse outdated customs cannot be taken for granted. Thanks to DOE's commitment and encouragement from other agencies, however, ecosystem management at the Nevada Test Site is becoming a reality, and the prospects for implementing it at other DOE sites are encouraging.

DOE's success joins a growing number of initiatives throughout the federal government that are employing an ecosystem approach for managing our nation's resources.[5] Collectively, these efforts can help sustain public lands for the benefit and enjoyment of generations to come.■

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**NOTES**

1. DOE, *Accelerating Cleanup: Focus on 2006*, DOE/EM-0327 (Washington, DC: DOE, 1997); DOE, *Environmental Restoration and Waste Management Site-Specific Plan: Fiscal Years 1994-1998* (Las Vegas: DOE Nevada Field Office, 1997).

2. DOE, "Framework for the Resource Management Plan," in *1996 Final Environmental Impact Statement for the Nevada Test site and Off-Site Locations in the State of Nevada*, NV DOE/EIS 0243 (Las Vegas: DOE Nevada Field Office, 1996).

3. D.S. Slocombe, "Environmental Planning, Ecosystem Science, and Ecosystem Approaches for Integrating Environment and Development," *Environmental Management* 17 (1993), pp. 289-303; R.E. Grumbine, "What Is Ecosystem Management?" *Conservation Biology* 8 (1994), pp. 27-38.

4. S.L. Yafee et al., *Ecosystem Management in the United States* (Washington, DC: Island Press, 1996).

5. Interagency Ecosystem Management Task Force, *The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies* (Washington, DC: White House Office of Environmental Policy, 1995-1996).

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# FORUM

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*Of Weapons and Wastes*

# CONTENTS







**ATTACHMENT J**

# The Southern Nevada Initiative: A Case of Federal Ecosystem Management in the United States

Charles R. Malone

The need for sustainable development in the U.S. is expressed in the concept and emerging practice of ecosystem management. Grumbine (1992, 1994) has documented the rise and application of ecosystem management from the 1930s to the early 1990s, and Malone (1998a) has described the federal policy that has developed since the mid-1980s. Current U.S. policy on ecosystem management arose from the White House Interagency Ecosystem Management Task Force (IEMTF 1995-1996). A Memorandum of Understanding executed by the White House and signed by all federal land management agencies (OEP 1995) established the policy of preserving ecosystem integrity while sustaining human economies and maintaining a base of natural resources for future generations of humans.

The extent of involvement of the U.S. land management agencies in ecosystem management is indicated by a recent examination of 105 ecosystem-based projects out of a total of 619 identified across the U.S. (Yaffee et al. 1996). Forty-five percent of the projects examined were initiated by federal agencies, 40% by state agencies, 6% by local agencies, and 24% by nongovernment organizations. Of the federal projects involved, 16 were administered by the U.S. Forest Service, 16 by the U.S. Fish and Wildlife Service (USFWS), six by the U.S. Bureau of Land Management (USBLM), and nine by the U.S. Environmental Protection Agency. Federal agencies, while initiating 45% of all the projects examined, were involved in 88% of the total number. Overall, 52% of the 105 projects surveyed resulted directly from federal policies and programs.

An emerging ecosystem-based management project in southern Nevada offers an opportunity to examine a case study of federal ecosystem management from its conception. All the lands involved are managed by federal agencies and occur within the natural boundaries of the southern Nevada hydrographic region (Figure. 1). Included are all or a major portion of three large federal reservations dedicated to single-purpose uses: the Nevada Test Site (NTS) managed by the U.S. Department of Energy (USDOE); the Nellis Air Force Range managed by the U.S. Air Force (USAF); and the Desert National Wildlife Range managed by the USFWS. A fourth federal agency, the USBLM, manages the remaining multiple-use public lands contiguous to the three reservations.

Increasing natural resources demands are being placed on all federal lands in southern Nevada as a result of rapid growth associated with the city of Las Vegas. For example, the USDOE is addressing future uses of the NTS for private ventures while down-sizing national defense missions at the site (Malone 1998b). Ecosystem management in the region presents the agencies involved with an

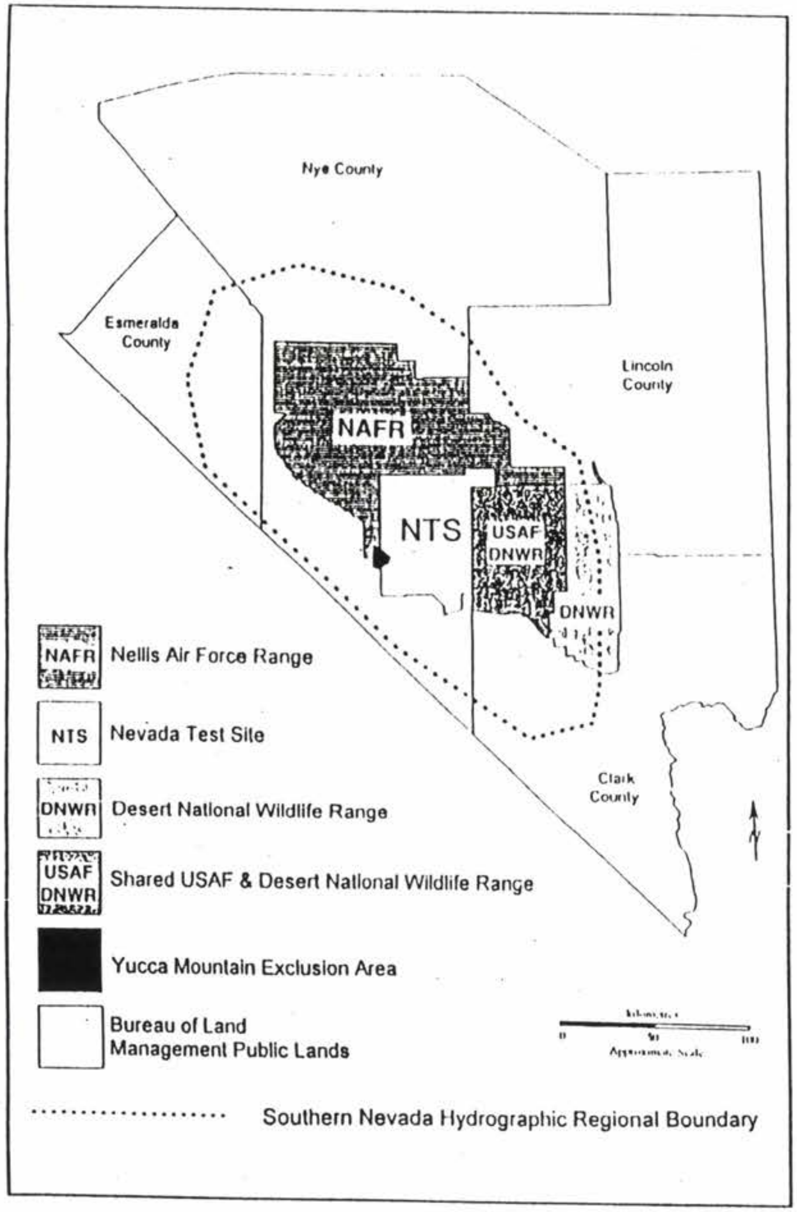


**Figure 1: Map showing the boundary of the southern Nevada hydrographic region and the federal administrative jurisdictions included. The region is being addressed by the Southern Nevada Ecosystem Management Initiative, except for the Yucca Mountain Exclusion Area that has been set aside for geologic disposal of U.S. high-level nuclear waste.**



opportunity to demonstrate land resource stewardship in an area long neglected in this respect. Thus, it is in the federal government's interest to promote the emerging initiative. The same is true for Nevada's state government. The present study was undertaken to encourage both levels of government in that respect.

Following is a discussion of the U.S. federal ecosystem management initiative as represented by concepts and theories as reflected principally by the IEMTF (1995-1996), Malone (1998a), The Keystone Center (TKC 1996), and Yaffee et al. (1996). Where these sources are insufficient, for example with respect to science, literature outside the federal initiative is used. The results are used to critique components of the southern Nevada initiative and to suggest how the initiative can be strenghened. An analytical framework is proposed for the southern Nevada initiative for supporting sustainable development through ecosystem management.

## The Federal Initiative and Evaluative Criteria

A standard definition of ecosystem management has not been accepted, but most general definitions, including the popular ones of the Ecological Society of America (ESA 1996), Grumbine (1994), Slocombe (1993), and Vogt, et al. (1997) are compatible. As this paper examines a case of federal ecosystem management in the context of U.S. policy, the definition is paraphrased from the IEMTF as:

> *Ecosystem management: (1) is a method for sustaining or restoring natural systems and their functions and values within a geographic framework defined by ecological boundaries; (2) integrates ecological, socioeconomic, and institutional factors; and (3) is driven by goals collaboratively developed by key stakeholders.*

The IEMTF (1995-1996) study is a good starting point for understanding the characteristics of federal policy on ecosystem management. Principal among the topics addressed were interagency coordination, establishing communication and partnerships among key stakeholders, developing a vision of desired conditions, and characterizing current ecosystem and socioeconomic conditions. The role of science in ecosystem management, particularly regarding the status of ecological theory, was not well developed by the IEMTF. Otherwise, the study provided a fundamental understanding of ecosystem management at the federal level.

Supplementing the IEMTF study is a survey by Yaffee et al. (1996) of ecosystem management projects in the U.S. The authors characterized the projects and noted factors that have contributed to the success of ecosystem management. Foremost among these was collaboration for building support among all stakeholders in the public, private, and government sectors. Also important were the availability of human resources, funding, and political support. These and other identified factors correspond to the principal concepts of ecosystem management established by the IEMTF, but like the IEMTF study, the survey did not emphasize science and theory.

Another supplementary study that provided general insight into ecosystem management in the U.S. was that of The Keystone Center (TKC 1996). The study involved the principal federal land management agencies and public and private stakeholder groups associated with the federal ecosystem management initiative. Like the IEMTF study and the survey conducted by Yaffee and colleagues, The Keystone Center activity emphasized the social aspects of ecosystem management rather than the scientific ones.

The scant mention of science in ecosystem management by The Keystone Center is consistent with the findings of an earlier review of the emerging federal initiative performed by the U.S. General Accounting Office (USGAO 1994). This is an issue here in that to develop evaluative criteria it was necessary to turn outside the federal initiative for insight into scientific and theoretical constructs for ecosystem management. This was done by using a report on ecosystem management by the Ecological Society of America (ESA 1996) and a detailed and comprehensive book on ecosystem management by Vogt et al. (1997).

The evaluative criteria selected for the southern Nevada case are presented in Table 1. Among them, the natural system and science have a role more in balance with the social system than may be apparent to some. This is because science underpins land ethics, defining the management unit, agreeing on desired ecosystem conditions, and using an interdisciplinary approach. From the broad perspective, it is clear that science must be kept at the forefront of consideration as initiatives are developed. Thus, interdisciplinary teams responsible for ecosystem management must include professionals with an understanding of science, management, social, and institutional issues (ESA 1996).

Fundamental explanations of the first five criteria in Table 1 are provided by IEMTF (1995-1996), The Keystone Center (TKC 1996), and Yaffee et al. (1996). These are the criteria reflecting the social elements of ecosystem management. Increasing attention by ecologists is being given to the non ecological aspects of ecosystem management (e.g., Gunderson et al. 1995, Loomis 1993, Yaffee 1994). Specific attention to the scientific roots of the concept, including issues such as biological diversity and bioregionality, ecosystem function, integrity, and dynamics, and uncertainty, have been discussed by the Ecological Society of America (ESA 1996) and by Vogt et al. (1997). These sources also touch on human aspects of ecosystem management and reflect the pervasiveness of ecological science in the interdisciplinary mix.

## The Southern Nevada Initiative

The Southern Nevada Ecosystem Management Initiative emerged in 1996-1997 and includes public lands in a region of the state conspicious for its growth and development. The lands involved are within the natural boundaries of the southern Nevada hydrographic region (Figure 1) and comprise 33,800 km², an area that constitutes 12% of the state. Within the region are two large national security facilities, the Nevada Test Site managed by the USDOE and the Nellis Air Force Range managed by the USAF. Together these two reservations comprise 45% of the land involved in the regional initiative. The remainder of the land is managed by the USFWS, and the USBLM, with the latter being responsible for 40% of the total area within the region.

Four federal actions comprise the origins and components of the southern Nevada initiative. The first was a 1996 environmental impact statement prepared by the USDOE for the Nevada Test Site (NTS). The USDOE also introduced a framework for resources management based on the ecosystem approach





**1. Renews Land and Environmental Ethics:**
- A. Recognizes the fundamental connection between human communities and the environment;
- B. Adopts a holistic approach to protecting ecosystem integrity that integrates environment and development;
- C. Sustains ecosystems, biodiversity, socioeconomics, and community goals;
- D. Includes humans as components of ecosystems and encourages responsible use of natural resources;
- E. Integrates ecological protection and restoration with human needs;
- F. Manages human needs and desires within the capacity of ecosystems to meet them;
- G. Minimizes and repairs impacts to the land and reconnects isolated parts of landscapes.

**2. Fosters Voluntary Partnerships and Cooperation Between Stakeholders:**
- A. Establishes partnerships with key stakeholders, including government, the public, nongovernment organizations, and private landowners;
- B. Enhances interagency and intergovernmental coordination;
- C. Involves public, private,and government stakeholders early;
- D. Improves public communication, public access to information, and public involvement in resource management decisions;
- E. Develops shared visions for sustaining human economies and the natural resources on which they depend;
- F. Develops a shared vision of desired ecosystem conditions among stakeholders;
- H. Builds widespread stakeholder participation, communication, collaboration, and cooperation;
- I. Assures that private land owners, communities, and agencies understand each other's concerns.

**3. Establishes Proper Roles and Arrangements for Institutions:**
- A. Inventories regional agencies and institutions and their procedures, definitions, and interactions;
- B. Explores possible reorganization and redefinition of institutions and processes to improve planning and management;
- C. Implements top down planning to change approaches to land management;
- D. Seeks adequate resources and support from government agencies and other stakeholder institutions.

*Continued . . .*

**Table 1. Criteria (precepts) and characteristics of ecosystem management that describe the U.S. federal initiative.**

*Continued . . .*

**4. Defines the Management Unit, Processes, and Goals:**
- A. Adopts a regional spatial scale to establish ecological boundaries that span jurisdictions;
- B. Determines kinds of information needed to define the unit;
- C. Recognizes the importance of historic land conditions and the trends in natural landscapes, i.e., the temporal scale;
- D. Sets realistic goals and develops consensus with stakeholders;
- E. Recognizes the role of environmental impact assessment in resources management;
- F. Establishes leadership and accountability for institutional streamlining, cooperation, coordination, and conflict resolution.

**5. Adopts An Interdisciplinary (Ecological, Socioeconomic, Institutional) Approach:**
- A. Enhances information gathering and data management capabilities such as geographic information systems;
- B. Develops a holistic and integrated understanding of the management unit;
- C. Includes multidisciplinary data collection and monitoring of present ecosystem conditions, behavior, and function;
- D. Explores methods for organizing, synthesizing, and communicating interrelationships of data collected;
- E. Uses the best science available and performs research to improve knowledge for adapting management practices;
- F. Monitors and evaluates actions to determine if goals and objectives are being achieved.

**6. Develops Sound Ecological Models and Understanding:**
- A. Strengthens the role of ecosystem science in resource management and considers humans as ecosystem components;
- B. Recognizes ecosystem complexity and connectedness, limits and stresses, dynamics, and uncertainty;
- C. Establishes baseline conditions for ecosystem functioning and sustainability against which change can be measured.
- D. Seeks to understand how the landscape works and determines landscape sensitivity to future land management;
- E. Recognizes temporal and spatial scales in ecosystem patterns and processes.

**Table 1 (Continued): Criteria (precepts) and characteristics of ecosystem management that describe the U.S. federal initiative.**



(USDOE 1996). The program was initiated a year later and the USDOE expects to have a first interation of the plan completed in late 1998.

Coincident with the NTS activity were two resources management actions taken by the USAF for the Nellis Air Force Range located on three sides of the NTS (Figure 1). These were an integrated natural resources management plan (INRMP) followed by a stakeholders dialogue on ecosystem management conducted by The Keystone Center, a nongovernmental organization. The INRMP (USAF 1997b) took a traditional, non-ecosystem approach while the dialogue (TKC 1998) emphasized conserving biological diversity through ecosystem management and resulted in a more expansive approach to natural resources management.

Both the USDOE resources plan and The Keystone Center dialogue adopted ecosystem management and embraced regional management as well. The USAF management plan did not. However, this plan recognized the necessity of interagency coordination among the federal land management agencies involved on the Nellis Air Force Range. Through interagency agreements, the USDOE, the USBLM, and the USFWS assist the USAF with resources management on the Nellis Range. With initiation of resources management at the NTS and the Nellis Range, the USDOE and the USAF recognized the need for a formal interagency management arrangement. Accordingly, in late 1997, a Five-Party Cooperative Agreement reflecting ecosystem-based resources management was reached (USAF 1997c). Although the agreement includes the NTS, the Nellis Range, and the USFWS wildlife refuge, it does not extend to adjacent USBLM lands to encompass all of the natural unit formed by the southern Nevada hydrographic region.

It is clear from the language of the cooperative agreement that the intent is to achieve ecosystem management in southern Nevada. However, the means for achieving ecosystem management are left open. Motivating the USDOE and the USAF regarding the federal ecosystem management policy is the need to retain federal lands for national security purposes. Included with the Nellis Range is a large portion of the USFWS's Desert National Wildlife Refuge that is shared with the USAF. Also within the region is the 280 $km^2$ site for the USDOE Yucca Mountain Project. The comparatively small site is environmentally significant because it is being considered for a geologic repository for disposing of high-level nuclear waste. Despite the potential for environmental contamination, the DOE has excluded the Yucca Mountain site from its ecosystem management program for the NTS. The ethical and scientific implications of the decision have been discussed by Malone (1995).

The goal for an ecosystem management initiative in the southern Nevada hydrographic region would be to manage public land resources in a manner that maintains federal missions and the public's interests in the environment. Management of public lands is a highly visible issue in the rapidly growing southern part of the state. The issues that need to be addressed are maintaining national security missions, conserving ecosystems, and balancing these issues with competing land uses. Ecosystem management is an appropriate approach in view of the region's limited resources for recreation, water supplies, and fragile natural resources that require careful management (Rundel and Gibson 1996).

## Evaluation of the Initiative

The four component actions of the emerging initiative were analyzed according to the six criteria in Table 1. Following that, a composite evaluation was made regarding the nature of the emerging initiative. The results of the evaluations are given in Table 2. Most conspicuous in the Table is lack of a sufficient conceptual perspective on science to support an analytical model that can pull the initiative together.

Among the components, The Keystone Center stakeholders dialogue for the Nellis Range (TKC 1998) excelled in the attention given to land and environmental ethics and placed its participants on a sound footing in that respect. Additionally, the dialogue offered cooperation and a broad perspective of views on ecosystem management for the Nellis Range because of the array of stakeholders involved. However, the involvement of a large number of non-scientists among the stakeholders in the dialogue resulted in a narrow perspective on science and interdisciplinary approaches to ecosystem management.

As for the USDOE's resources management program for the NTS, considerations of ethics and stakeholder involvement were marginal. The agency reached out to some stakeholders, principally units of government, on a selective and modest basis regarding resources issues and goals. However, collaboration and cooperation among non-governmental stakeholders on the USDOE's part have

| Criteria | RMP | INRMP | TKCD | 5-PCA | OVERALL |
|---|---|---|---|---|---|
| Ethics (1)* | + | - | ++ | - | + |
| Cooperation (2) | - | + | ++ | + | + |
| Institutions (3) | + | + | + | + | + |
| Management Unit and Process (4) | + | — | + | - | + |
| Interdisciplinary (5) | + | — | + | + | + |
| Science (6) | + | — | - | - | - |

Ranking: ++ satisfactory + marginal - weak — deficient

* The numbers in parentheses following each criterion denotes the precept number from Table 1 that is consistent with the criteria in this table.

**Table 2: Ranking of the four components of the Southern Nevada Ecosystem Management Initiative with respect to the evaluative criteria in Table 1. The components are: Resources Management Plan (RMP), Integrated Natural Resources Management Plan (INRMP), The Keystone Center Dialogue (TKCD), and the Five-Party Cooperative Agreement (FPCA).**



been restrained. In the context of a regional initiative, a strength of the USDOE resources management activity is that it was designed to follow through directly with implementation. As a consequence, the NTS management plan is being implemented as it is developed (Malone 1998b) and could be considered as an example to be followed throughout the southern Nevada hydrographic region.

The Nellis Range resources management program (USAF 1997a) commenced well after the USDOE action and is about two years behind the NTS ecosystem-based management program. The planning activity was found by The Keystone Center dialogue (TKC 1998) to be remedial with respect to the concept and principles of ecosystem management. Several factors contributed to the shortcoming, including a lack of understanding of ecosystem management by the USAF in Nevada as well as a lack of interest, management processes and commitment for such an effort. At Nellis, this is reflected in insufficient personnel, expertise, and budgetary resources for natural resources management. An example of the consequences of these weaknesses is that only 40% of the 11,800 km2 Nellis Range has been surveyed for threatened and endangered plants (USAF 1997a). This stands in contrast to the NTS and the national wildlife refuge for which natural resources surveys have been completed (TKC 1998).

A burden falls on the Five-Party Cooperative Agreement for implementing an ecosystem management initiative. Lacking at the outset was sufficient emphasis on land ethics, recognition of the need for bioregionality in ecosystem management, and a management process. The cooperative agreement includes only lands within the boundaries of the federal reservations involved and offers no framework for a management process, leadership, and recognition of the role of science in ecosystem management. As the initiating agency for the cooperative agreement, the USAF in Nevada will chair the arrangement for at least the first year. Judging from the Nellis resources management plan, there is scant basis for optimism regarding sound and timely results from the cooperative agreement.

As matters stand in mid-1998, the USDOE resources management process for the NTS provides the only incentive for using the Five-Party Cooperative Agreement. The USAF and other agencies participating in the Five-Party Cooperative Agreement have before them much of the basis for framing a regional ecosystem management initiative. With this in mind, a preliminary set of precepts complementing Table 1 is given in Table 3 for an ecosystem-based initiative in southern Nevada. These were developed from the nature of the southern Nevada hydrographic region and the four existing components for an initiative evaluated in Table 2.

The preliminary precepts aim to strengthen the initial evaluation of the emerging initiative by demonstrating how a broad set of criteria characteristic of ecosystem management, such as those in Table 1, can be applied in a specific bioregional context. If the component actions evaluated in Table 2 had benefited from an organized planning procedure such as is implied by the precepts in Table 3, the evaluation would have resulted in far fewer negative marks. Table 3 also indicates the point discussed previously regarding the pervasiveness of science throughout ecosystem management. Implications of interdisciplinary and scientific considerations are associated with most of the precepts, particularly with those involving a renewal of land and environmental ethics.

- Support and sustain existing federal defense missions by assuring the missions are managed to effectively and efficiently use the natural resources available. (1, 5, 6)
- Maintain existing federal facilities through proactive integrated resources management planning to accomodate future uses of a site. (1, 5, 6)
- Sustain regional native ecosystems, with emphasis on important biota and their habitats. (1, 6)
- Manage water resources for existing and future human uses while protecting native ecosystems in wet areas. (1, 5, 6)
- Coordinate, cooperate, and share scientific data across jurisdictional boundaries throughout the regional landscape. (2, 3, 6)
- Collaborate with key regional stakeholders to reconcile conflicts and to develop priorities and that acknowledge and consider national interests. (3, 4, 5, 6)
- Identify and manage resources at the appropriate spatial scale, such as the common regional landscape. (4, 6)
- Monitor progress, evaluate impacts, and adapt based on new information on the basis of benchmarks for monitoring and evaluating outcomes. (5, 6)
- Site new facilities to be on or near previously disturbed lands and in areas with suitable soil, slope, drainage, and other natural features. (1, 5, 6)

**Table 3: Proposed precepts for the Southern Nevada Ecosystem Management Initiative. The numbers in parentheses following each statement denotes the precept number from Table 1 that is consistent with the one in this table.**

## A Proposed Scientific Framework

To progress further, the emerging Southern Nevada Ecosystem Management Initiative needs to develop a framework for implementing ecosystem management. Existing weaknesses in the initiative could be strengthened if a strong methodology were adopted for continued planning of the initiative. Hornbeck and Swank (1992) advocate watershed analysis as a basis for recommending land uses consistent with holistic ecosystem management. Among the advantages obtained through watershed ecosystem analysis is that knowledge and information are made available to a wide audience including the scientific community, government institutions, and public and private interest groups. This feature of



a management strategy is consistent with the need for stakeholder involvement in ecosystem management.

A framework for implementing ecosystem management based on watershed and landscape analysis has been put forth by Montgomery et al. (1995). Evolving from recent experiences in the U.S. Pacific Northwest, the strategy is consistent with the views of Hornbeck and Swank (1992) as well as with the criteria and characteristics of ecosystem science discussed above. The approach couples management objectives to landscape capabilities by combining knowledge of the physical environment with information on the biotic component. Land management decisions thus can be made that consider the balances between using public lands for national security, economic development and recreation, and sustaining ecosystems and natural resources.

A representation of the landscape approach to ecosystem management for southern Nevada is shown in Table 4. The framework represented, adapted from Montgomery et al. (1995), reflects matters of geophysical structure, ecosystem function, disturbance history, and current and potential future land conditions. Types of information needed about ecological characteristics and conditions is reflected in the Table's two column listing of critical issues and the scope of inquiry into them. The issues identified in the analytical framework can be addressed by alternative management and land uses pursued by the appropriate methodologies. As explained by Hornbeck and Swank (1992) and by Montgomery et al. (1995), such an approach allows input of socioeconomic considerations for balancing natural resource objectives in pursuing sustainable development through ecosystem management.

An early step toward a landscape approach would be for the federal agencies in southern Nevada jointly to use compatible methods and to synthesize existing environmental information available regarding the southern Nevada hydrographic region. Some useful studies of ecosystems and watershed structure have been conducted for the NTS and the Yucca Mountain site (USDOE 1996). Each agency involved has its own information regarding conditions within its jurisdiction, but developing a synthesis of the data has not been attempted. Were this to be done early in the emerging ecosystem-based initiative, the resource managers involved could determine if a satisfactory information base exists that is representative of the southern Nevada hydrographic region. If needed, supplementary baseline studies could be initiated, for example, on the Nellis Range, the national wildlife refuge, and adjacent public lands. In this manner, the need for studies of ecosystem function among different biotic patterns within the region would emerge. As matters stand, the functional differences among the Great Basin, the Mohave Desert, and the ecotone between the two provinces are poorly understood (Rundel and Gibson 1996).

Once landform and ecological functions are better known, an understanding would emerge about the sensitivity of landscape processes to environmental changes and disturbances. Following the analytical framework of Montgomery et al. (1996), models based on information about watershed characteristics and conditions would allow functional linkages across the regional landscape to be established. In this manner, the lands managed by the different federal agencies could be integrated into the context of regional ecosystem management. Desired landscape conditions then could be identified and management techniques could be adopted for achieving the conditions throughout the region.

It should be noted that a framework consistent with Table 4 and landscape analysis is implied by the resources management plan for the NTS (USDOE 1996, Malone 1998b). This can be seen by comparing Table 4 with the column in Table 2 that evaluates the USDOE plan. Frameworks similar to that in Table 4 or to the management plan for the NTS could be adopted by other land managers in the southern Nevada hydrographic region. This would support establishing regional ecosystem-based models that would help select management techniques suited to achieving desired landscape conditions. Identifying desired conditions and designating management practices through stakeholder

| CRITICAL ISSUES | SCOPE OF INQUIRY |
|---|---|
| **Understand landscape structure and function**<br>• hydrology and geohydrology<br>• soils<br>• carrying capacities | **Use ecological heirarchy and ecosystem analysis techniques**<br>• ecosystems<br>• watersheds<br>• landscapes |
| **Discern historical conditions and uses**<br>• native ecosystems<br>• ecotones and edges<br>• disturbances and contaminants | **Collect data to perceive past history**<br>• existing sources<br>• additional needs<br>• special species |
| **Establish existing conditions**<br>• wet areas-<br>• ecotones and edges<br>• disturbances and contamination | **Study current landscape as a result of past legacies**<br>• habitats and biota<br>• roadless areas<br>• ecosystem surveys |
| **Determine alternative land uses**<br>• national security<br>• commercial development<br>• recreation<br>• biodiversity refuges | **Scenario generation and analysis**<br>• short, mid-, and long term<br>• restoration of ecosystems and springs |
| **Ascertain resources/management needs for sustaining natural resources and economies**<br>• professional expertise<br>• management and accountability<br>• interagency cooperation<br>• stakeholder involvement | **Design strategies for achieving desired landscape and human conditions**<br>• resource management plan<br>• goals<br>• implementation plan<br>• peer review and public participation |

**Table 4. Preliminary analytical framework of critical issues and the scope of inquiry for regional ecosystem management. Beneath each horizontal block examples are listed that are specific to the southern Nevada hydrographic region.**



involvement could occur under the Five-Party Cooperative Agreement. The capabililities for developing ecological models rests with the federal agencies, as does resolution of the issues of leadership and commitment to ecosystem management.

## Conclusions

The emergence of ecosystem management in southern Nevada presents the federal government with an opportunity to demonstrate land resource stewardship in a region long neglected in this respect. A regional initiative in that regard would be timely because of increasing contention over public land use from development and recreational interests in the Las Vegas area. The USDOE currently is applying the ecosystem approach to pursue alternative land uses of the NTS for private economic ventures. Also, the USAF is considering ecosystem management to sustain its mission at the Nellis Range. It is in the federal government's broader interests to promote and strengthen the ecosystem management initiative that is emerging in southern Nevada. Similarly, Nevada's state government has a stake in the success of the emerging Southern Nevada Ecosystem Management Initiative. However, the state has neither the institutional means nor a policy on ecosystem management to lend assistance. This could be remedied if the state government were to adopt a policy endorsing the federal ecosystem management initiative. Such a policy would be justified by the fact that 85% of Nevada is owned by the federal government.

Among the existing components for moving toward a mature ecosystem management initiative in the southern Nevada hydrographic region are many of the fundamental elements for pursuing sustainability. Some elements, however, are undeveloped or missing. Most apparent in this regard are expertise, leadership, and commitment on a regional scale. This especially is of concern with respect to the Five-Party Cooperative Agreement through which cooperation among the relevant government agencies must occur. The newly established agreement is the means by which the Southern Nevada Ecosystem Management Initiative should continue to develop. A solid foundation for the compact is essential for establishing the cooperation needed among involved government parties. It will fall to the participants in the agreement — with stakeholder collaboration and influence — to establish a regional analytical framework for implementing an ecosystem-based approach that integrates science, management, socioeconomics, and institutions.

Concern remains about the DOE's Yucca Mountain Project which views the ecosystem-based process as being overly complicated and problematic. Additionally, threats are perceived in the openness embodied in the concepts of achieving sustainable development through ecosystem management. Reversing outdated customs of secrecy and technocracy through ecosystem management is a matter of environmental ethics and institutional trust that cannot be taken for granted. Additional concerns exist, such as achieving federal interagency cooperation as intended by the Five-Party Cooperative Agreement. Likewise, effective communication between federal agencies and the public is needed to create public trust and form parternships vital to the success of all ecosystem management initiatives.

Society increasingly values public lands not merely for economic commodities but for the various services provided by natural ecosystems. Likewise, federal land management agencies are viewed by the public as facilitators of cooperative efforts to achieve sustainable development through ecosystem management. And, the policies being implemented by federal agencies should be responsive to growing debates over the use and management of public natural resources. If the obstacles to achieving sustainable development through ecosystem management are overcome, the Southern Nevada Ecosystem Management Initiative can join a growing number of successes in the U.S. To succeed, long-term commitments to the initiative must be made by all involved parties and land managers in the region.

Public and private stakeholders in southern Nevada are encouraged by the resources management opportunity presented by the recent cooperative agreement. However, much remains to be achieved by the government institutions responsible for ecosystem management in southern Nevada. Recourse to political processes remains an alternative course to be followed by public and private interests. The state government should be an instrument that stakeholders could turn to in this respect. A potential role for the state exists by virtue of the federal policy on ecosystem management established by the White House in 1995-1996. Similar executive action by the state would facilitate the opportunity presented for collaboration among all stakeholders in southern Nevada. A state policy supporting the federal ecosystem management initiative would be justified on the basis that 85% of the lands in Nevada are owned and managed by the federal government.

## References


ESA (Ecological Society of America). 1996. "The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management." *Ecological Applications.* 6(3): 665-691.

Grumbine, R.E. 1992. *Ghost Bears: Exploring the Biodiversity Crisis.* Washington, DC: Island Press.

________. 1994. "What Is Ecosystem Management?" *Conservation Biology.* 8(1): 27-38.

Gunderson, L.H., C.S. Holling, and S.S. Light, eds. 1995. *Barriers and Bridges to the Renewal of Ecosystems and Institutions.* New York, NY: Columbia University Press.

Hornbeck, J. W. and W. T. Swank. 1992. Watershed ecosystem analysis as a basis for multiple-use management of eastern forests. *Ecological Applications.* 2(3): 238-247.

IEMTF (Interagency Ecosystem Management Task Force). *The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies in 1995-1996.* Vols. I, II, III. The White House Office of Environmental Policy, Washington, DC.

Knight, R.L. and S.F. Bates, eds. 1995. *A New Century for Natural Resources Management.* Washington, DC: Island Press.

Loomis, J.B. 1993. *Integrated Public Lands Management: Principles and Applications to National Forests, Parks, Wildlife Refuges, and BLM Lands.* New York, NY: Columbia University Press.

Malone, C.R. 1995. "Ecology, Ethics, and Professional Practice: The Yucca Mountain, Nevada, Project as a Case Study." *The Environmental Professional.* 17(3): 271-284.





Malone, C.R. 1998a. "The Federal Ecosystem Management Initiative in the U.S." In *Environmental Sustainability: Case Studies on the Prospects of Science and Ethics.* J. Lemons, R. Goodland, and L. Westra, eds. Dordreche, The Netherlands: Kluwer Academic Publishers, 203-217.

Malone, C.R. 1998b. "Implications of Resources Management at the Nevada Test Site." *Federal Facilities Environmental Journal.* 9(1): 51-62.

Montgomery, D.R., G.E. Grant and K. Sullivan. 1995. "Watershed Analysis as a Framework for Implementing Ecosystem Management." *Water Resources Bulletin.* 31(3): 369-386.

OEP (Office of Environmental Policy). 1996. Memorandum of Understanding to Foster the Ecosystem Approach. White House, Washington, DC.

Rundel, P.W. and P. Gibson. 1996. *Ecological Communities and Processes in a Mojave Desert Ecosystem: Rock Valley, Nevada.* Cambridge, England: Cambridge University Press.

Sampson, F.B. and F.L. Knopf. 1996. "Putting 'Ecosystem' Into Natural Resources Management." *Journal of Soil and Water Conservation.* 51(4): 288-292.

Slocombe, D.S. 1993. "Implementing Ecosystem-Based Management." *BioScience.* 43(9): 612-622.

TKC (The Keystone Center). 1996. *Keystone National Policy Dialogue on Ecosystem Management: Implementing Community-Based Approaches.* Keystone, CO: The Keystone Center.

________. 1998. *Final Report of the Keystone Dialogue on Nellis Air Force Range Stewardship.* Keystone, CO: The Keystone Center.

USAF (U.S. Air Force). 1997a. *Integrated Natural Resources Management.* AFI 32-7064. USAF, Washington, DC.

________. 1997b. *Integrated Natural Resources Management Plan - Nellis Air Force Base/Nellis Air Force Range.* Nellis Air Force Base, NV.

________. 1997c. *Five-Party Cooperative Agreement.* USAF, Nellis Air Force Base, Las Vegas, NV.

USBLM (U.S. Bureau of Land Management). 1994. *Ecosystem Management in the BLM: From Concept to Commitment.* USBLM, Washington, DC.

USDOE (U.S. Department of Energy). 1996. *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada: Volume 2. Framework for the Resource Management Plan.* DOE/EIS 0243. US DOE, Las Vegas, NV.

USFWS (U.S. Fish and Wildlife Service). 1994. *An Ecosystem Approach to Fish and Wildlife Conservation and The Role of Refuges in an Ecosystem Approach.* USFWS, Washington, DC.

USGAO (U.S. General Accounting Office). 1994. *Ecosystem Management: Additional Actions Needed to Adequately Test a Promising Approach.* USGAO, Washington, DC.

Yaffee, S.L., A. Phillips, I. Frentz, P. Hardy, S. Malekl, and B. Thorpe. 1996. *Ecosystem Management in the United States.* Washington, DC: Island Press.

Vogt, K.A., J.C. Gordon, J.P. Wargo, and D.J. Vogt. 1997. *Ecosystems: Balancing Science and Management.* New York, NY: Springer-Verlag New York, Inc.

# ATTACHMENT K

# Implications of Resources Management at the Nevada Test Site

*Charles R. Malone*

*The U.S. Department of Energy's Nevada Test Site (NTS) is taking steps to implement the department's policy on long-term stewardship of land and facilities. They are following an approach consisting of comprehensive resources management based on the federal ecosystem management initiative. Results of the program will be applied to planning new facilities and future land uses at the NTS. One important aspect will be the NTS Environmental Restoration Program, a critical factor in future uses of the site. Information acquired through resources management planning can be used at the NTS for evaluating environmental risks, deciding cleanup priorities and alternative remedial strategies, and for future land use planning. The NTS land and facilities resources management program might serve as a model for other DOE sites.*

The U.S. Department of Energy (DOE) has embarked on a creative program of environmental stewardship at the Nevada Test Site (NTS). Sustaining both DOE missions and natural resources through comprehensive, integrated resources management is both the framework and the goal of the program.[1] This objective responds to DOE Policy 430.1 concerning land and facility use planning. Adopted in 1996, the policy aims at achieving sustainable development through ecosystem management. Activities at the NTS that will benefit from this initiative are the Environment Registration (ER) Program and the National Environmental Policy Act (NEPA) process. With both the ER Program and NEPA, the resources management program will significantly enhance human and ecological health risk assessments. These are crucial elements of setting cleanup priorities, evaluating alternative cleanup solutions, siting new facilities, and planning for long-term uses of the NTS.

The ecosystem-based approach to resources management at the NTS is consistent with what would be needed for a DOE-wide effort toward a comprehensive method for environmental protection and resources

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management at DOE nuclear weapons complex sites. The essential administrative components for such an approach to environmental management, including DOE Policy 430.1, already exist within the DOE's national resources stewardship program.[2] The stewardship program, announced in late 1994, addresses DOE land and facilities. By mid-1997, the stewardship policy and a corresponding implementing order (DOE Order 430.1) were in place. Both directives concern achieving sustainable development through ecosystem management. For example, DOE Policy 430.1 states:

> It is the Department of Energy's policy to manage its land and facilities as valuable national resources. Our stewardship will be based on the principles of ecosystem management and sustainable development. We will integrate mission, economic, ecological, social, and cultural factors in a comprehensive plan for each site that will guide land and facility decisions. Each comprehensive plan will consider the site's larger regional context and be developed with stakeholder participation. This policy will result in land and facility uses that support the Department's critical missions, stimulate the economy, and protect the environment.

***A novel aspect of the policy includes developing goals and objectives jointly between the DOE and its stakeholders.***

The DOE framed its creative environmental stewardship policy in the context of managing site life-cycles as a way to sustain site development, future uses, and associated natural resources.[3] A novel aspect of the policy includes developing goals and objectives jointly between the DOE and its stakeholders. Equally novel is that the comprehensive land and facility use plans to be developed for each DOE site will consider the site's larger regional context. These enlightened principles for managing DOE's resources, natural and man-made, stem from the ecosystem management concept that arose from the White House's 1993 National Performance Review.[4] In the DOE, implementing the reformative resource principles in the context of life-cycle asset management will occur through DOE Order 430.1, which calls for the comprehensive land-use planning process mentioned in DOE Policy 430.1.

The idea that the DOE's innovative land and facility stewardship process would affect the DOE ER Program was presented in a booklet that accompanied the Secretary of Energy's announcement of the resources stewardship policy in 1994 (see note 2). Entitled *Department of Energy—Stewards of a National Resource*, the publication included a section that addressed the DOE ER and Waste Management Programs in the context of determining human health risks and setting remediation goals for long-term land use decisions. The cleanup program is vital to comprehensive land use planning for future uses of all DOE sites.

Future reuse of lands and facilities managed by the DOE will involve stakeholder participation, a defining principle of ecosystem management. This aspect of the applied ecological approach is new to the DOE, but the DOE recognizes its importance. Ecosystem management should not be dismissed as an esoteric idea before considering the concept's defining principles (**Exhibit 1**). The concept is more about people than it is about traditional ecology.[5] True, ecosystem management is grounded in recent developments of applied ecology, but it grew from lessons learned the hard way concerning improper management of natural resource commodities and collapsing human economies. An often intimidating feature of the concept for federal land management agencies is its keystone principles of openness and of involving diverse stakeholders in cooperative and coordinated environmental decisionmaking. Those principles alone explain why ecosystem management rapidly evolved into the foundation for pursuing sustainable development.

**Exhibit 1. Defining Principles of Ecosystem Management as a Means for Achieving Sustainable Development**

- Includes humans as part of ecosystems and assumes that humans must depend on and be responsible for sustaining natural resources and human economies.
- Requires partnerships and cooperation between federal, state, and local governments with respect to managing public lands in a sustainable manner.
- Involves open, joint decisionmaking that includes affected stakeholders and interests.
- Uses an interdisciplinary approach that integrates the socioeconomic and ecological goals of regional stakeholders.
- Bases management on ecological regions as opposed to jurisdictional boundaries.
- Recognizes the limits of current ecological knowledge and involves adaptive management policies and practices as information becomes available.

## ECOSYSTEM MANAGEMENT AND THE NEVADA TEST SITE

An integrated approach to cleaning up ER sites at the NTS is a timely idea in view of the enlightened federal policy regarding "a proactive approach to ensuring a sustainable economy and a sustainable environment through ecosystem management." The preceding quote defines the postmodern approach to comprehensive environmental protection and resources management and is from a report by Vice President Al Gore that accompanied the White House National Performance Review.[6] From this followed creation of the Interagency Ecosystem Management Task Force (IEMTF) and its June 1995 overview report on using the ecosystem approach to achieve healthy ecosystems and sustainable economies.[7] Subsequently, the White House produced a memorandum of understanding (MOU) to foster ecosystem management, which was signed by all federal land management departments and agencies.

Following the MOU, the federal departments and agencies that had not already done so took steps to initiate the new approach to environmental management. The DOE anticipated the White House policy by announcing its revised land and facility resource policy in late 1994. The DOE Nevada Operations Office saw the useful application of the new management strategy to the NTS ER Program and took steps to relate cleanup activities to the forthcoming directives on land and facilities management during a site-wide Environmental Impact Statement (EIS) process initiated in 1994. To accommodate the DOE land and facilities use policy at the NTS, the Nevada Operations Office developed a comprehensive Resources Management Plan (RMP) for the site (see note 1). In this context, "resources" includes both land and DOE facilities.

During the NTS EIS process, the DOE and interested stakeholders interacted regarding managing land and facilities. This led to a framework for the resources management process based on ecosystem management. The final EIS included the framework as Volume Two. Stakeholders considered the framework document to be sound with respect to the Secretary of Energy's December 1994 policy statement on stewardship of DOE's land and facility resources. The "comprehensive plan for each site" mentioned in the Secretary's statement is the plan mandated by DOE Order 430.1 on Life Cycle Asset Management that is required of each DOE site, which was the goal for the NTS RMP. The goal was stated in the RMP framework document as follows:

> The goal of the Resource Management Plan is to establish a process for managing resources to ensure long-term diversity and productivity of affected ecosystems and sustainable use of land and facilities on the NTS. The process will be based on the principles of ecosystem management and be developed with the participation of surrounding land managers and other interested parties. The DOE/NV will use this process to assess the impact of existing facilities and activities, and evaluate the selection, design, location, and impact of proposed facilities and activities. The plan will identify the criteria for evaluating the compatibility of these activities with human health and safety, ongoing missions, existing infrastructure, cultural and natural resources, public values, and other resource issues and constraints.

*When DOE mission requirements at the NTS and the goals for resources conflict, NEPA will evaluate proposed resolutions.*

**Exhibit 2** illustrates the qualitative goals for managing resources at the NTS as identified in the RMP framework document. As the process develops, the goals will take on more definitive, quantitative characteristics that can be used to identify limits on resource uses and conflicts between alternative uses of the NTS resources. The goals are meant to be used to evaluate DOE activities' effects on resource issues and to identify management actions needed for wise resource use and sound ecosystem management.

When DOE mission requirements at the NTS and the goals for resources conflict, NEPA will evaluate proposed resolutions. In such

**Exhibit 2. Goals for Resource Management at the Nevada Test Site That Are To Be Pursued Through the Resource Management Plan, DOE Policy 430.1, and DOE Order 430.1**

- Ensure the sustainability of DOE missions, land resources, and existing facilities by managing them in a way that most effectively uses and protects them.
- Accommodate expanded uses of the NTS through proactive planning based on sustainable development.
- Maintain adequate water supplies on the NTS while ensuring long-term sustainability of DOE missions and surrounding ecosystems.
- Site new facilities to minimize human health risks, to take advantage of existing facilities, and to enhance future uses of the site.
- Site new facilities to comply with legal controls on land use, to protect undisturbed ecological areas, and to be in areas with suitable natural features such as soils, slope, and drainage.
- Sustain ecosystems and assets, including existing capital, native biota, uncontaminated water, and cultural resources.
- Achieve these goals in a manner that considers and stimulates local and regional socioeconomic values.

cases, solutions may include canceling a proposed mission, modifying a proposed mission to reduce impacts on a resource, modifying existing missions, or not achieving a goal. Stakeholders would have a voice in the resolution procedures through the informal RMP process, as well as through the mandated NEPA process. Decisionmakers thus would have stakeholder comments and project costs and benefits to consider in resolving a conflict.

A careful analysis of DOE's land and facility use policy and the purpose of the NTS RMP reveals that changes can be expected regarding how the DOE Nevada Operations Office manages the environment and the environmental impact assessment process. This is especially true with respect to public and stakeholder participation in DOE programs at the NTS. The changes will evolve as the NTS RMP process develops. That this will occur is evident from the NTS RMP Project Execution Plan (U.S. DOE 1997b) (see note 1). Presented in the plan is the project work schedule through FY99 with a total budget of $1.8 million. The plan also includes significant details on the work breakdown structure and the schedule (**Exhibit 3**) for accomplishing the RMP.

In accomplishing its goal, the NTS RMP will include baseline conditions for ecosystems as well as for the DOE facilities at the NTS. The ecosystems are not well understood at the NTS because attention has focused principally on regulated components of ecosystems, such as

**Exhibit 3. Schedule for the Resource Management Plan Process for the Nevada Test Site as of Fall 1997**

| | |
|---|---|
| SUMMER 1997— | Briefings to key stakeholders to acquaint them with the NTS RMP process. |
| FALL 1997— | Resource workshops with stakeholders to identify resource issues and goals. |
| EARLY 1998— | Identification of resource limitations to achieving sustainable development. |
| EARLY 1998— | Identification of available resource information and the tools needed to acquire needed information. |
| MID-LATE 1998— | Monitoring resource use and determining the changing status of resources. |
| MID-1998— | Assessment of cumulative impacts associated with ecosystem-based resource management. |
| LATE 1998— | Updating and publishing the first iteration of the RMP. |
| OUTLYING YEARS— | Reiterations of the RMP based on additional knowledge of ecosystems and on updated information on NTS facilities. |

threatened and endangered species. Compensating for the deficit of information on baseline ecosystem conditions cannot be accomplished in just a few years. Thus, the first iteration of the NTS RMP will utilize what information is available, identify additional information needs, and contain plans for establishing comprehensive baseline conditions. Much of this task will be accomplished through a long-term ecosystem monitoring program that is part of the ecosystem management process.

Because of insufficient information on baseline ecosystem conditions at the time the NTS site-wide EIS was prepared, the DOE was unable to apply ecosystem management for that process. The DOE Nevada Operations Office made an informal agreement with stakeholders, including the State of Nevada, to proceed with the traditional DOE approach to the EIS process for the NTS in exchange for a commitment to prepare an RMP once the EIS was completed. This working arrangement between the two sides of the issue is proceeding to the advantage of both. For example, the DOE has a final EIS which can be amended for new facilities at the NTS while the RMP is being developed. Stakeholders are assured that the DOE in Nevada will pursue ecosystem management for the NTS, as well as for the region. The regional context will be achieved through cooperative agreements with other government agencies, including those of the State of Nevada. The decisionmaking process also will be open to other stakeholders as provided for by the principles of ecosystem management.

## REGIONAL IMPLICATIONS AND OTHER OPPORTUNITIES

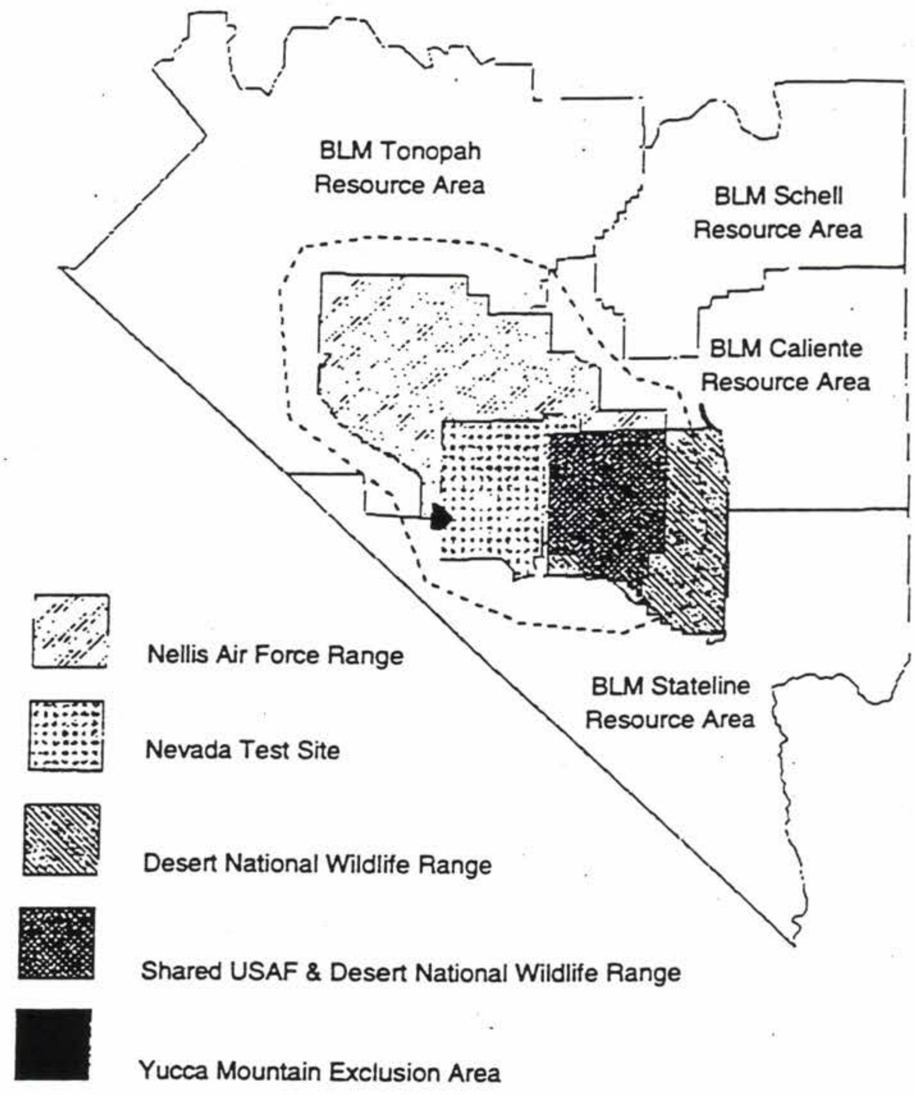
At this point it is a good idea to consider some of the implications and opportunities associated with ecosystem-based resources management planning at the NTS. Recall that one of the novel aspects of the DOE land and facility use policy was that resources management at DOE sites is to address not only the site itself but also to consider the site's importance on a regional basis. **Exhibit 4** shows the region in southern Nevada shared by the DOE with the U.S. Department of Defense (the Air Force) and the U.S. Department of the Interior's Bureau of Land Management (BLM) and Fish and Wildlife Service (FWS). The Air Force, the BLM, and the FWS have policies and directives regarding ecosystem management. Especially noteworthy in this regard is the Nellis Air Force Range, which is located on three sides of the NTS.

*One of the novel aspects of the DOE land and facility use policy was that resources management at DOE sites is to address not only the site itself but also to consider the site's importance on a regional basis.*

In managing the Nellis range, the Air Force must adhere to integrated natural resources management directives that involve ecosystem management. These mandates are similar to those of the DOE's resources stewardship program. Thus, the Air Force's required Integrated Natural Resources Management Plan (INRMP) is similar to the NTS RMP regarding use of the ecological approach to sustain military missions (i.e., sustainable development). In general, however, the Air Force has less institutional experience and technical expertise in such matters than the DOE has and, for now, must look to others for assistance with respect to ecosystem management. Thus, for preparing the first INRMP document for the Nellis range, guidance is being provided under a partnership agreement with The Keystone Center and The Nature Conservancy. Especially noteworthy is the two private organizations' natural resources stewardship dialogue. The dialogue is similar to earlier generic policy dialogues carried out by The Keystone Center and The Nature Conservancy (see note 5). In this instance, however, the activity is site specific, in that it addresses the Nellis Air Force Range and the common ecological region the range shares with the DOE NTS and other federal lands and agencies. The Air Force's action presents an opportunity to apply the ecosystem approach across jurisdictional boundaries, as does the NTS RMP.

The Nellis range dialogue process involves not only the DOE but the U.S. Department of the Interior, the State of Nevada, and local governments. Key stakeholders also are involved in an effort to achieve a coordinated and cooperative approach to achieving sustainable development in the NTS-Nellis region. Both The Keystone Center and The Nature Conservancy are at the forefront of implementing ecosystem management on public lands. For this reason, chances are reasonably

**Exhibit 4. Map of Southern Nevada Showing the Ecological Region, Enclosed by the Dashed Line, That Includes the Nevada Test Site and Other Federal Lands**




good that the regional effort in southern Nevada can succeed.

The Nellis range dialogue is anticipated to result in an interagency cooperative agreement that will include the agencies of the Department of the Interior participating in the regional ecosystem management effort. Both the BLM and FWS have policies in place for committing to the ecosystem management processes of the NTS and the Nellis range. This is important because, as Exhibit 4 shows, the western half of the FWS wildlife refuge is shared with the Nellis Air Force Range. The shared portion of the refuge will be addressed by the Air Force INRMP now underway. Fundamental natural resources management is a process familiar to the Interior agencies, and the add-on principles of postmodern ecosystem management can be accommodated readily.

As for the opportunities the NTS RMP presents to the DOE, two obvious ones concern the baseline environmental data that will be kept current. First, the information will expedite the NEPA process for proposed new facilities by having up-to-date information on the natural resources and existing facilities at the NTS. This means that alternative facility siting decisions and their environmental impact assessments need await only the proposed design specifications. The second opportunity will be the ready availability of much of the environmental information needed for the ER Program. Useful baseline information will include much of the data on environmental conditions necessary for performing human and ecological health risk assessments and for deciding the degree of cleanliness needed for future uses of the NTS.

The DOE could similarly use the NTS RMP regarding its Yucca Mountain site. Located partly on the NTS and partly on lands managed by the Air Force and the BLM (Exhibit 4), Yucca Mountain is the site DOE selected for the world's first geologic repository for permanent storage of the nation's defense and commercial high-level nuclear waste. The DOE has excluded the Yucca Mountain Project from coverage by the NTS RMP process principally to avoid potential delays that the process may incur. For this reason, the site stands as the sole area within the surrounding ecological region that is not included in the regional ecosystem management initiative stemming from the NTS RMP and the INRMP for the Nellis range. This is unfortunate because the health and integrity of the regional ecosystem that includes the Yucca Mountain site is important to the long-term performance of a nuclear repository at the site.[10]

With respect to the DOE's NEPA process, the comprehensive and integrated resources management approach followed by the NTS RMP should improve the interdisciplinary character of related assessments, evaluations, and decisions. Advocates of NEPA have long sought a comprehensive approach to ecosystem management as the Act and its regulations imply. However, there has not been a functional holistic concept for achieving the degree of comprehensiveness and integration NEPA envisions. Only in recent years has the state-of-the-art of ecosystem science reached a state of development to facilitate the applied ecosystem approach.

*Only in recent years has the state-of-the-art of ecosystem science reached a state of development to facilitate the applied ecosystem approach.*

Essentially the same can be said of the DOE ER Program. Integrated environmental risk assessment and the science of ecosystem restoration are new disciplines that ecosystem management serves well. It is unlikely that achieving an integrated approach for the cleanup program with revised laws and regulatory schemes will come any time soon. The ecosystem management strategy being taken for the NTS RMP can be tested at the NTS. If found promising, the approach can be considered for the DOE nuclear weapons complex cleanup program under the recently launched 10-year Integrated Strategic Planning Program.[11] A useful characteristic of the NTS RMP approach is that it cuts across DOE's various programs (i.e., defense, environmental health and safety, environmental management, environmental restoration, and waste management) at DOE's nuclear weapons complex sites.

## CONCLUSIONS

The DOE's ongoing national resources stewardship initiative stands to benefit the Department in view of enlightened postmodern ideas regarding managing public lands and resources. Planning for integrated resources management such as is underway at the NTS appears to be a credible and effective means for conforming with the DOE's directives regarding resources stewardship. Thus, the NTS RMP approach accommodates the Department's Land and Facility Use Planning Policy (DOE Policy 430.1) and its Life Cycle Asset Management Order (DOE Order 430.1), both of which require ecosystem management as a basis for administering DOE's land and facility resources. This approach to land and facility stewardship would complement the DOE's expanding attitudes concerning openness and collaboration with stakeholders. Existing administrative directives within the DOE are sufficient for undertaking resources management based on ecosystem management.

The NTS RMP approach could serve as a model for other DOE nuclear weapons complex sites. Such a department-wide program would facilitate the DOE's broad initiative regarding future uses of former nuclear weapons complex sites. A paramount issue faced by all DOE sites engaged in the ER Pogram is "How clean is clean enough for what uses?" This is a vital socioeconomic concern regarding DOE's public stakeholders and their perception of the Department's intentions. Such matters are at the heart of the national policy initiative regarding sustainable development and ecosystem management that arose from the White House's 1993 National Performance Review.

*The NTS RMP approach could serve as a model for other DOE nuclear weapons complex sites.*

The resources stewardship activity coincides with an effort to foster government interagency cooperation in managing regional natural resources. Along with two other federal departments, the DOE is involved with key public land stakeholders in addressing resources management issues within a common ecological region in southern Nevada. To date, a significant benefit of the regional initiative is that predominantly adverse public opinion is improving in the state. This is yet another benefit that can follow from a sincere commitment to human-oriented ecosystem management principles. The same would be true for the Yucca Mountain Project if the DOE would include the prospective repository site in the NTS RMP.

Innovative, progressive resources management planning at the NTS appears to be the first such attempt within the DOE. Another first at the NTS is the DOE's involvement with regional ecosystem management at a former nuclear weapons site. These creative and enterprising initiatives capture the spirit of national resources stewardship set forth by the Secretary of Energy in 1994. They are not to be dismissed lightly as the DOE progresses into the post-Cold War era. Much of what the Department still needs to accomplish depends on initiatives similar to those being taken for the NTS. Serious consideration should be given to the appropriateness and advantages that such actions have to offer regarding other nuclear weapons complex sites. ❖

## NOTES

1. A "Framework for the Resources Management Plan" was developed as Volume Two of U.S. DOE, Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada, US DOE/NVO, Las Vegas, 1996, NV DOE/EIS 0243. A commitment to prepare a resource management plan for the NTS was included in the Record of Decision for the 1996 NTS final environmental impact statement, Federal Register 61 (16 December 1996), no. 241: 65551-65563. A Resources Management Plan Project Execution Plan, dated June 2, 1997, was made public by the DOE on July 8, 1997.

2. The DOE's national resources stewardship initiative was announced in H. O'Leary, Land and Facility Use Policy, Memorandum to Secretarial Officers and Operations Office Managers, Secretary of Energy, Washington, DC, 21 December 1994. Included with the memorandum was U.S. Department of Energy, Department of Energy: Stewards of a National Resource, US DOE, Washington, DC, December 1994, DOE/FM-0002. The formal stewardship program was established by U.S. DOE, Land and Facility Use Planning Policy, DOE, Washington, DC, 9 July 1996, P 430.1, and by U.S. DOE, Life Cycle Asset Management Order, U.S. DOE, Washington, DC, 24 August 1997, DOE O 430.1.

3. U.S. DOE, Charting the Course. U.S. DOE, Washington, DC, April 1996, U.S. DOE, DOE/EM-0283; Resourceful Reuse: A Guide to Planning Future Uses of Department of Energy Sites, U.S. DOE, Washington, DC, May 1996, DOE/EM-0285.

4. Federal policy for the ecological approach to managing natural resources on federal lands was set forth in Vice President Al Gore, Reinventing Environmental Management: Accompanying Report of the National Performance Review, Creating a Government That Works Better & Costs Less, White House National Performance Review, Washington, DC, September 1993; Interagency Ecosystem Management Task Force 1995-1996, The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies, Vols. I–III. The White House Office of Environmental Policy, Washington, DC.

5. The Keystone Center, The Keystone National Policy Dialogue on Ecosystem Management, The Keystone Center, Keystone, CO, October 1996; The Nature Conservancy, Conserving Biodiversity on Military Lands: A Handbook for Natural Resources Managers, The Nature Conservancy, Arlington, VA, 1996; Ecological Society of America, The Report of the Committee on the Scientific Basis for Ecosystem Management, *Ecological Applications* 6 (1995) no. 3: 665-691; R.E. Grumbine, "What Is Ecosystem Management?" *Conservation Biology* 8(1994) no. 1: 27-38; C.A. Wood, "Ecosystem Management: Achieving the New Land Ethic," *Renewable Resources Journal*, Spring 1994: 6-12.

6. See note 4.

7. Id.

8. Air Force and U.S. Department of Defense policies and directives for INRMP documents are explained in U.S. Air Force, Draft Integrated Natural Resources Management Plan—Nellis Air Force Base/Nellis Air Force Range, Environmental Management Directorate, 99th Air Base Wing, Nellis Air Force Base, Nevada (March 1997).

9. The State of Nevada has encouraged the federal agencies involved to cooperatively address land resource planning and management including the ecological region shared by the Nellis range and the NTS. This occurred in a meeting at the BLM's Las Vegas District office on November 6, 1996. The meeting was hosted by the Bureau of Land Management Resources Advisory Council for southern Nevada.

10. C.R. Malone, "Ecology, Ethics, and Professional Environmental Practice: The Yucca Mountain, Nevada Project as a Case Study," *The Environmental Professional* 17 (1995): 271-

284; C.R. Malone, "The Federal Ecosystem Management Initiative in the U.S.," In J. Lemons, R. Goodland, and L. Westra (eds.), *Environmental Sustainability: Case Studies on the Prospects of Science and Ethics*, Kluwer Academic Publishers, Dordreche, The Netherlands (in press).

11. Details for the U.S. DOE's 10-year Integrated Strategic Planning Program are in US DOE, Accelerating Cleanup: Focus on 2006 (Discussion Paper), DOE, Washington, DC, 1997, DOE/EM-0327.

**ATTACHMENT L**

# THE FEDERAL ECOSYSTEM MANAGEMENT INITIATIVE IN THE UNITED STATES

**Charles R. Malone***

## 1. The Need for Ecosystem Management in the U.S.

In a recent book, *Lost Landscapes and Failed Economies*, Power (1996) argues convincingly that the quality of the natural landscape is an essential part of an area's permanent economic base and should not be sacrificed in short-term efforts to maintain economic interests and pursuits that are ultimately not sustainable. In another book, *Ecosystem Management in the United States* (Yaffee et al. 1996), Yaffee and his students at the University of Michigan list 619 projects that reflect elements of ecosystem management, the emerging new paradigm for achieving sustainable development in the U.S.

Additionally, the President's National Science and Technology Council (NSTC 1995) established an Ecosystem Working Group as part of an effort to address such issues as research and development strategies on global change, biodiversity and ecosystem dynamics, and resource use and management. The NTSC (1995) concluded (1) that pursuit of improved quality of life often threatens the sustainability of ecosystems, (2) continued decreases in productivity and vitality of ecosystems which can result in increased deterioration of ecosystems that are incompletely understood, (3) the basis for human development has been the availability of healthy natural ecosystems and the resources they provide, and (4) that to sustain further human development, the ecological base to support it must be sustained. These are among the many signs that in the U.S. public perception is increasing that the short-term economic value of renewable natural resources is not worth risking damage to ecosystem that can threaten the environment of future generations. Awareness of the need for ecological sustainability is being expressed in the rising popularity of the ecosystem approach to resource management (e.g., ESA 1996a, Grumbine 1994, Slocombe 1993, Wood 1994). The federal government in particular has undertaken an ecosystem management initiative for public lands in an effort to foster ecologic and economic sustainability (CRS 1994, Gore 1993, IEMTF 1995). In the context of the federal initiative, ecosystem management reflects humanistic views of nature which seek to support development that is compatible with the environment.

The concept of ecosystem management suggests different things to different people. The popular version of the idea, addressed here, implies that humans are considered as integral components of ecosystems and that the sustainability of human

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socioeconomics and ecosystems is interwoven. Further, the ethic embodied by ecosystem management means that renewable natural resources are to be managed by each generation such that succeeding ones will have access to comparable resources through time. This humanistic precept is consistent with that of Darling and Dasmann (1969) concerning the ecosystem view of human society and the ecological approach to maintaining the environment.

Sustainable development through human-oriented ecosystem management is seen as a means for restoring and maintaining natural systems and human economies where traditional commodity-directed resource management has failed to do so (Lemons and Brown 1995, Slocombe 1993, van den Bergh and van der Straten 1994). This approach to resource management that is compatible with human development integrates politics, institutional arrangements, natural resource management, and socioeconomics.

Principal among events in the U.S. that led to ecosystem management as an applied interdisciplinary practice were the grizzly bear controversy in the Greater Yellowstone Ecosystem and northern spotted owl controversy in the Pacific Northwest (Grumbine 1994, Yaffee 1994). In the 1970s and 1980s these events influenced the integration of ecosystem science, conservation biology, traditional natural resource management, socioeconomics, institutional arrangements, and diverse stakeholders interests. By the late 1980s this synthesis had resulted in an ecosystem approach to land management. And, it was during this period that usage of the term "ecosystem management" to mean an integration of the biophysical and human dimensions for managing natural resources became common.

The recent origins of ecosystem management in the U.S. have been documented by Grumbine (1994), Knight and Bates (1995), Slocombe (1993), and Yaffee (1994). The present paper addresses the concept of ecosystem management as it is reflected in the federal ecosystem management initiative in the U.S. Origins and evolution of the ecosystem management concept, its strengths and weaknesses, its role in the pursuit of sustainable development, and the role of professional ethics in ecosystem management, as exemplified by a case study of a major federal program, will be discussed here.

(In the U.S., historical accounts of ecosystem management, including this one, typically ignore the Central and Eastern European origins of the concept through the discipline of landscape ecology after World War II, as documented by Naveh and Lieberman (1994). Landscape ecology is gaining favor in the U.S. because (1) a central feature of the discipline is recognition of the dynamic role of humans in the landscape and the ecological implications (2) a realization that almost all landscapes have been influenced by cultural forces, and (3) cultural, social, aesthetic, and economic considerations are incorporated in landscape ecology. However, in the U.S. the discipline has yet to be integrated extensively from academic circles into application such as the federal ecosystem management initiative.)

## 2. Nature of the Federal Ecosystem Management Initiative in the U.S.

Since the late 1980s, some federal agency officials, scientists, and natural resource policy analysts have advocated a broader approach to natural resource management than the traditional focus on commodity production. For a decade prior to that time, the dominant resource management paradigm was "multiple use." However, this management strategy, like the preceding focus on production of commercially valuable commodities, met with only limited success in sustaining ecosystem goods and services. The reason was that under multiple use management the federal land management agencies continued to place priority on managing resources of economic value, e.g., livestock grazing lands and timber production lands, at the expense of ecosystems.



Now, the state of ecosystem science is sufficient to contribute its part to an interdisciplinary nucleus for ecosystem management. For example, it is recognized that ecosystems are open, regulated by events outside their boundaries, do not reach stable equilibrium points, and include humans (Allen and Hoekstra 1992, ESA 1996a, Gunderson et al. 1995, Pahl-Wostel 1995). The knowledge that ecosystems are subject to natural changes and uncertainty lends to a focus on long-term sustainability rather than traditional management to maximize short-term yield.

The popularized form of ecosystem management adopted for the federal ecosystem management initiative is labelled as humanistic or anthropocentric. It typically emphasizes socioeconomics, political science and institutional arrangements more than it does science (e.g., Cortner and Moote 1994, Keystone Center 1996). The contrasting view of ecosystem management is the biocentric view that focuses first on sustaining ecosystems and their biodiversity and only secondarily on the economic benefits to humans derived from sound ecosystems having integrity and resilience (Lackey 1995, Stanley 1995). Biocentric ecosystem management rejects sustainable development as being a fallacy in view of human nature being to seek ever greater economic gains at the expense of the natural environment. The biocentric view says that ecosystems cannot be scientifically managed because their complexity defies human understanding and control (Arrow et al. 1995, Ludwig et al. 1993).

In the U.S. federal initiative, ecosystem management rests on several characteristics and tenets (Table 1). While all the factors in Table 1 are critical to humanistic ecosystem management, one merits special attention regarding human dimensions. This is the interdisciplinary nature of ecosystem management that involves four interacting systems consisting of (1) the natural system including humans, (2) the social system of human values and behavior, (3) the economic system related to land, labor, and capital, and (4) the political system of policy making, laws, and institutional arrangements (Kennedy et al. 1995). Each system is dynamic and can change with a different frequency than the other three thereby complicating the interactions and confounding the matching of land capability with sustainable resource use.

The conceptual basis of the federal ecosystem management initiative is coupled with sustainable development. The vision of sustainable development means maintaining the well being of both humans and the ecosystems that provide renewable natural resources and ecosystem services necessary for socioeconomic progress (IETC 1996, Lemons 1995, van den Bergh and van der Straaten 1994). Science is useful in such efforts, but no matter how interdisciplinary it may be, many decisions about people and environmental objectives must include value judgements. Bridging the objective and subjective natures of ecosystem management is a major challenge to the initiative in the U.S.

Table 1. Characteristics of humanistic (anthropocentric) ecosystem management.

- Embraces a land ethic based on sustainable ecosystems, natural resources, and economics for future generations and reflects socially defined goals and management objectives that support sustainable resources, communities, and economies.
- Recognizes that ecosystems are complex, dynamic, inherently unstable, and their components, including people, are interrelated.
- Includes humans as part of almost all ecosystems and assumes that humans must depend on and be responsible for natural resources.
- Uses an interdisciplinary approach that integrates biophysical and human dimensions and is based on the best science and information available while recognizing the limits of current knowledge.
- Requires partnerships between federal, state, and local government, landowners, and other stakeholders for collaborative decision making.
- Fosters incentive-based solutions to natural resource and environmental management and downplays regulatory approaches.
- Draws heavily on scientific principles, research, and state of the environment monitoring and requires an improved understanding of ecosystems.
- Must be built on cooperative interagency institutions because ecosystems transcend jurisdictional boundaries.
- Recognizes uncertainty and relies on adaptive management for redirection of programs based on new knowledge.

## 2.1. EMERGENCE OF THE POLICY

The federal policy on ecosystem management began emerging in 1993 from the White House's National Performance Review (Gore 1993). As part of the review, Vice President Al Gore called for the federal government to adopt an approach for ensuring sustainable economic development while also sustaining the environment through ecosystem management. To carry out the environmental mandate of the National Performance Review, in August 1993 the White House Office of Environmental Policy (OEP) took the lead for the federal initiative on ecosystem management by establishing the Interagency Ecosystem Management Task Force (IEMTF) to carry out Vice President Gore's mandate. The task force examined five major issue areas relevant to ecosystem management including budgetary, institutional, public participation, science and



information, and legal authorities. Case studies of ecosystem management to identify barriers to the approach and to evaluate ways to overcome them.

Numerous recommendations were made by the task force regarding (1) improving interagency coordination, (2) improving partnerships with non-federal stakeholders, (3) improving communication with the public, (4) improving resource allocation and management; supporting the role of science, (5) improving information and data management, and (6) increasing flexibility for adaptive management. The recommendations in these areas are noteworthy because in January, 1996, the White House executed a Memorandum of Understanding to Foster the Ecosystem Approach (OEP 1996) that was signed by the 14 federal agencies that had participated in the interagency task force on ecosystem management.

The idea of using ecosystem management to sustain human development did not suddenly arise in the White House in 1993 or 1995. Prior to that time ecosystem management had been developing within various land management agencies, most notably the USFS and the BLM. In 1992 the USFS conducted a national workshop on the ecological approach to resource management (USFS 1992) and two years later the agency's policy on ecosystem management was articulated in a general technical report (USFS 1994). Meanwhile, the U.S. BLM (1994) and other federal agencies (CRS 1994, USDOE 1995, USFWS 1995, USNBS 1994) also were pursuing ecosystem management as a means for managing public lands.

Students of ecosystem management will be interested in a report developed for the US Senate (1994) and another one prepared by the U.S. General Accounting Office (USGAO 1994). The first of these contains a broad spectrum of views from government, academia, public interest, and commercial interests on ecosystem management and the role of the federal government. The second is a critique both of the ecosystem management concept and how it is being pursued by the federal government.

## 2.2. ROLE OF INTEGRATION

As being fostered by the federal initiative in the U.S., ecosystem management involves integrating the participation of public and private stakeholders, professionals, policy makers, and government institutions in joint decision making. Strong intergovernmental cooperation and coordination for fostering resource stewardship are essential to ecosystem management. These joint give-and-take processes combines public involvement with interdisciplinary expertise rather than the multidisciplinary approach that to this time has predominated.

Social, economic, and ecologic components of ecosystem management must be addressed over a long timeframe in order to sustain the natural resource base from one human generation to the next. The idea is that ecosystem management emphasizes changing how people perceive natural resources, especially resources on public lands where conflicts are common. Part of the desired change is to have people learn to look farther into the future than their own generation. Thus, pursuing sustainable development through ecosystem management requires changing human values, economics, and ecological realities, ideas, and knowledge, i.e. the human dimension. This means that interdisciplinary knowledge involving sociology, economics, political science, and ecology must be used to better understand the role of humans in the natural environment and the importance of natural resources to human socioeconomics, public health, and quality of life.

Unfortunately, the various disciplines involved in human dimensions are not well integrated with the natural sciences that underpin ecosystem management (Sheifer 1996). Achieving a transdisciplinary perspective and practice is essential to the success of humanistic ecosystem management as a means of achieving sustainable development.

## 3. Concern, Controversy, and Barriers to Ecosystem Management

Ecosystem management continues to be subject to debate and controversy. Concerns include whether or not the concept can deliver what it promises and whether or not human activities and natural processes can be integrated to benefit both (ESA 1996a). The humanistic path toward ecosystem management that is being fostered by the U.S. government is an ambiguous one that fails to be definitive. Thus, there is much rhetoric from federal land management agencies that profess to be engaged in ecosystem management. Many bureaucrats embrace the words associated with ecosystem management but not the philosophy (Lackey 1995).

Part of the difficulty is that there is little agreement among the various parties involved in ecosystem management regarding explicit features and definitive characteristics of ecosystem management. An effort toward reaching agreement is the late 1996 report on the Keystone Center National Policy Dialogue on Ecosystem Management (Keystone Center 1996). This includes the concept's key components, although principal emphasis was given to non-scientific, human dimension aspects of ecosystem management. Most notable about the Keystone Center dialogue on ecosystem management is the emphasis given to such matters as the role of stakeholders in decisionmaking and the organizational structure for implementing ecosystem management centered on human interests and values rather than ecosystem science.

Some critical observers of the ecosystem management concept and the federal initiative are highly skeptical. For example, Ludwig et al. (1993) believe that claims of sustainability are to be distrusted because they defy historical facts about human behavior and may lead to a complacency about ecosystem management or sustainable development. These and other concerns, such as how science handles uncertainty and how it envisions sustainable yield of resources, lead Ludwig and his coauthors to view natural resource problems not as technical problems but as human ones resulting from political, social, and economic systems, much as the Keystone Center (1996) approached ecosystem management.

Another critic, Stanley (1995), raises the matter of the "arrogance" of humanism in the context of the ecosystem management paradigm as it is being popularized and pursued by federal land resource managers. The concept of ecosystem management being popularized and fostered by government agencies is viewed by Stanley as being overly anthropocentric. Anthropocentrism emphasizes the human use of natural resources to the benefit of development and includes ecological as well as socioeconomic considerations. In contrast, the opposing biocentric view considers humans as a component of ecosystems equal to and subject to the same resource constraints as any other biotic component. Under biocentricism the biosphere has limits to its carrying capacity, and human use of resources ultimately has to be constrained to meet the challenge of sustaining ecosystem integrity (Arrow et al. 1995).



### 3.1. CONFLICT OVER ECOSYSTEM MANAGEMENT

There are some aspects of ecosystem management that lead to conflict. For example, most ecosystems and landscapes lack precise boundaries and do not ordinarily conform to administrative borders. Land ownership and political boundaries have little scientific meaning in the sense of natural ecosystems and landscapes. Consequently, as public land management agencies seek to apply ecosystem management, private properties and various jurisdictional boundaries are confronted. Institutional mechanisms for managing across jurisdictions under an ecosystem approach are largely unknown (Cortner and Moote 1994).

Other concerns arise such as (1) government encroachment onto private properties that share ecosystems and landscapes with public land, (2) issues of how different government agencies cooperate regarding their management activities and conflicting legal mandates, (3) questions about stakeholder participation in decision making, and (4) the threat that private and commercial users of public land for economic or other benefits will face increasing regulations that compromise their livelihoods (Fitzsimmons 1996, Wood 1994). Regarding the issue of economics, goods and services derived from federal lands provide jobs for many local communities that stand to be threatened by ecosystem management of public land resources. However, the extent of the economic consequences of ecosystem management remain unknown.

These issues are important in the cultural context in the U.S. and this is the principal reason why the federal ecosystem management initiative involves chiefly public lands, i.e., to stem fears of federal intrusion into private ownership rights. Rights of property owners and local loss of jobs resulting from federal ecosystem management programs are major concerns of the public that ecosystem management strategies must deal with positively (ESA 1996a). Varner (1994) envisions a steady progression, under sustainable development and ecosystem management, toward all land, regardless of ownership, being viewed as a public resource owned in common and held by individuals only in a stewardship capacity.

### 3.2. BARRIERS TO ECOSYSTEM MANAGEMENT

Other concerns and barriers to ecosystem management (Table 2) fall into five broad categories - scientific, informational, institutional, decision making, and ethics. In particular, the Keystone Center (1996) expressed concerns about ecosystem management lacking an accepted definition and a set of definitive practices. Critical importance was ascribed to the need to clarify characteristics sometimes ascribed to ecosystem management but that are not congruent with the forum's vision of community-based ecosystem management processes. Principal among the concerns were the issues of the threat of expanding government control over private land use decisions, diminished focus of communities and regions on NEPA and other national environmental laws, a giveaway of public lands to local economic interests, top down federal planning and the tendency for land manager bureaucrats to embrace the philosophy of ecosystem

Table 2. Barriers and needs that agencies face in implementing ecosystem management.

- Understanding ecosystem structure and function and the role of biodiversity in sustaining ecosystems.
- Determining appropriate spatial scales and hierarchical units for establishing ecosystem management boundaries.
- Establishing indicators for evaluating the success of ecosystem management.
- Establishing and managing a base of knowledge and monitoring information.
- Gaining an understanding of biophysical and socioeconomic interrelationships in ecosystems.
- Achieving federal interagency coordination and cooperation.
- Communicating between federal agencies and the public and establishing trust.
- Forming partnerships with non-federal stakeholders for reconciling diverse management goals and collaborative decision making.
- Remaining flexible for applying adaptive management.
- Improving adherence to principles of environmental ethics and standards of professional practice among all categories of environmental professionals.

management and move away from traditional ways of managing public land resources. Statutory barriers to ecosystem management also exist in the U.S. (Keiter 1994). These need to be examined and revised if necessary to provide positive incentives for ecosystem management, particularly regarding stakeholder participation in decision making. Federal land management agencies are guided by legislation concerning resource management planning. These constructs, along with the National Environmental Policy Act, were developed before ecosystem management was conceptualized and may be administered in ways that preclude an ecosystem, landscape, or ecoregion view consistent with the goals of ecosystem management as a new paradigm. Such concerns and potential barriers to ecosystem management led the Keystone Center (1996) to recommend that implementing regulations for the involved federal statutes be reviewed and revised where appropriate to promote ecosystem management goals and partnerships for resource management initiatives on a landscape scale.

Apprehensions and obstacles to ecosystem management will continue as the discipline evolves. However, the most divisive issues are not scientific or technical: they are moral and philosophical (Lackey 1995). Science cannot resolve the moral issues involving ecosystem management. A proper role for science is to strive to reduce the



scientific uncertainty in much of ecosystem science and the technical aspects of ecosystem management. Resolution of both the moral issues and the scientific uncertainties must attempt to remain astride of the continued social trend in the U.S. and elsewhere toward placing ever greater weight on nonconsumptive societal benefits. Thus, the underlying reasons for the emergence of ecosystem management as a new paradigm for resource management and sustainable development is unlikely to disappear.

## 4. Ecosystem Management and Professional Ethics

Much is written about ecosystem management and environmental ethics (e.g., Cortner and Moote 1994, ESA 1996a, Francis 1993, Grumbine 1994, Lemons and Brown 1995, Wood 1994). Nothing will be added here to that important topic. Instead, the seldom considered issue of professional ethics in relation to ecosystem management will be addressed. This matter is important because while most ecologists and other environmental professionals profess to being environmentally ethical, relatively fewer in the U.S. view matters of professional ethics and standards of professional practice with similar importance.

It is true that professionals involved with matters affecting the environment generally recognize that the synthesis of facts and values is a professional responsibility. Beyond that, many ecologists and other natural scientists do not recognize a need for guidance on other matters of professional ethics and standards of practice. The Ecological Society of America (ESA), for example, has touched only slightly on this matter through its Code of Ethics (ESA 1996b). The point to be made here is that while the ESA Code of Ethics serves researchers and educators well, it is inadequate for consulting ecologists. This is especially true for ecological consultants involved with matters and affairs of applied ecology, environmental policy, and federal programmatic direction affecting public interests.

On the other hand, traditional environmental professionals such as the members of the National Association of Environmental Professionals (NAEP) that are involved principally in matters of regulatory compliance characteristically subscribe to a Code of Ethics and Standards of Professional Practice (Malone 1995, NAEP 1996). When the ESA (1996b) Code of Ethics is compared to the NAEP (1996) Code of Ethics and Standards of Professional Practice some important principles of professional ethics and standards are not found in the ESA (1996b) Code of Ethics (Table 3).

For example, the ESA's Code of Ethics does not specifically target the consulting profession even though significant numbers of ecologists are full-time or part-time consultants, often on matters important to ecosystem management and sustainable development. The dilemma posed here with respect to ecosystem management and professional ethics is illustrated by considering ecosystem management in the U.S. Department of Energy (DOE) which was the last federal land management agency to adopt ecosystem management.

An ecosystem management policy was adopted by the DOE in December 1994 (USDOE 1994). The policy's objectives were laudable, i.e., for DOE to manage its land and facilities as valuable national resources in accordance with the principles of ecosystem management and sustainable development. The policy sought to integrate the

Table 3. Ethical principles that are fundamental to the National Association of Environmental Professionals (NAEP 1996) do not appear in Ecological Society of America's Code of Ethics (ESA 1996B).

- Professional consultants must conduct themselves in a manner consistent with the principles of environmental ethics.
- Environmental professionals must recognize that total environmental (i.e., ecosystem) management involves consideration of all environmental factors including technical, economic, ecological, and sociopolitical and their relationship.
- Environmental professionals must incorporate the best principles of design and environmental planning (e.g., ecosystem management) when recommending measures to reduce environmental harm and enhance environmental quality.
- They must provide their services in areas where they are qualified and turn to other experts where they are unqualified.
- The formation of interdisciplinary teams for resource management planning and for determining environmental impacts must be fostered.
- Communication with other professionals and respect for their contributions in developing and reviewing policies, plans, and projects must be pursued.

agency's mission with ecologic, economic, and social factors in a comprehensive plan for each DOE site that would guide land and facility use decisions. Comprehensive plans developed for each site were to consider the site's larger regional context and be developed with stakeholder participation.

The policy was first used for the Nevada Test Site (NTS) in the context of a site-wide environmental impact statement (EIS) that included a framework for a Resource Management Plan (RMP) (USDOE 1996). The RMP, the first ever for the DOE, is to be developed and implemented subsequent to the EIS, released to the public which occurred in October 1996. Ecosystem management is to be the foundation for the RMP, and the DOE approach in this case is consistent with the federal ecosystem management initiative.

Stakeholders and interested parties were pleased with the DOE initiative at NTS because it involves a regional planning strategy that will integrate stakeholder and community concerns and goals consistent with the pursuit of healthy ecosystems and sustainable development. Notable is the fact that the RMP framework document (USDOE 1996) reflects credible professional work that was led by an environmental professional on DOE's staff who is a member of the NAEP and thus subject to the association's Code of Ethics and Standards of Practice.



Despite the DOE's decision to implement ecosystem management at the NTS, it failed to include a large and costly long-term project meant to construct and operate an environmentally significant geologic repository for high-level nuclear waste, the Yucca Mountain Project (Malone 1995). Although a portion of the project site is located on the test site, DOE arbitrarily decided to exempt the project from the NTS EIS, resource management planning, and compliance with the DOE's Land and Facility Use Policy (USDOE 1994). Instead, project decisions fail to involve stakeholder collaboration, are inconsistent with adjacent public lands management, and do not address long-term environmental impacts associated with a repository at Yucca Mountain (Malone 1995).

The situation with respect to the Yucca Mountain Project is important because at present time there is no empirical basis for predicting what might occur at Yucca Mountain over the long term. Geologic disposal of high-level nuclear waste raises unique issues that have never before been faced. For example, the repository must isolate nuclear waste from the environment accessible to man for a minimum of 10,000 years. Malone (1995) presented a plausible scenario under global climate change whereby accelerated erosion and adverse geohydrologic changes could compromise the integrity of a repository and its waste packages at Yucca Mountain to prematurely release radioactive material to the environment.

Research based on the scientific premises of ecosystem management and coupled with long-term environmental pathway modeling could be conducted to shed light on the early-release scenario. However, the DOE Yucca Mountain Project has, on the basis of no data or objective evidence, used subjective judgement to rule out the scenario and the need for its study. The principal basis for the DOE's refusal to address the issue is the recommendation of the ecologist leading the Yucca Mountain environmental and ecological program. The leader is a community ecologist whose staff does not include ecosystem scientists. Without any empirical basis, and on subjective judgement alone, the program leader has concluded that nothing like the early-release scenario could occur.

The DOE accepts the leading ecologist's advice, which is convenient for the repository project. In this case, ignorance is expedient because ecosystem studies of long-term environmental potential of the Yucca Mountain site conflict with the fast-tract schedule for the project. This is despite the fact that ecosystem-level studies will be pursued at the Nevada Test Site under a resource management plan (USDOE 1996) from which the Yucca Mountain Project has excluded itself.

While the ecology program leader is a member of the Ecological Society of America, the society fails to endorse high principles of professional ethics and standards of practice comparable to those of the NAEP (Table 3). The NAEP (1996) Code of Ethics and Standards of Practice includes the concept of the integrated, interdisciplinary ecosystem approach to environmental protection, i.e., ecosystem management. By comparison, the DOE Yucca Mountain Project emphasizes only plant community ecology, reclamation of disturbed areas, and the population biology of one legally protected species. There is no professional way for critics of the ecology program to influence the program with respect to enforcing professional ethics and standards of practice (Malone 1995).

It can be seen from this case that there can be a role for ecosystem management and professional ethics to play in important environmental issues. Professional associations like the Ecological Society of America and the National Association for

Environmental Professionals have a major role to play in matters of professional ethics and in providing guidance on the necessity for integrated studies and resource management programs. The ecological society's present ethical codes are insufficient for helping avoid difficult issues like the DOE Yucca Mountain Project present.

## 5. Summation

Traditionally, resource management practices have sought to achieve changes in ecosystems without concurrently achieving lasting social changes. Many management plans and programs have failed because both kinds of changes were not sought concurrently. A fundamental challenge to ecosystem management is to accomplish lasting management of resources consistent with maintaining economic progress and realizing responsible resource stewardship. In this respect, the importance of integrating human and biophysical dimensions is paramount, and disciplines such as economics, sociology, political science, and the study of institutional arrangements are as important to ecosystem management as are the natural sciences.

Sustaining renewable natural resources requires a land resource ethic that downplays traditional commodity-oriented, command-and-control management. Achieving this change requires using sociology, economics, ecology, political science, and studies of institutional arrangements in an interdisciplinary manner to reach goals and objectives that have been socially defined. Collaboration of this sort involves the public, policy makers, and government working cooperatively.

The concept of achieving sustainability through interdisciplinary ecosystem management involves adopting an ethic that integrates patterns of human thought and action with ecological reality and prospects for the future. Indeed, some believe that a new paradigm and ethic are emerging (Cortner and Moote 1994, Grumbine 1994, Wood 1994). Traditional resource management guided by a paradigm characterized by maintaining commodity production has been discredited and a new ideal is emerging based on biophysical and human dimensions, institutional coordination, and collaborative decision making. The principles of ecosystem management thus seem form the philosophical underpinning of a new ethic, one designed to safeguard ecological integrity, ecosystem sustainability, and biodiversity for future generations (ESA 1996, Lemons and Brown 1995, Westra and Lemons 1995).

As the new paradigm develops, scientists need to be involved throughout the policy making process of ecosystem management, but in a clearly defined, interactive role where the values and priorities of the public are implemented, not those of scientists. Ecosystem management clearly is an applied science, something that ecologists long have viewed with detachment. This is unfortunate because developing a useful and feasible approach to ecosystem management calls for a participatory, consultative approach involving ecological research. At the present time, the traditional disciplines of natural resource management and human dimensions are more attuned to this situation than is academic ecological science. However, there are refreshing signs that ecosystem scientists are recognizing their essential role in the U.S. effort toward achieving sustainable development through ecosystem management.



## 6. References


Allen, T.F. and T.W. Hoekstra. 1992. *Toward a Unified Ecology*. Columbia University Press, New York, NY.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C.S. Holling, B.O. Jansson, S. Levin, K.G. Maler, C. Perrings, and D. Pimentel. 1995. Economic Growth, Carrying Capacity, and the Environment. *Science* 268: 520-521.

Cortner, H.J. and M.A. Moote. 1994. Trends and Issues in Land and Water Resources Management: Setting the Agenda for Change. *Environmental Management* 18(2): 167-173.

(CRS) Congressional Research Service. 1994. Ecosystem Management: Federal Agency Activities. 94-339 ENR, April 19. CRS, Washington, DC.

Darling, F.F. and R.F. Dasmann. 1969. The Ecosystem View of Human Society. *Impact of Science on Society* 19: 109-121.

(ESA) Ecological Society of America. 1996a. The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. *Ecological Applications* 6(3): 665-691.

(ESA) Ecological Society of America. 1996b. Code of Ethics. ESA, Washington, DC.

Fitzsimmons, A.K. 1996. Sound Policy or Smoke and Mirrors: Does Ecosystem Management Make Sense? *Water Resources Bulletin* 32(2): 217-227.

Francis, G. 1993. Ecosystem Management. *Natural Resources Journal* 33(Spring): 315-345.

Gore, A. 1993. Reinventing Environmental Management: Accompanying Report of the National Performance Review. ISBN 0-16-042000-8. U.S. Government Printing Office, Washington, DC.

Grumbine, R.E. 1994. What is Ecosystem Management? *Conservation Biology* 8(1): 27-38.

Gunderson, L.H., C.S. Hollings, and S.S. Light. 1995. *Barriers and Bridges to the Renewal of Ecosystems*. Columbia University Press, New York.

(IEMTF) Interagency Ecosystem Management Task Force. 1995. The Ecosystem Approach: Healthy Ecosystems and Sustainable Economies. White House Office of Environmental Policy, Washington, DC.

(IETC) International Environmental Technology Centre. 1996. Environmental Risk Assessment for Sustainable Cities. Technical Publication Series [3]. UNEP, Osaka/Shiga.

Keiter, R.B. 1994. Beyond the Boundary Line: Constructing a Law of Ecosystem Management. *University of Colorado Law Review* 65(2): 293-333.

Kennedy, J.J., B.L. Fox, and T.D. Olsen. 1995. Changing Social Values and Images of Public Rangeland Management. *Rangelands* 17(4): 127-132.

Keystone Center. 1996. Keystone National Policy Dialogue on Ecosystem Management: Implementing Community-Based Approaches. The Keystone Center, Keystone, CO.

Knight, R.L. and S.F. Bates (eds.). 1995. *A New Century for Natural Resources Management*. Island Press, Washington, DC.

Lackey, R.T. 1995. Ecosystem Management: Implications for Fisheries Management. *Renewable Resources Journal* 13(4): 11-13.

Lemons, J. 1995. Sustainable Development and Environmental Protection: A Perspective on Current Trends and Future Options for Universities. *Environmental Management* 19(2): 157-165.

Lemons, J. and D. Brown (eds.). 1995. *Sustainable Development: Science, Ethics, and Public Policy*. Kluwer Academic Publishers, Boston, MA.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, Resource Exploitation, and Conservation: Lessons from History. *Science* 260: 17-36.

Malone, C.R. 1995. Ecology, Ethics, and Professional Practice: The Yucca Mountain, Nevada, Project as a Case Study. *The Environmental Professional* 17(3): 271-284.

(NAEP) National Association of Environmental Professionals. 1996. Code of Ethics and Standards of Practice for Environmental Professionals. NAEP, Washington, DC.

Naveh, Z. and A. Lieberman. 1993. *Landscape Ecology: Theory and Application* (Second Edition). Springer-Verlag, New York, NY.

(NSTC) National Science and Technology Council. 1995. Building a Scientific Basis to Ensure the Vitality and Productivity of U.S. Ecosystems. White House, Washington, DC.

(OEP) Office of Environmental Policy. 1996. Memorandum of Understanding to Foster the Ecosystem Approach. OEP, White House, Washington, DC.

Pahl-Wostl, C. 1995. *The Dynamic Nature of Ecosystems: Chaos and Order Entwined*. John Wiley, Chichester, England.

Power, T.M. 1996. *Lost Landscapes and Failed Economies*. Island Press, Washington DC.

Sheifer, I.C. 1996. Integrating the Human Dimension in Ecoregion/Ecosystem Studies - A View from the Ecosystem Management National Assessment Effort. *Bulletin of the Ecological Society of America* 77(3): 177-180.

Slocombe, D.S. 1993. Ecosystem Planning, Ecosystem Science, and Ecosystem Approaches for Integrating Environment and Development. *Environmental Management* 17(3): 289-303.

Stanley, T.R., Jr. 1995. Ecosystem Management and the Arrogance of Humanism. *Conservation Biology* 9(2): 255-262.

(USBLM) US Bureau of Land Management. 1994. Ecosystem Management in the BLM: From Concept to Commitment. BLM/SC/GI-94/005+1736. January. USBLM, Washington, DC.

(USDOE) US Department of Energy. 1994. DOE Order 4320.1B, Land and Facility Use Management. USDOE, Washington, DC.

(USDOE) US Department of Energy. 1995. Department of Energy: Stewards of a National Resource. DOE/FM-0002. USDOE, Washington, DC.

(USDOE) US Department of Energy. 1996. Final Environmental Impact Statement for the Nevada Test Site and Off-site locations in the State of Nevada: Volume 2. Framework for the Resource Management Plan. DOE/EIS 0243. USDOE, Las Vegas, NV.

(USFS) US Forest Service. 1992. Taking an Ecological Approach to Management. WO-WSA-3. USFS, Washington, DC.



(USFS) US Forest Service. 1994. An Ecological Basis for Ecosystem Management. GTR RM-246. USFS Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

(USFWS) US Fish and Wildlife Service. 1995. An Ecosystem Approach to Fish and Wildlife Conservation: Concept Document. February. USFWS, Washington, DC.

(USGAO) US General Accounting Office. 1994. Ecosystem Management: Additional Actions Needed to Adequately Test a Promising Approach. GAO/RCED-94-111. USGAO, Washington, DC.

(USNBS) US National Biological Service. 1994. National Biological Service: The NBS Ecosystem Initiative Program. 950110, April 19. NBS, Washington, DC.

US Senate. 1994. Ecosystem Management: Status and Potential. Senate Print 103-98, December. U.S. Government Printing Office, Washington, DC.

van den Bergh, J.C. and J. van der Straaten (eds.). 1994. *Toward Sustainable Development*. Island Press, Washington, DC.

Varner, G.E. 1994. Environmental Law and the Eclipse of Private Property. In *Ethics and Environmental Policy: Theory Meets Practice*, F. Ferre and P. Hartel, eds. The University of Georgia Press, Athens, GA.

Westra, L. and J. Lemons (eds.). 1995. *Perspectives on Ecological Integrity*. Kluwer Academic Publishers, Boston, MA.

Wood, C.A. 1994. Ecosystem Management: Achieving the New Land Ethic. *Renewable Resources Journal* (Spring): 6-12.

Yaffee, S.L. 1994. *The Wisdom of the Spotted Owl: Policy Lessons for a New Century*. Island Press, Washington, DC.

Yaffee, S.L., A. Phillips, I. Frentz, P. Hardy, S. Maleki, and B. Thorpe. 1996. *Ecosystem Management in the United States*. Island Press, Washington, DC.

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**ATTACHMENT M**

# THE POTENTIAL FOR ECOLOGICAL RESTORATION AT YUCCA MOUNTAIN, NEVADA

*Charles R. Malone*
*Nuclear Waste Project Office*

**Abstract.** Federal policy for siting and developing a geologic repository for high-level nuclear waste at Yucca Mountain, Nevada, includes taking "reasonable and necessary" steps to restore the site to its predisturbed ecological condition. However, the state of the art for restoration of disturbed arid lands and the nature of the Yucca Mountain ecosystem are not encouraging with respect to the feasibility of achieving ecological restoration at the site without taking heroic steps. There is a need for establishing practical goals and economical restoration techniques for the site, a task that will be complicated by the presence of an endangered species, the desert tortoise (*Gopherus agassizii*). The Yucca Mountain Project should be viewed as an opportunity to influence both the direction of restoration ecology and future federal policies toward restoring disturbed lands.

## INTRODUCTION

The U.S. has embarked on a unique project that could have important consequences for national policy with respect to ecological restoration involving major federal actions that have adverse environmental impacts. At the Yucca Mountain site in southern Nevada, the U.S. Department of Energy (DOE) is conducting studies to determine the suitability of the location for a geologic repository for disposing of high-level nuclear waste. In accordance with the Nuclear Waste Policy Act (NWPA) of 1982, as amended in 1987, the DOE must take "reasonable and necessary" steps to reclaim the site. The DOE's proposed environmental program plan for carrying out this and other environmental requirements (U.S. DOE, 1988a) equates "reclamation" with the accepted definition of "ecological restoration" (Bonnicksen, 1988; Jordan *et al.*, 1988; Allen, 1989). Thus, the DOE's goal of reclaiming the site upon completion of the Yucca Mountain Project is to return the ecosystem to a condition similar to the predisturbed state. The DOE Yucca Mountain Project thus constitutes one of the few instances where federal policy clearly has adopted the goal of ecological restoration.

The Yucca Mountain site is located adjacent to, and partly on, the DOE Nevada Test Site. The site is remote, has not been used heavily, and is considered by the DOE to be in a stable ecological condition (U.S. DOE, 1986). Because of the arid environment, no socially acceptable land use at Yucca Mountain can be envisioned as a goal for reclamation, other than returning the site to its predisturbed condition. The concept of taking reasonable and necessary steps to achieve restoration occurs in both the Nuclear Waste Policy Act, as amended, and the DOE's proposed environmental and reclamation plans (U.S. DOE, 1988a and 1989). This concept is significant to the science and practice of restoration ecology, because it constitutes an opportunity for demonstrating the practicability of restoring an ecosystem.

This article addresses the potential for successful ecological restoration at the Yucca Mountain site and draws upon the following:

- Regional and site-specific information on ecological and related environmental conditions at Yucca Mountain (U.S. DOE, 1986);
- The DOE's proposed environmental program for the site (U.S. DOE, 1988a and 1989; Parker *et al.*, 1990) and critiques of the plan (Malone, 1990a; Winsor and Malone, 1990);
- Information on practices for restoring arid ecosystems; and
- Studies conducted by the state of Nevada for the Yucca Mountain Project.

The last of these categories of information results from independent review of the DOE nuclear waste repository program by the state of Nevada, a function authorized and funded by the Nuclear Waste Policy Act, as amended. Activities are carried out with the assistance of contractors like Environmental Science Associates, Inc., Resource Concepts,

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Inc., and A.E. Karl. Much of this article is summarized from reports prepared by the contractors, which describe study methods, present analytical results, and in some cases, contain original field data. Copies of the reports, including maps, figures, and complete results of the studies, are available from the Nevada Nuclear Waste Project Office. They address the following topics:

- Remote sensing to determine the extent of existing disturbance of the Yucca Mountain site as a result of the DOE preliminary siting activities (ESA, 1989);
- Preliminary soil and biological surveys (RCI, 1989a; Karl, 1989; ESA, 1990); and
- A review of alternatives and costs for reclaiming and restoring the site (ESA, 1989; RCI, 1989b).

## SITE AND PROJECT DESCRIPTIONS

Emphasis in the state of Nevada environmental program is on a 20 square kilometer study area at Yucca Mountain, where the potential for disturbance from repository siting and the need for ecological restoration are the greatest. Detailed environmental information on existing conditions at the site is not available, although an extensive information base exists for portions of the adjacent Nevada Test Site (U.S. DOE, 1986; US/IBP, 1978; Wallace *et al.*, 1980). The extent to which this information applies to Yucca Mountain must be evaluated, because the Yucca Mountain site runs north-to-south across the Great Basin-Mojave Desert ecotone, a type of ecosystem not studied on the Nevada Test Site. Yucca Mountain differs from the test site, also, because the closed basins, alluvial flats, playas, and predominately calcareous soils typifying the test site are absent at Yucca Mountain.

Three dominant landforms occur in the Yucca Mountain study area (Table 1). Mountainous volcanic uplands occupy the western 20 per cent of the site, and piedmont slopes comprised of alluvial fill occupy the 45 per cent of the site to the east. Between the uplands and piedmont slopes are mesas and sideslopes comprised of remnants of steep ridges and alluvial fans (ESA, 1989; RCI, 1989a and 1989b). Elevation ranges from 1,062 meters in the valley to the east to 1,458 meters on the ridge of Yucca Mountain. Annual precipitation varies according to elevation and averages about 16 to 19 centimeters (Karl, 1989; RCI, 1989a and 1989b; ESA, 1990). Regionally, 60-65 per cent of the precipitation falls between mid-September and late March; 10-15 per cent from late March to early June; and 25 per cent from early June to early September. The area has hot summers (daily high average temperature in July is 35 °C) and mild winters (daily low average temperature in December is -2 °C). Extremes vary from between -10 and -28 °C in January to between 42 and 49 °C in July.

Evaluation and planning for ecological restoration must rely on comprehensive, site-specific environmental information.

**Table 1. Dominant Landforms of the Yucca Mountain Study Area: Extent of Occurrence and Amount of Existing Disturbed Area.**

| Landform Category | Area Covered (square kilometers) | Area Disturbed (hectares) |
|---|---|---|
| Mountainous Volcanic Uplands | 4 | 10 |
| Mesas and Side Slopes | 7 | 74 |
| Piedmont Slope | 9 | 171 |
| TOTALS | 20 | 255 |

Because the DOE has not undertaken such studies, the state of Nevada initiated soil and plant surveys in 1989 (RCI, 1989a; ESA, 1990). Results of the first year's investigations are summarized in Table 2. Major soil units, described and mapped in 1989, were found to consist of soft to loose loamy sands with a 100 per cent gravel surface on the alluvial fans, dense gravels and cobbles on the slopes, and bedrock and boulders on the ridges. All the soils have poor water holding capacity, due to coarse textures and low silt, clay, and organic matter content. Attempts to characterize the vegetation were frustrated by drought conditions that prevented seeds of herbaceous species from germinating. However, the survey was able to cover the study area in sufficient detail to indicate that vegetation at the site is complex and reflects a diverse environment. Detailed maps made with the aid of color stereo aerial photos taken in June, 1988, assisted identification of soil units, vegetation associations, and landforms.

With respect to the fauna of Yucca Mountain, the state of Nevada environmental program has concentrated only on the desert tortoise (*Gopherus agassizii*). As an endangered species (U.S. DOI, 1989), the desert tortoise and its habitat must be important considerations for ecological restoration at the Yucca Mountain site. In the fall of 1989, a survey was conducted throughout the study area to estimate abundance and distribution of desert tortoise. A strip transect method was used for estimating distribution, habitat associations, and relative abundance of the species (Karl, 1989). Data on tortoises and their signs (carcasses, scat, burrows, and evidence of nests) were used to estimate tortoise abundance. The survey found that more signs of tortoises occurred on alluvial fans dominated by creosote bush than in other types of habitats (Table 3). It is reasonable to conclude that the best habitat for the tortoise is located in the eastern portion of the

**Table 2. Environmental Characteristics of the Yucca Mountain Study Area.**

| Climax Vegetation Series | Dominant Plants | Percent of Site Occupied | Landform | General Soil Characteristics | Elevation (m) | Area Disturbed (ha) |
|---|---|---|---|---|---|---|
| Creosote Bush | *Larrea/Menodora/Ambrosia* (creosote bush/mendora/bursage) | 35 | Piedmont Slope | Moderately deep to indurate duripan; sandy loam | 1095-1290 | 152 |
| Great Basin Mixed Scrub | *Ephedra/Eriogonum* (ephedra/buckwheat) | 20 | Mountainous Volcanic Uplands | Shallow to bedrock; gravelly and stony | 1253-1395 | 26 |
| Transition Mixed Scrub | *Ambrosia/Ephedra/Kameria* (bursage/ephedra/ratany) | 15 | Mesas and Side Slopes | Shallow to bedrock; recent alluvium | 1062-1290 | 21 |
| Blackbrush/ Creosote | *Coleogyne/Larrea* (blackbrush/creosote bush) | 15 | Mesas and Side Slopes | Shallow to duripan; recent alluvium | 1143-1260 | 23 |
| Blackbrush | *Coleogyne/Ambrosia/Menodora* (blackbrush/bursage/menodora) | <5 | Mesas and Side Slopes | Shallow to duripan; gravelly sandy loam | 1080-1305 | 31 |
| Sagebrush | *Artemisia/Eriogonum* (sagebrush/buckwheat) | <5 | Mesas and Side Slopes | Shallow to bedrock; cobbly sand | 1350-1450 | 1 |
| Joshua Tree | *Yucca/Coleogyne* (Joshua tree/blackbrush) | <5 | Mountainous Volcanic Uplands | Shallow to bedrock; gravelly and stony | 1440-1458 | 1 |
| High Wash | *Salazaria* (bladdersage) | <5 | Mesas and Side Slopes | Moderately deep to hardpan; sandy loam | 1260 | 0 |

Table 3. Occurrence of Desert Tortoise in the Yucca Mountain Study Area.

| Climax Vegetation Series (# of transects) | Habitat Conditions | Number and Kind of Sign | Mean Density (no./sq. km) |
|---|---|---|---|
| Creosote Bush (7) | fair | 12 burrows<br>3 scat<br>1 remains | 8 |
| Great Basin Mixed Scrub (7) | poor | 6 burrows<br>6 scat<br>1 remains | 7 |
| Transition Mixed Scrub (3) | poor to fair | 3 burrows<br>2 scat | 7 |
| Blackbrush/Creosote (5) | fair | 15 burrow<br>2 scat<br>1 eggshell | 1 |
| Blackbrush (1) | poor to fair | 1 burrow | 1 |
| Sagebrush (2) | poor to very poor | 2 scat | 2 |
| Joshua Tree (2) | fair to poor | 1 burrow<br>1 scat | 2 |
| High Wash | | not sampled | |

study area, dominated by large alluvial fans, inset fans, and gentle ridge remnants. This corresponds to the area covered by the DOE for complying with the Endangered Species Act (U.S. DOE, 1989b). However, the state of Nevada survey also found tortoise signs in the uplands and along ridge remnants not surveyed by the DOE. These results confirm that the limited surveys conducted by the DOE corresponded to the tortoise's preferred habitat, but that some of the less favorable habitats at the Yucca Mountain site cannot be ignored, because animals do occur there.

The DOE repository siting program involves activities that include vegetation and topsoil removal, surface compaction, and alteration of the terrain (Table 4). Preliminary siting activities consisting largely of geologic and hydrologic field studies like drilling, trenching, and seismic surveys have been performed by the DOE at Yucca Mountain for over a decade. Additional proposed repository siting activities are similar to those already conducted, but additionally will include extensive underground mining and construction of surface support facilities such as buildings, utilities, muck piles, and effluent ponds (U.S. DOE, 1988b). Anticipated disturbances from such activities are generalized in Table 4 under "Bladed Use Areas."

The DOE has no accurate inventory of the extent and location of areas already disturbed, and no reclamation has occurred. To provide the state of Nevada with an understanding of the present condition of the site, a study was performed using remote sensing techniques to locate existing disturbed areas (ESA, 1989). Disturbance features were categorized according to climax vegetation, and ground truth data were used to identify the kind of activity that had caused disturbances. Results of the study are reflected in Tables 1, 2, and 4, showing that 255 hectares of disturbed area already exists at Yucca Mountain, and at least another 176 hectares is anticipated during site characterization.

## POTENTIAL FOR ECOLOGICAL RESTORATION

Ecological restoration of arid lands is highly problematic (Wallace *et al.*, 1980; Jordan *et al.*, 1988; Allen, 1988), and for this reason successful restoration of the Yucca Mountain ecosystem is not assured. The presence of the desert tortoise will complicate matters, depending on the extent to which efforts are made to restore the species' habitat. Studies by both the state of Nevada and the DOE at Yucca Mountain have focused only on occurrence of animals and not on distribution, cover, and forage. Thus, what follows here with respect to restoration potential does not include consideration

**Table 4. Existing and Proposed Disturbances from Repository Siting Activities at Yucca Mountain**

| Activity Type | Existing (# - ha) | Proposed (# - ha) |
|---|---|---|
| Drilling and coring | 62 - 36 | 365 - 50 |
| Trenching, test pits, and plots | 59 - 5 | 116 - 6 |
| Seismic surveys | 16 - 6 | unknown - 28 |
| Monitoring stations | 6 - 1 | unknown |
| Bladed use areas | 41 - 40 | unknown - 42 |
| Access roads, trails, and corridors | 313 - 166 | unknown - 50 |
| Erosion control | 5 - 1 | unknown |
| TOTAL AREA | 255 | 176 |

Kind of activity, numbers (#), and amount of disturbed area in hectares (ha).

of the desert tortoise, an issue that requires considerable research into the animal's ecology.

In many respects, managed ecological restoration is comparable to early secondary succession. Therefore, it is important to understand the processes and species involved in natural revegetation of disturbed areas. In deserts, natural revegetation is slow, and may require decades or centuries, primarily because precipitation is severely limited (Romney *et al.*, 1980; Wallace *et al.*, 1980; Lathrop, 1983; Vaseck *et al.*, 1975). Recovery speed also depends on factors like the degree of soil compaction, and in cases of severe disturbance, recovery may take as long as 1,000 to 2,000 years (Webb and Wilshire, 1980; Webb *et al.*, 1983). Information exists with respect to some species common to the Great Basin and the Mojave Desert that reestablish themselves naturally and are potentially suited to restoration at Yucca Mountain. The most promising of these are listed in Table 5, while another 43 require significant additional study (RCI, 1989b).

### Revegetation Practices

Management practices for reestablishing vegetation on arid lands involve providing plants or seeds, water, and sometimes nutrients at the proper time. At Yucca Mountain, the most limiting and critical factor is availability of soil water for plant development. Revegetation efforts without supplemental irrigation in regions with less than 25 to 30 centimeters of precipitation annually risk failure (DeRemer and Bach, 1978; Thornburg and Fuchs, 1978). In the Mojave Desert south of Yucca Mountain, irrigation typically is considered essential for seeding or transplanting vegetation (Kay and Graves, 1983). On the Nevada Test Site near Yucca Mountain, it was found that irrigation of transplants is needed during the first year, unless winter precipitation wets the soil to a depth of about 100 centimeters (Romney *et al.*, 1981). Instead of irrigation at Yucca Mountain, the DOE proposes using water harvesting and spreading by recontouring and reshaping the surface to collect and direct water to newly-established plants (U.S. DOE, 1988a). It remains to be seen whether this technique will be effective in place of irrigation.

In addition to measures for supplementing moisture, management options also include fertilizing, mulching, and fencing. Plant species currently recommended for deserts are adapted to conditions of low fertility, and the addition of nutrients may encourage only undesirable species that compete for water with preferred vegetation (Kay and Graves, 1983). The potential advantages of fertilizing should be determined on a site-specific basis, but such information for the Yucca Mountain site has yet to be developed. Mulching also is a useful practice, but has not been evaluated on sites like Yucca Mountain. Fencing, on the other hand, has been found essential for preventing grazers, such as lagomorphs and rodents, from otherwise destroying new plants. Grazing has been shown to be an especially acute problem near Yucca Mountain (Hunter *et al.*, 1980a and 1980b). Both mulching and fencing are among the practices to be evaluated during the DOE reclamation program for the Yucca Mountain site (U.S. DOE, 1988a and 1989).

Decisions on the use of containerized vegetation for transplanting will be influenced by the availability of plant material. Species like those listed in Table 5 are necessary for ecological restoration at the Yucca Mountain site, but in many cases are unavailable commercially in containers. Because seeds are not always available, it is advisable that in good years seeds be collected as close as possible to the site of interest and stored until needed (Kay and Young, 1988). This is especially important for the Yucca Mountain site, because it is likely that the plant species occurring there are adapted to an atypical environment for which it may be difficult to find suitable analogs. Commercial availability of containerized plants also may be complicated by the site's atypical environmental setting.

Studies involving the western Mojave desert concluded that managed, artificial revegetation neither hastened consistently nor improved ecological recovery of disturbed sites (Kay and Graves, 1983; Kay, 1988). Similar results were obtained from an unpublished study for the U.S. Soil Conservation Service near Caliente, Nevada, east of Yucca Mountain (RCI, 1989b). Of plantings made in 1987, the

**Table 5. Plant Species Considered to be Suited for Ecological Restoration at Yucca Mountain (From RCI, 1989b).**

| Scientific and Common Names | Known to Naturally Reestablish | Has Been Seeded or Transplanted | Recommended But Not Tested |
|---|---|---|---|
| *Acampotopapus Schockleyi* (Shockley goldenhead) | X | | X |
| *Ambrosia dumosa* (bursage) | X | X | X |
| *Atriplex canescens* (fourwing saltbush) | X | X | X |
| *Atriplex confertifolia* (shadscale) | X | | X |
| *Bromus rubens* (red brome) | X | | X |
| *Ceratoides lanata* (winterfat) | X | X | X |
| *Chrysothamnus nauseosus* (rubber rabbitbrush) | X | X | X |
| *Ephedra nevadensis* (Nevada ephedra) | X | X | X |
| *Hymenoclea salsola* (cheesebush) | X | X | X |
| *Larrea tridentata* (creosote bush) | X | X | X |
| *Ledidum fremontii* (desert alyssum) | X | | X |
| *Lycium andersonii* (Anderson desert thorn) | X | | X |
| *Oryzopsis hymenoides* (Indian ricegrass) | X | X | X |
| *Stipa speciosa* (desert needlegrass) | X | | X |

results of only a few were considered to be fair or good one year later, and after two years, almost none of the vegetation survived. Transplanting vegetation grown in containers and irrigating during the first growing season is the most viable option for revegetating arid sites like Yucca Mountain (Romney *et al.*, 1981). The DOE's preference for water harvesting and spreading over irrigation at Yucca Mountain may limit the chances of successful ecological restoration.

**Estimated Costs**

Restoration costs are influenced greatly by the features of a site. For the state of Nevada's estimate of costs for the Yucca Mountain site, the types of landforms, vegetation, soils, and disturbed areas were used to establish categories, reflecting the level of effort anticipated to be involved with site restoration. The resulting classifications were matched with prescribed reclamation and restoration practices (*e.g.*, soil scari-

Table 6. Amount of Existing Disturbed Area at the Yucca Mountain Site and Estimated Costs (1988 Dollars) of Ecological Restoration Classified by Cause of Disturbance and Landscape Category.

| Disturbance Type and Landscape Category | Hectares | Cost/Hectare ($) | Total Cost ($) |
|---|---|---|---|
| Graded disturbances | | | |
| Restrictive | 30 | 101,300 | 3,039,000 |
| Nonrestrictive | 150 | 78,300 | 11,745,000 |
| Nongraded disturbances | | | |
| Restrictive | 8 | 76,900 | 615,000 |
| Nonrestrictive | 42 | 74,000 | 3,108,000 |
| Improved roads | 25 | 115,800 | 2,895,000 |
| TOTALS | 255 | – | 21,402,000 |

fication, contouring, seeding, fertilizing, mulching, and irrigating) used in the Mojave Desert and the Great Basin (Kay and Graves, 1983; Kay, 1988; RCI, 1989b). This information served as the basis for cost estimates for the Yucca Mountain site (ESA, 1989; RCI, 1989b). The categories adopted for the disturbed areas were "graded" and "nongraded," to indicate where topsoil had been removed, thus making revegetation more difficult and costly. For landscape features, the categories used were "restrictive" and "nonrestrictive," to represent two levels of difficulty based on terrain features, with the former reflecting the greater degree of effort needed for restoration. Involved in restoring the Yucca Mountain site would be: (1)reshaping disturbed land to approximate original contour, (2)providing a substrate suitable for plant growth, (3)revegetating with previously-existing species in an effort to approximate the original plant communities, and (4)providing supplemental nutrients and moisture to enhance plant establishment.

Results of the cost estimates for restoring existing disturbed land at Yucca Mountain are summarized in Table 6. The estimated costs ranged from $74,000 to $115,800 per hectare, and the total estimated cost was about $21,400,000. Comparative information on the costs for restoration of arid ecosystems is sparse, but field experiments on restoration in Wyoming reported a cost of $8500 per hectare (Jordan *et al.*, 1988). The approximate order of magnitude difference for the Yucca Mountain site is due to the rugged terrain, harsh climate, remoteness of the site, complexity of plant composition, lack of readily available containerized nursery stock and seeds for species adapted to the site, and the need for irrigation for at least one year following attempts to reestablish vegetation (RCI, 1989b). Per unit area costs for restoring future disturbed areas at Yucca Mountain should be comparable to those given in Table 6. However, because of the large uncertainty with respect to the amount of additional land to be disturbed at Yucca Mountain, no attempt was made to estimate total reclamation costs that ultimately could result from DOE site characterization.

## DISCUSSION AND CONCLUSIONS

Although the DOE Yucca Mountain Project can be viewed as an opportunity to demonstrate the efficacy of restoration ecology and to further the application and acceptance of restoration in federal environmental policy, such a perspective holds uncertain promise, because restoring desert ecosystems is problematic. Discussions like those presented in Allen (1988) emphasize that the convergence of theory and practice has not been achieved yet with respect to restoration of disturbed arid lands. Concepts and theories remain to be proven, and effective methods and techniques have to be developed (Wallace *et al.*, 1980; Jordan *et al.*, 1988). At Yucca Mountain, costs also may prove to be a concern, because of the rugged terrain.

While it would be encouraging to believe that the mandate to restore the Yucca Mountain site is evidence of a restoration ethic in Congress, that interpretation is questionable. Often a restoration ethic is associated with the belief that preexisting climax vegetation at a site can be returned successfully following ecosystem disturbance, and that unless this can be achieved, a site should not be altered (Bradshaw and Chadwick, 1980). It is questionable whether the policymakers involved in the NWPA and the DOE nuclear waste program really comprehended the implications of requiring ecological restoration at Yucca Mountain. Little is known about restoration of transition desert ecosystems, and practice has been limited largely to stabilization for purposes of erosion control and aesthetics. Even these efforts typically fail. Thus, if successful ecological restoration were a criterion for siting a nuclear waste repository, it seems unlikely that the Yucca Mountain site would have been singled out from the range of alternative sites available when the Nuclear Waste Policy Act was amended in 1987. Because of limitations to restoration imposed by ecologic and economic factors, there can be no argument that Yucca Mountain is among the least likely of sites to hold any reasonable degree of potential for successful restoration.

Despite the present discouraging prognosis for successful ecological restoration at Yucca Mountain, the work of Wallace *et al.* (1980) can be viewed as a starting point for establishing management practices applicable to the site. They concluded that a better understanding is needed of the following: (1)water harvesting and irrigation, (2)fertilization and addition of organic soil amendments, (3)preserving fertile islands as sources of propagules for species critical for revegetation, and (4)using pioneer species and vigorous shrubs species adapted to the site.

Allen (1988) has emphasized ecological landscape approaches that enhance successional processes as a feasible approach for restoration of disturbed arid lands. Clearly, for the Yucca Mountain site, a creative approach to restoration planning will be needed. As the DOE continues to plan its environmental program, it should identify critical information needs and implement a pilot ecosystem restoration study aimed at developing methods and guidelines that are effective and practical. Among the critical issues that remain to be addressed and resolved is the extent to which the desert tortoise and its habitat will be considered in restoration planning. Important matters such as inclusion or exclusion of exotic species like red brome (*Bromus rubens*) also have to be considered for the Yucca Mountain restoration program.

An undecided fundamental issue for the Yucca Mountain site is whether ecological restoration will be modeled on structural/functional characteristics. The goals by which the success of restoration at the site can be judged remain to be established, as there are no criteria, guidelines, or endpoints for the program. There is, for example, indecision and controversy over such matters as selecting baseline environmental conditions. The DOE proposes using the disturbed, post-site characterization condition for its ecological baseline, and plans to characterize fully the Yucca Mountain ecosystem only after the impacts of siting studies have occurred (U.S. DOE, 1988a; Parker *et al.*, 1990). The state of Nevada, on the other hand, holds that the undisturbed, pre-site characterization environment should constitute the baseline (Malone, 1990a; Winsor and Malone, 1990).

The DOE ecological restoration program also should include a monitoring plan with schedules for obtaining information about the success of restoration efforts and contingency plans for implementing, if monitoring shows restoration efforts to be unsuccessful. A study for the state of Nevada (RCI, 1989b) recommended that one group conduct all monitoring activities and that a committee meet with the group to establish standards and methodologies for determining results of the alternative restoration practices investigated. The study also recommended that a clearinghouse be designated to maintain information about restoration practices. These ideas are not included in the DOE's draft environmental program plans for the Yucca Mountain Project (U.S. DOE, 1988a and 1989; Parker *et al.*, 1990).

Not addressed here are the DOE plans for repository construction, operation, closure, and abandonment, which are in the conceptual stage only. It is believed that during development of the repository, an additional 400 to 500 hectares of land will be disturbed (U.S. DOE, 1986). Especially noteworthy is that entombed nuclear waste at Yucca Mountain is expected to cause an increase of as much as 3 °C at the surface of the repository (U.S. DOE, 1988b; Blejwas, 1990). The elevated temperature is expected to last up to 1,000 years, and could effect ecosystem recovery drastically. The heat also could induce uplifting and fracturing of the repository overburden that, along with inhibited revegetation of the disturbed area, would contribute to accelerated erosion. Impacts of this nature not only would affect future ecosystems at Yucca Mountain, but also could alter the site's long-term physical integrity and ability to contain nuclear waste safely. These concerns are among many that remain to be addressed by the DOE and are indicative of the complexity and uncertainty that characterize the effort to dispose of high-level nuclear waste in a geological repository at Yucca Mountain safely (Lemons *et al.*, 1989; Lemons and Brown, 1990; Malone, 1990a, 1990b, and 1990c).

Despite many unresolved issues, the DOE Yucca Mountain Project provides an unusual opportunity for extensive, well-funded, long-term research and study. If adequately conceived and executed, the ecosystem restoration program could test the premise put forth in Allen (1988) that an ecological basis exists for developing means for restoring disturbed arid lands. The project provides an opportunity for the discipline of restoration ecology to benefit from efforts to determine what is reasonable and necessary for returning a desert ecosystem to a predisturbed condition. An unusual opportunity also is at hand for demonstrating the efficacy of ecological restoration as an integral component of federal environmental policy. Although the Yucca Mountain site may not be an ideal ecological laboratory for these purposes, it is an opportunity that should not be missed. The DOE ecosystem restoration program deserves the attention of restoration researchers and practitioners alike.

## REFERENCES

Allen, E.B., ed. 1988. *The Reconstruction of Disturbed Arid Lands: An Ecological Approach*. Westview Press, Inc., Boulder, CO.

Blejwas, T.E. 1990. Influence of Thermally-Induced Effects on Repository Design. Report No. NMTHIM5P A24/3, 20-90. Sandia National Laboratory, Albuquerque, NM.

Bonnicksen, T.M. 1988. Restoration Ecology: Philosophy, Goals, and Ethics. *The Environmental Professional* 10: 25-35.

Bradshaw, A.D. and M.J. Chadwick. 1980. *The Restoration of Land*. University of California Press, Berkeley.

DeRemer, D., and D. Bach. 1978. Irrigation of Disturbed Lands. In *Reclamation and Use of Disturbed Land in the Southwest*, J.L. Thames, ed. University of Arizona Press, Tucson, pp. 224-237.

(ESA) Environmental Science Associates, Inc. 1989. Interim Impact Assistance Report: Past DOE Disturbance Inventory and Estimated General Reclamation Costs, Yucca Mt., Nevada. San Francisco, CA.

(ESA) Environmental Science Associates, Inc. 1990. 1989 Vegetation Studies at Yucca Mountain, Nye County, Nevada. San Francisco, CA.

Hunter, R.B., E.M. Romney, and A. Wallace. 1980a. Rodent-Denuded Areas of the Northern Mojave Desert. *Great Basin Naturalist Memoirs* 4: 208-211.

Hunter, R.B., A. Wallace, and E.M. Romney. 1980b. Fencing Enhances Shrub Survival and Growth for Mojave Desert Revegetation. *Great Basin Naturalist Memoirs* 4: 212-215.

Jordan, W.R., R.L. Peters, and E.B. Allen. 1988. Ecological Restoration as a Strategy for Conserving Biological Diversity. *Environmental Management* 12: 55-72.

Karl, A.E. 1989. Yucca Mountain Project: Investigations of Desert Tortoise Abundance and Distribution on the Focused Baseline Study Area, Fall 1989 Field Studies. San Francisco, CA.

Kay, B.L. 1988. Artificial and Natural Revegetation of the Second Los Angeles Aqueduct. Mojave Revegetation Note 24. Agronomy and Range Science Department, University of California, Davis.

Kay, B.L., and W.L. Graves. 1983. Revegetation and Stabilization Techniques for Disturbed Desert Vegetation. In *Environmental Effects of Off-Road Vehicles, Impacts, and Management in Arid Regions*, R.H. Webb and H.G. Wilshire, eds. Springer-Verlag, New York, pp.324-240.

Kay, B.L., and J.A. Young. 1988. Long-Term Storage of Desert Shrub Seed. Mojave Revegetation Note 23. Agronomy and Range Science Department, University of California, Davis.

Lathrop, E.W. 1983. Recovery of Perennial Vegetation in Military Maneuver Areas. In *Environmental Effects of Off-Road Vehicles, Impact, and Management in Arid Regions*. R.H. Webb and H.G. Wilshire, eds. Springer-Verlag, New York, pp. 152-166.

Lemons, J., and D.A. Brown. 1990. The Role of Science in the Decision to Site a High-Level Nuclear Waste Repository at Yucca Mountain, Nevada, USA. *The Environmentalist* 10(1): 3-24.

Lemons, J., C. Malone, and B. Piasecki. 1989. America's High-Level Nuclear Waste Repository: A Case Study of Environmental Science and Public Policy. *International Journal of Environmental Studies* 34: 25-42.

Malone, C.R. 1990a. Implications of Environmental Program Planning for Siting a Nuclear Waste Repository at Yucca Mountain, Nevada, USA. *Environmental Management* 14: 25-32.

Malone, C.R. 1990b. Performance Assessment and Long-Term Environmental Problems. *Project Appraisal* 5(3): 134-138.

Malone, C.R. 1990c. Geologic and Hydrologic Issues Related to Siting a Repository for High-Level Nuclear Waste at Yucca Mountain, Nevada, USA. *Journal of Environmental Management* 30: 381-396.

Parker, G.J., J.R. Krummel, K.E. LaGory, G.J. Marmer, and S.P. Goel. 1990. The Environmental Protection Program for Site Characterization at Yucca Mountain, Nevada. *The Environmental Professional* 12: 186-196.

(RCI) Resource Concepts, Inc. 1989a. Soil Survey of Yucca Mountain Study Area, Nye County, Nevada. Carson City, NV.

(RCI) Resource Concepts, Inc. 1989b. Review of Revegetation Practices Appropriate for Reclamation of the Proposed Nuclear Waste Repository at Yucca Mountain, Nevada. Carson City, NV.

Romney, E.M., R.B. Hunter, and A. Wallace. 1981. Environmental Effects of Solar Thermal Power Systems—Experiments on Restoration of Disturbed Desert Land by Means of Revegetation. UCLA 12-1312 (UC/11,62). Laboratory of Biomedical and Environmental Sciences, University of California, Los Angeles.

Romney, E.M., A. Wallace, and R.B. Hunter. 1980. The Pulse Hypothesis in the Establishment of *Artemisia* Seedlings at Paiute Mesa. *Great Basin Naturalist Memoirs* 4: 28-30.

Thornburg, A.A., and S.H. Fuchs. 1978. Plant Materials and Requirements for Growth in Dry Regions. In *Reclamation and Use of Disturbed Land in the Southwest*, J.L. Thames, ed. University of Arizona Press, Tucson, pp.411-423.

(U.S. DOE) U.S. Department of Energy. 1986. Nuclear Waste Policy Act (Section 112) Environmental Assessment: Yucca Mountain Site, Nevada. DOE/RW-0073, Vols. 1-3. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1988a. Draft Environmental Program Overview. DOE/RW-0207. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1988b. Site Characterization Plan: Yucca Mountain Site, Nevada. DOE/RW-0199. Washington, DC.

(U.S. DOE) U.S. Department of Energy. 1989. Draft Reclamation Program Plan for Site Characterization, Yucca Mountain Project. DOE/RW-0244. Washington, DC.

(U.S. DOI) U.S. Department of Interior. 1989. Endangered and Threatened Wildlife and Plants: Emergency Determination of Endangered Status for the Mojave Population of the Desert Tortoise. *Federal Register* 54 (149): 32326-32331.

(US/IBP) U.S. International Biological Program. 1978. *US/IBP Synthesis Series* 9. Dowden, Hutchinson & Ross, Inc., Stroudsburg, PA.

Vasek, F.C., H.B. Johnson, and D.H. Eslinger. 1975. Effects of Pipeline Construction on Creosote Bush Scrub Vegetation of the Mojave Desert. *Madrono* 23: 1-13.

Wallace, A., E.M. Romney, and R.B. Hunter. 1980. The Challenge of a Desert: Revegetation of Disturbed Desert Lands. *Great Basin Naturalist Memoirs* 4: 216-225.

Webb, R.H., and H.G. Wilshire. 1980. Recovery of Soils and Vegetation in a Mojave Desert Ghost Town, Nevada, U.S.A. *Journal of Arid Environments* 3: 291-303.

Webb, R.H., H.G. Wilshire, and M.A. Henry. 1983. Natural Recovery of Vegetation Following Human Disturbance. In *Environmental Effects of Off-Road Vehicles, Impacts, and Management in Arid Regions*. R.H. Webb and H.G. Wilshire, eds. Springer-Verlag, New York, pp. 279-314.

Winsor, M.F., and C.R. Malone. 1990. State of Nevada Perspective on Environmental Program Planning for the Yucca Mountain Project. *The Environmental Professional* 12: 196-207.

# ATTACHMENT N

# *Roundtable*

# High-level nuclear waste disposal and long-term ecological studies at Yucca Mountain

Yucca Mountain, in southern Nevada, is a volcanic ridge (elevation 1494 meters) that sits astride a little-known transition area at the juncture of the Mojave and Great Basin deserts (Figure 1). Ecologically dominant plants are desert shrubs, grasses, and forbs that are adapted to arid conditions. A unique program is under way at Yucca Mountain that has significant ecological and environmental implications.

The 175-square-kilometer site (Figure 2), managed by the US Department of Energy (DOE), is being considered for permanent disposal of the nation's commercially generated and defense related high-level nuclear waste. Studies to determine the suitability of the location for a deep geologic repository for permanent emplacement of the waste are to begin this year and will require 7 to 12 years to complete. If the location proves acceptable, repository development (i.e., construction, operation, closure, and site restoration) is expected to proceed for another 30 to 40 years. Concurrent with repository development, and for an indefinite period afterward, ecological and environmental monitoring is to be conducted to provide for successful restoration of the site's ecosystem and to confirm that the entombed nuclear waste remains isolated.

The proposed site-characterization studies and monitoring activities are intended to provide assurances that high-level nuclear waste and associated hazardous chemicals can be isolated from the biosphere for at least 10,000 years. A technological and physical performance-assessment methodology is being developed, in conjunction with environmental and safety assessments, to demonstrate that a combined engineered and natural geologic disposal system at Yucca Mountain will provide long-term protection to the environment and human health from radioactive and other hazardous materials. Specifically, performance assessment is to include projections of future geologic events that could affect repository performance; of evolving climatic factors and the availability of surface- and groundwater; of hydrologic factors that control availability of water, transport of radionuclides to the environment, and ecosystem development; of ecological factors that influence the environment; and of pathways by which radionuclides might reach humans. Such an ambitious effort has never before been attempted.

The complex issues of intergenerational environmental consequences make the success of the Yucca Mountain program especially important. However, we question whether aspects of the scientific underpinning of the program are sound and whether it will afford adequate assurances of protecting the environment and human health. In this article, we discuss environmental objectives for the Yucca Mountain project and the policy that has resulted in the current environmental program. We conclude with a critique of the program's shortcomings and provide a rationale for redirecting it to accommodate baseline and long-term ecological studies that would enhance assessment of repository performance and minimize potential adverse effects. Further, we argue that a restructured and comprehensive environmental


Figure 1. Location of the proposed high-level nuclear waste repository at Yucca Mountain, Nevada.

by John Lemons and
Charles Malone

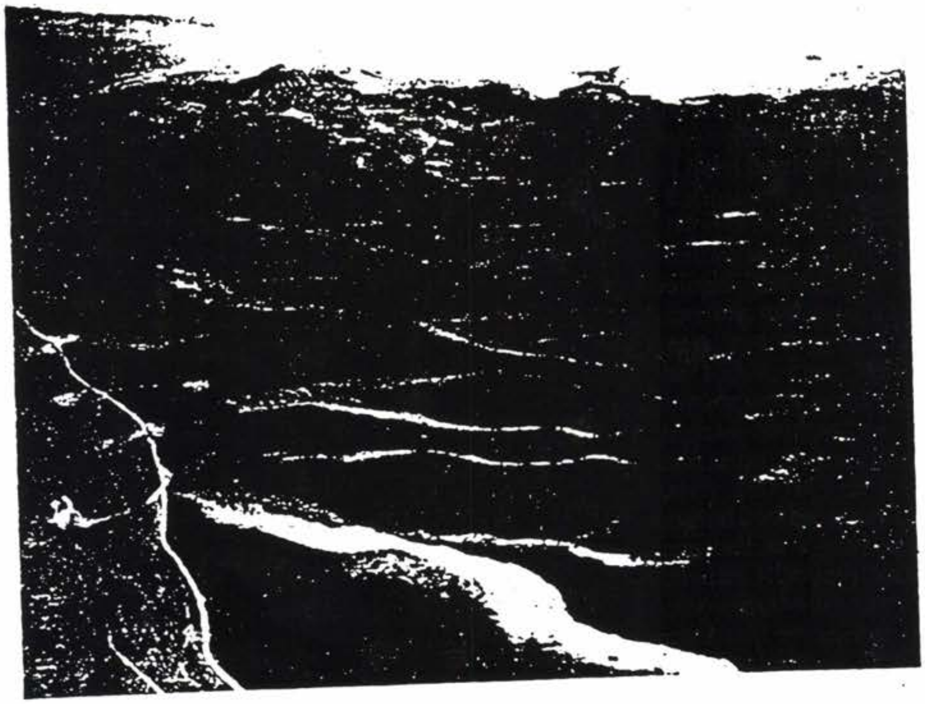

Figure 2. Yucca Mountain.

program would increase opportunities for basic long-term ecological research on desert ecosystem structure and function. A considerable need exists for such research.

Our current involvement in the Yucca Mountain project complements our previous work in interdisciplinary environmental research at Yucca Mountain (e.g., Brown and Lemons 1991, Lemons and Brown 1990, Lemons and Malone 1989, Lemons et al. 1989, 1990, Malone 1990a,b, Winsor and Malone 1990). Our work has been performed in our respective capacities as an independent university professor and as an environmental scientist for the Nevada Agency for Nuclear Projects, the state agency authorized by the Nuclear Waste Policy Act (NWPA), as amended, to review DOE's nuclear waste repository environmental program at Yucca Mountain.

## The policy of geologic disposal

With passage of NWPA in early 1983, it became national policy to permanently dispose of high-level nuclear waste in deep geologic repositories (Carter 1987). The concept of geologic disposal relies on the characteristics of a natural environmental system to isolate radioactive materials and hazardous chemicals from the biosphere for a sufficient length of time to protect the environment and human health. NWPA establishes this time-length as 10,000 years, based on the anticipated durability of engineered canisters to retain waste materials for 300–1000 years before corrosion results in release of waste into the repository cavern. Safe sequestering of the waste for the balance of the isolation period depends on the integrity of the natural geologic setting in which a repository is constructed.

A procedure for selecting suitable sites for two repositories was set forth by NWPA. The act also designated DOE as the agency responsible for the geologic repository program (Parker et al. 1990). After DOE failed to identify sites for characterization studies under provisions of NWPA, the act was amended by the Nuclear Waste Policy Amendments Act (NWPAA) in late 1987 to simplify the task of repository site selection (Cooper 1989, Lemons et al. 1989). NWPAA mandated that only one repository be constructed, so only one site needed to be investigated for suitability. A year earlier, DOE (1986) had judged the Yucca Mountain site as the most likely of three sites under active consideration to be acceptable for a repository. Accordingly, NWPAA terminated the search for alternative repository sites and focused the efforts of DOE solely on the Yucca Mountain site, where preliminary siting activities had been carried out since the 1970s.

Repository siting investigations involve typical construction and mining activities such as exploratory drilling, geologic trenching, seismic studies, tunneling, and building the associated access and support structures (Malone 1990a, Parker et al. 1990). Preliminary work at the Yucca Mountain site has resulted in disturbance to vegetation and soils on approximately 260 hectares of land. An additional 210 hectares is expected to be disturbed as a result of further siting activities scheduled to begin this year. Although the full extent of disturbance that would result from repository development over the course of several decades has not been firmly established, there may be an additional 500–1000 hectares of land disturbed, principally as a result of rail and highway access and surface facilities needed for repository construction and waste processing and packaging.

The repository program does not include adequate planning for baseline or long-term ecological studies, which are now considered necessary for environmental assessment (DOE 1989, National Research Council 1990, Winsor and Malone 1990). The program should be restructured to assess cumulative effects and to include long-term ecological studies to determine the projected effects of repository performance on the environment and projected effects of environmental perturbations on repository performance.

There are several reasons for gathering baseline information and conducting long-term ecological studies at Yucca Mountain. First, the desert ecology of Yucca Mountain is fragile and has not been studied adequately (Beatley 1980, Collins et al. 1981 Winsor and Malone 1990). Second there is no accepted method for evaluating repository performance (Buxton 1989, Lieberman and Lee 1986) An acceptable method would likely require adequate consideration of ecological baseline conditions at the repository site and long-term ecological studies to assess repository performance (Malone 1990b). The cur rent DOE plans do not include gathering of site-specific baseline data before undertaking additional characterization activities or plans for long-term ecological studies (Parker et al. 1990). Third, a number of countries are considering disposal of high-level nuclear waste, but none are as advanced in implementing a program as is the United States. Information on baseline conditions and long-term ecological studies are of potential interest to others involved in nuclear-waste siting issues (Garcia 1989, McCombie et al. 1989, van Dorp et al. 1989). Fourth, because the Yucca Mountain repository site will be protected from human intrusions (other than those due to the repository), it can serve as an ecological study area for long-term research. Knowledge from ecosystem studies conducted at the site could make a significant contribution to understanding of desert ecology.

## Requirements for short-term environmental information

The Yucca Mountain project is different from traditional technological programs with respect to environmental regulation and attendant information needs. For example, the repository siting program is exempt from some major requirements of the National Environmental Policy Act (NEPA) for environmental documentation and review. Instead of requiring preparation of an environmental impact statement (EIS) for repository siting, NWPA required only a preliminary environmental assessment (EA). To speed the process, NWPA prohibited acquisition of any new data for the EA, thus requiring DOE to rely on incomplete information, much of which was of a regional generic nature as opposed to being site-specific.

The exemption from traditional NEPA review was meant to be compensated for by a subsequent detailed, site-specific investigation program. Thus the preliminary EA (DOE 1986) for the Yucca Mountain site did not contain complete information on biota at the site, contained no information on soils or effects on soils, contained no information on air quality and meteorological conditions at the site, and did not address water resources, including potential effects on ground water quality (Winsor and Malone 1990). Without adequate site-specific information, the EA concluded there would be no significant environmental impacts from repository siting activities (DOE 1986). It was on the basis of this document that the decision was made to select Yucca Mountain, as opposed to another site, as the sole location to be considered for a repository.

Consequently, DOE accepted the preliminary EA as evidence that repository siting activities would not result in significant environmental impacts (DOE 1988, Parker et al. 1990). DOE sought to comply with further requirements of NWPA, as amended, regarding the need to minimize effects expected from the siting program, mitigate any effects that did occur, and return the site to its previous condition if it proved unsuitable for a repository. It was reasoned by DOE decision-makers that because the preliminary EA found that no significant effects were expected from repository siting, it was unnecessary to conduct many detailed ecological studies and environmental analyses of pre-site characterization conditions at Yucca Mountain. However, to comply with the stipulations about impact mitigation and site restoration, it was necessary for DOE at least to plan for a limited program that would address the specific locations to be directly disturbed by proposed siting activities.

The DOE environmental program plan for the Yucca Mountain project follows directly from the requirements of NWPA, as amended, rather than constituting an approach based on the principles of integrated environmental management (DOE 1988, Winsor and Malone 1990). The plan consists principally of ecological surveys of areas to be disturbed, follow-up surveys after an activity is completed, and reclamation protocols for restoring the area to its prior ecological condition. A minor aspect of the program plan focuses on field activities that might be necessary for complying with limited environmental statutes and regulations that might apply outside of NWPA and NEPA.

The plan is not comprehensive either with respect to all important components of the environment or the entirety of the 175-square-kilometer Yucca Mountain site. As a consequence, the program does little to compensate for the absence of a comprehensive description of baseline environmental conditions. Furthermore, site-characterization activities could alter the fundamental nature of the ecosystem without those characteristics ever having been described in terms of ecological integrity, biological diversity, or ecosystem structure and function (Malone 1990b).

## Need for long-term ecological research

Additional regulatory requirements relevant to an assessment of needs and prospects for long-term ecological research stem from NWPA, as amended, and other regulatory standards (Brown and Lemons 1991). The US Environmental Protection Agency has promulgated containment standards (40 CFR 191) for protecting human health and the environment from excessive releases of radionuclides from a high-level nuclear waste repository. These include standards that limit projected releases of radioactivity from the repository to the interface of the geosphere with the biosphere for 10,000 years after disposal. There are no standards that require consideration of the movement and consequences of radionuclides that enter the biosphere. However, NWPA, as amended, calls for preparation of an EIS pursuant to NEPA that addresses the consequences of developing a repository at Yucca Mountain.

Although planning for the EIS will not begin until at least 1997, it can be presumed that long-term effects that might be caused to the environment and to human health due to releases of radionuclides and persistent hazardous chemicals will be addressed in the context of protecting future generations, as required by NEPA. To accommodate such analyses, it is imperative that a long-term ecological perspective be taken. This work should be done on the basis of a sound description of existing environmental conditions at Yucca Mountain. However, by postponing the planning of such studies for an additional 5–10 years, the baseline conditions for ecological analyses will be those of the environment after site characterization rather than of the original environment. This is a significant consequence of exempting the siting program from preparing a traditional EIS in accordance with NEPA, and it is unfortunate given the fragile nature of the Yucca Mountain site and what little we know about it.

Most ecological studies in the vicinity have been conducted at the Nevada Test Site (Collins et al. 1981). Conclusions from these studies focus on the importance of air and soil temperatures in the distribution of flora, soil fungi in micronutrient cycling, shrubs in soil-forming processes, and activity of Hymenoptera, which is associated with soil temperatures and moisture, and the role of that group in the decomposition process. However, according to the studies, no definitive soil surveys have been conducted, knowledge of physiological characteristics of flora has been derived mostly from greenhouse and laboratory studies, most soil-mineral plant relationships are unknown, and most types of insects and their functional roles are poorly known. Few site-specific studies have focused on important ecological parameters, including those necessary for long-term studies (Franklin et al. 1990, Magnuson 1990, Swanson and Sparks 1990). Further, DOE has no plans to conduct research on many of these parameters.

Recently, the Nuclear Waste Technical Review Board (NWTRB 1990) concluded that site characterization activities are not as negligible as stated in the Yucca Mountain EA. Consequently, it recommended that DOE should provide data to support its findings of negligible effects or should expand the scale of its ecosystem studies so that site characterization effects can be evaluated more fully.

DOE has decided not to study the implications and potential consequences of radionuclide releases into the biosphere or the effects of environmental perturbations on the repository's geohydrological setting (DOE 1988, Malone 1990a). This decision is predicated, in part, on 40 CFR 191, which establishes regulatory standards for the movement of radioactive waste through the geosphere to but not including into the biosphere. Although DOE may have a regulatory basis for its decision to exclude studies of radionuclides in the biosphere, it should be acknowledged that the decision was made even though researchers believe long-lived radionuclides ultimately will escape and be dispersed in the biosphere, either from repository failure or from environmental perturbations that may alter the repository's geohydrological barriers (Egan et al. 1989, National Research Council 1990, Ross 1989).

For example, the nuclear waste stored in the repository is projected to generate sufficient heat to increase soil surface temperature by 2–6° C (Blejwas 1990, NWTRB 1990). The temperature increase is expected to occur while the repository is being filled and to last for a period of approximately 1000 years. This warming may result in 200–300 cm of induced uplifting above the repository. A projected result of uplifting is the fracturing of the repository's geologic overburden, which can create new routes for groundwater to infiltrate and for stored wastes to exit the repository. The rate of soil erosion would also likely accelerate and further damage the environment or induce changes in the site's landscape and geohydrological characteristics. Such changes in the repository setting might increase gaseous fluxes of $^{14}C$, tritium, and other radionuclides into the biosphere at Yucca Mountain (NWTRB 1990).

Another environmental pertubation that can be expected to affect long-term repository performance is regional climate change due to buildup of greenhouse gases in Earth's atmosphere. Climate change could alter characteristics of the repository's geohydrologic setting and ecosystem successional states, thereby affecting radionuclide cycling in the biosphere.

Assessing the risks to humans from releases of radionuclide and hazardous chemicals is also complicated by Kirchner's (1990) critique of models used to calculate hazards after failure of a geologic repository. He shows that calculations of hazards to humans must include simultaneous consideration of isotopic composition of the waste, transport of radionuclides to humans, and cycling in the biosphere. They must also consider time-dependent changes of the potential for risk due to radioactive buildup and decay processes after disruption of the repository and the entry of waste into the biosphere. Models that include ecosystem processes increase required isolation times by several orders of magnitude compared with models that are based only on radionuclide composition and radiotoxicity to humans.

The parameters identified by Kirchner cannot be included in performance assessments of the Yucca Mountain repository unless DOE decides to conduct long-term studies of radionuclides released into the environment. In contrast to the US plans, which exclude study of long-term effects of radionuclides that enter the biosphere and of how physical conditions at the site may be altered by repository performance, European repository plans rely on environmental modeling in an endeavor to understand and quantify the fates and consequences of radionuclides in the biosphere over periods of tens of thousands to millions of years (Garcia 1989, van Dorp et al. 1989).

DOE will have to assess the fate and effects of radionuclides in the biosphere and risks to future generations beyond the 10,000-year period when it conducts the EIS required by NEPA, as modified by NWPA, for repository construction. However, the assessment is likely to be flawed by current DOE decisions to forego analysis of cumulative effects from site characterization activities, by not having a reliable and definitive baseline, and by not performing comprehensive and integrated ecological studies.

## Conclusions

Provisions of NWPA/NWPAA and DOE policies have defined the environmental program for the planned high-level nuclear waste repository at Yucca Mountain. The provisions and policies have resulted in plans to collect limited environmental data for purposes of monitoring and mitigating effects of proposed characterization activities and repository development. Consequently, the program consists of overviews of the environmental program, reports of plans for environmental monitoring and mitigation, regulatory requirements, and field activities for acquisition of environmental information to support monitoring, mitigation, regulatory compliance, and site reclamation. Accordingly, DOE's environmental plans, with the exception of those pertaining to field activities, are procedural and do not provide for the gathering of baseline data before site characterization activities.

The absence of baseline data before site characterization activities reduces the chances of developing a comprehensive and integrated environmental program. Unmonitored effects would not be detected, and remediation of disturbed areas critical to the performance of the repository would not occur or would be compromised. The absence of appropriate baseline studies coupled with the lack of long-term ecological studies will limit understanding of interactions between the geohydrologic setting of the repository and the biosphere. In other words, it may not be possible to assess how the repository potentially affects the environment (e.g., soil temperature increases from stored radionuclides or the effects of the changing composition of radionuclides over time) or how environmental perturbations affect repository performance (e.g., uplifting or fracturing of the repository overburden due to heat release from stored radionuclides or regional climate change). Consequently, significant uncertainty will exist about the effects of repository performance on the biosphere and to future generations.

NWTRB (1990) has stated its belief that there is no scientific or technical reason why a satisfactory geologic repository cannot be built. However, it notes that success for the repository program depends on meeting public concerns about long-term safety of repository performance. The environmental program at Yucca Mountain should be restructured to permit assessment of characterization activities on the site's ecosystem and to provide a basis for understanding fates and pathways for radionuclides that might escape the repository's geohydrologic surrounding. Specifically, such a program might entail development of comprehensive and integrated ecological studies to obtain baseline information before site characterization activities, assess the effects of repository performance on the site's ecosystem and integrity of the repository's geohydrologic surroundings, assess the effects of environmental perturbations on repository performance, assess the distribution and transport of radionuclides in the biosphere, assess implications to the biosphere of the changing composition of radionuclides over time, and estimate risks from radionuclides to future generations both within and beyond a 10,000-year time frame.

There are two additional reasons for restructuring the environmental program at Yucca Mountain, a site that will be protected from most human intrusions other than those related to the repository. First, data from a comprehensive scientific research program would complement radioecological studies gathered from other nuclear facilities, such as Oak Ridge, Savannah River, the Idaho National Engineering Laboratory, Hanford, and Los Alamos. Second, the site could serve as a site for basic long-term ecological research pertaining to desert ecosystem structure and function. Recently, the importance of obtaining data from long-term ecosystem studies and expanding the network of scientists and research sites to provide comparative analyses has been documented (Franklin et al. 1990, Magnuson 1990, Swanson et al. 1990). Long-term studies are uncommon despite the obvious need and the evidence that short-term research results are misleading.

We believe we have demonstrated both a need and a potential for long-term ecological studies at Yucca Mountain, due to the anticipated 30–50 year longevity of the DOE repository program and requirements for continued environmental and ecological monitoring. Such studies depend on the willingness of DOE to develop an environmental program consistent with that need and potential.

## References cited


Beatley, J. C. 1980. Fluctuations and stability in climax shrub and woodland vegetation of the Mojave, Great Basin, and transition deserts of southern Nevada. *Isr. J. Bot.* 28: 149–168.

Blejwas, T. E. 1990. Influence of thermally-induced effects on repository design. NMTH1M5P A24/3–19, 20–90. Sandia National Laboratories, Albuquerque, NM.

Brown, D. A., and J. Lemons. 1991. Scientific certainty and the laws that govern the location of a high-level nuclear waste repository. *Environ. Manage.* 15: 311–319.

Buxton, B. E. 1989. *Geostatistical, Sensitivity, and Uncertainty Methods for Ground-Water Flow and Radionuclide Transport Modeling.* Battelle Press, Columbus, OH.

Carter, L. C. 1987. *Nuclear Imperatives and Public Trust: Dealing with Radioactive Waste.* Resources for the Future, Washington, DC.

Collins, E., T. P. O'Farrell, and W. A. Rhoads. 1981. Annotated bibliography for biological overview for the Nevada Test Site, Nye County, Nevada. EGG 1183-2419. EG&G Energy Measurements, Santa Barbara Operations, Goleta, CA.

Cooper, B. S. 1989. Focus shifts from capitol to Nevada. *Applied Research and Public Policy* 4: 26–28.

Department of Energy (DOE). 1986. Environmental assessment, Yucca Mountain site, Nevada research and development area, Nevada. DOE/RW-0073. Office of Civilian Radioactive Waste Management, DOE, Washington, DC.

______. 1988. Site characterization plan. DOE/RW-0199. Office of Civilian Radioactive Waste Management, DOE, Washington, DC.

______. 1989. Report to Congress on reassessment of the civilian radioactive waste management program. DOE/RW-0247. Office of Civilian Radioactive Waste Management, DOE, Washington, DC.

Egan, D. J., R. L. Clark, F. L. Gaopin, and W. F. Holcomb. 1989. Repromulgation of US EPA's environmental standards for disposal of spent nuclear fuel and high-level and transuranic radioactive wastes. Pages 155–159 in R. Post, ed. *Waste Management '89: Proceedings of the Symposium on Waste Management.* vol. 1. University of Arizona, Tucson.

Franklin, J. F., C. S. Bledsoe, and J. T. Callahan. 1990. Contributions of the Long-Term Ecological Research Program. *BioScience* 40: 509–523.

Garcia, A. L. 1989. Repository programs in Europe. *Trans. Am. Nucl. Soc.* 58: 94–101.

Kirchner, G. 1990. A new hazard index for the determination of risk potentials of disposed radioactive wastes. *J. Environ. Radioact.* 11: 71–95.

Lemons, J., and D. A. Brown. 1990. The role of science in the decision to site a high-level nuclear waste repository at Yucca Mountain, Nevada. *Environmentalist* 10: 3–24.

Lemons, J., D. A. Brown, and G. E. Varner. 1990. Congress, consistency, and environmental law: nuclear waste at Yucca Mountain, Nevada. *Environmental Ethics* 12: 311–327.

Lemons, J., and C. R. Malone. 1989. Siting America's geologic repository for high-level nuclear waste: implications for environmental policy. *Environ. Manage.* 13: 435–441.

Lemons, J., C. Malone, and B. Piasecki. 1989. America's high-level nuclear waste repository: a case study of environmental science and public policy. *Int. J. Environ. Stud.* 34: 25–42.

Lieberman, J. A., and W. W. L. Lee. 1986. Mathematical modeling of waste repository performance: a peer review. Pages 749–758 in H. C. Burkholder, ed. *High-Level Nuclear Waste Disposal*. Battelle Press, Columbus, OH.

Magnuson, J. J. 1990. Long-term ecological research and the invisible present. *BioScience* 40: 495–501.

Malone, C. R. 1990a. Performance assessment and long-term environmental problems. *Project Appraisal* 5: 134–138.

______. 1990b. Environmental planning for siting a high-level nuclear waste repository at Yucca Mountain, Nevada. *Environ. Manage.* 14: 25–32.

McCombie, C., T. Papp, and S. Coplan. 1989. The development and status of performance assessment in radioactive waste disposal. In *International Symposium on the Safety Assessment of Radioactive Repositories*. Paris, 9–13 October. Commission of European Communities, Organization of Economic Cooperation and Development/Nuclear Energy Agency, and International Atomic Energy Agency.

National Research Council Board on Radioactive Waste Management. 1990. *Rethinking High-Level Radioactive Waste Disposal*. National Academy Press, Washington, DC.

Nuclear Waste Technical Review Board (NWTRB). 1990. Second report to the U.S. Congress and the U.S. Secretary of Energy. US Government Printing Office, Washington, DC.

Parker, G. J., J. R. Krummel, K. E. LaGory, G. J. Marmer, and S. P. Goel. 1990. The environmental protection program for site characterization at Yucca Mountain, Nevada. *Environ. Prof.* 12: 185–195.

Ross, B. 1989. Scenarios for repository safety analysis. *Engineering Geology* 26: 285–299.

Swanson, F. J., and R. E. Sparks. 1990. Long-term ecological research and the invisible place. *BioScience* 40: 502–508.

van Dorp, F., H. Grogan, and C. McCombie. 1989. Disposal of radioactive waste. *Radioactive Physics and Chemistry* 34: 337–347.

Winsor, M. F., and C. R. Malone. 1990. State of Nevada perspective on environmental program planning for the Yucca Mountain project. *Environ. Prof.* 12: 196–207.

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# ATTACHMENT O

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# Environmental assessment

## Performance assessment and long-term environmental problems

Charles R Malone

*This paper discusses quantified scenario methods of performance assessment and the problems of what time horizon to take. These questions are raised in connection with the Yucca Mountain Project for disposal of nuclear waste. Currently the method being developed will model the behaviour of the engineered and natural components of the system over a 10,000-year period but will exclude the biosphere and environmental consequences. Now is an appropriate time for consideration to be given to repository performance assessment with a view to facilitating the development of a methodology that has potential for application to broader environmental issues.*

Keywords: performance assessment; environmental impact assessment; time horizons

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THE CONCEPT OF performance assessment is being used in the USA to predict whether or not a geologic repository will safely isolate and contain high-level nuclear waste for at least 10,000 years. The method being developed will model the behavior of the engineered and natural components of the system as well as the below-ground movement of radionuclides, but it excludes the biosphere and environmental consequences. If the conceptual changes recommended in this review of the US program are made, performance assessment could provide a model for how society can evaluate future long-term technological threats to the environment.

The disposal of high-level nuclear waste is an example of a technology that has the potential for affecting the environment and health of future generations. It has been suggested that how such decisions are made may contribute to methodologies for evaluating the consequences of new technologies for thousands of years (National Board for Spent Nuclear Fuel, 1988).

Several countries are considering disposal of high-level radioactive waste but none are as far advanced in implementing a program as the USA where Yucca Mountain, Nevada, has been selected as a prospective site for constructing a deep geologic repository for permanent disposal of the waste. The US Department of Energy (US DOE) is responsible for the program and the Yucca Mountain site is being characterized, design of a repository is underway, and a methodology for assessing repository performance over a 10,000-year period is being developed (Hunter and Bingham, 1989).

This article reviews the performance assessment program for the Yucca Mountain Project with the



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purpose of introducing the concepts, methods, and implications for technology assessment to others. It is this aspect of the US high-level nuclear waste program that is most likely to contribute to how society can appraise future technologies that pose long-term environmental threats.

Readers interested in the history of high-level radioactive waste management in the USA are referred to Carter (1987; 1989) who has documented events leading to passage of the Nuclear Waste Policy Act of 1982 (NWPA) and its revision in 1987. Others discuss nuclear waste programs in Europe (Garcia, 1989; van Dorp *et al*, 1989; McCombie *et al*, 1989) although a comparative critique of the various approaches to performance assessment and other aspects remains to be done and is needed.

## Performance assessment

In the traditional engineering sense performance assessment involves understanding and evaluating how a system will function or behave. Assessing the performance of engineered systems such as a space shuttle or a nuclear power plant, for example, is essential for managing the risks involved with complex technologies.

Performance assessment for a geologic disposal system for nuclear wastes is complicated by the coupling of engineered and natural components of the system. The engineered component consists of a canister required to contain the waste for 300 to 1000 years. The natural component of the system, the geologic and hydrologic setting of the repository, is meant to retain most of the radioactive waste for 10,000 years or longer.

Total system performance depends principally on the geologic, hydrologic, and geochemical characteristics of the environment functioning as the primary barrier to migration of the radioactive wastes from the repository to portions of the environment accessible to man. An accepted method for evaluating the long-term behavior of a geologic disposal system does not exist in the USA or elsewhere (Lieberman and Lee, 1986; Stepp and Williams, 1989; McCombie *et al*, 1989; van Dorp *et al*, 1989; Davis *et al*, 1990).

In the USA the Environmental Protection Agency (US EPA) issued a 10,000-year containment standard for protecting the environment from excessive releases of radionuclides from a geologic repository (US EPA, 1985; Egan *et al*, 1989). Probabilistic standards were set that limit certain radioactive releases to a chance of one in ten of occurring within 10,000 years and limit other kinds of releases to between one chance in ten and one chance in 1,000 of happening. For estimating the release rates of radionuclides from a repository, the standards require that certain credible future phenomena be considered with respect to how a geologic repository might respond over the long term.

The environmental standards are included in the

**Table 1. Purposes of performance assessment in the US Geologic Repository Program for disposing of high-level nuclear waste**

- Identifies processes and phenomena that can influence the behavior of a repository system.
- Screens the likelihood of occurrence of scenarios for the future.
- Quantifies current and expected future behavior of the repository system.
- Estimates extent of uncertainties in predictions of long term behavior.
- Predicts releases of pollutants that could impact the environment and man.
- Quantifies system behavior over time to assist with evaluating regulatory compliance and demonstrating safety.
- Provides information feedback for project design and development.

US Nuclear Regulatory Commission (US NRC, 1983) regulations for licensing a geologic repository and consequently probabilistic performance assessment provides the framework for the Yucca Mountain Project (US DOE, 1988). The purpose and goals of the US performance assessment program are shown in Table 1.

## Yucca Mountain project

To be successful, a performance assessment method must be able to analyze how a natural environmental setting like that at Yucca Mountain will behave over thousands of years. Climatic, geologic, and human factors can influence the ability of a geologic repository to safely contain radioactive waste (Chapman and McKinley, 1987; Roxburgh, 1987; Berlin and Stanton, 1989).

Climate is important because changes over a 10,000-year period in precipitation, erosion, and infiltration of water would affect performance of the natural barrier and influence the movement of radionuclides to the environment. Epeirogeny (deformation of the earth's crust), tectonics (folding and faulting), and volcanism also could drastically alter the geohydrologic regime, and catastrophic events like faulting and volcanism could even compromise the integrity of the engineered barrier.

Human factors that could influence repository performance during the 10,000-year containment period include drilling of wells and exploring for mineral resources. Societal and human-related processes and phenomena have not received much attention in the US repository program and generally are considered irrelevant except for intentional and unintentional

**To be successful a performance assessment method must be able to analyze how a natural environmental setting like that at Yucca Mountain will behave over thousands of years**

intrusion associated with resource exploration.

Omitted from performance assessment for the Yucca Mountain Project are considerations of the biosphere and environmental consequences of radionuclides that escape a repository and the surrounding geosphere. Instead of directly confronting the uncertainties imposed by considering environmental factors, the program conceptually excludes them by limiting concerns to the movement of radioactive waste through the geosphere to but not across the boundary with the biosphere (US DOE, 1988; Hunter and Bingham, 1989). What happens to the waste after it reaches the biosphere is avoided because foodchains, ways of life, and population distribution are considered too difficult to address (US EPA, 1985; Ross, 1986; Davis *et al*, 1990).

During the long time period being addressed for the Yucca Mountain Project the environment is expected to change, and how this is likely to affect a repository at the site must be well understood. This aspect of repository performance assessment comprises the major difference between traditional assessment of the performance of engineered systems and that which includes the natural environment.

Scenarios representing future site conditions are being based largely on event tree methods coupled with probabilistic risk assessment of geologic phenomena (Hunter, 1988; Ross, 1989). Judgmental methods increasingly are being used where uncertainty is excessively great as typically is the case when dealing with events that may occur in the distant future (Bonano *et al*, 1989; Ross, 1989).

The goal of scenario analysis is to depict future events that might allow radionuclides to escape the repository and reach the biosphere. As noted, this approach does not address the fate and effect of radionuclides in the biosphere because the phenomena included are restricted largely to physical ones. Omitted are such factors as anthropogenic climate change, ecosystem development, demography, and land use.

Once plausible scenarios are constructed they are analyzed by computational modeling to predict radionuclide movement. The modeling process (Table 2) has to assume that the range of possible scenarios are completely and correctly specified, that probabilities of occurrence of alternatives are accurately estimated, and that radionuclide transport pathways through the geosphere are reliably understood. The last step, evaluation, must address and resolve the question of whether or not the uncertainty associated with the results is sufficiently small to meet regulatory requirements.

**Table 2. Steps in modeling to develop a repository performance assessment method**

- Review and evaluate data and information suitability.
- Develop conceptual models and alternative scenarios.
- Decide on performance criteria to be predicted.
- Develop computer codes and perform model calculations.
- Predict probabilities and consequences associated with scenarios for future states of the geologic disposal system.
- Evaluate results to determine if uncertainty is sufficiently small.

The state-of-the-art of predictive modeling is insufficient to accomplish this objective with the degree of assurance usually associated with regulatory compliance and there is much debate about how to resolve the uncertainties (Brandstetter and Buxton, 1989; Hunter and Mann, 1989; Ross, 1989; Bonano and Cranwell, 1988; Chapman and Come, 1989). Some believe that many of the natural phenomena involved in scenario analysis and performance assessment are so poorly understood that data are statistically meaningless and theoretical models unprovable (Bartlett, 1988; Ross, 1989; Bonano and Cranwell, 1988).

The problematic nature of these issues gave rise to the restructuring of the US DOE high-level nuclear waste program in late 1989 to de-emphasize the quantitative, probabilistic based approach to regulatory compliance in favor of using qualitative judgement (DOE, 1989; Duffy, 1989). A problem with this approach is that probabilities based on judgment have no statistical validity (Chapman and Come, 1989) and their use in regulatory compliance is questionable.

Uncertainty also exists with respect to the appropriate timespan that should be addressed concerning nuclear waste. Recently Kirchner (1990) has shown that assumptions about the hazards posed often do not consider the changing nature of the waste over sufficiently long time periods. Based on environmental simulation modeling that included isotopic composition of nuclear waste, cycling in the biosphere, probability of transport of nuclides to man, radiotoxicity to man, and changing risk potential Kirchner showed that nuclear waste involves risks over a period about two orders of magnitude greater than that on which the US program is based.

These factors were not addressed in developing the US environmental protection standards and the selected 10,000-year period was chosen, rather than a million years as recommended by Kirchner, because it was believed that the state-of-the-art for predicting events by performance assessment was insufficient beyond 10,000 years (US EPA, 1985; Davis *et al*, 1990).

## Comments

Environmental variables pose difficulties for repository performance assessment due to the lack of sound theories and data for predicting the behavior of natural systems. In the US program for the Yucca Mountain site the problems are compounded by the exclusion of non-physical phenomena from the environmental factors considered. This limitation could be overcome with a comprehensive and integrated environmental approach to repository performance assessment, if the US DOE were to promptly initiate the environmental assessment required for the repository by the NWPA, the National Environmental Protection Act (NEPA), and the US NRC

**The assessment of the Yucca Mountain site will be deficient if it does not attempt to resolve the issues regarding the biosphere and long-term environmental risks posed by nuclear waste**

repository licensing requirements.

The assessment, which must evaluate the environmental consequences of a repository at Yucca Mountain and consider near-term impacts as well as those to future generations, will be deficient if it does not attempt to resolve the issues raised by Kirchner (1990) regarding the biosphere and long-term environmental risks posed by nuclear waste. The US DOE has chosen to delay initiating the environmental assessment until late 1997 (US DOE 1988 and 1989), well after site characterization and performance assessment are underway.

Although there is no insight as to how environmental assessment will be accomplished, no conceptual alternative exists for assessing long-term impacts to the environment other than sound, comprehensive environmental performance assessment. Pursuing such a course now instead of deferring it would eliminate the artificial distinction between the geosphere and the remainder of the environment that characterizes the Yucca Mountain Project, and contribute significantly to technology assessment methodology.

Clearly much remains to be done before performance assessment provides a means for evaluating technologies capable of affecting future generations. There is no accepted method for nuclear waste repositories and the US effort illustrates the relatively early development and state-of-the-art of the methodology. The decision to exclude the biosphere from performance assessment will result in even greater uncertainties than already characterize the existing methodology. This and the related shortcomings summarized in Table 3 reflect a perspective dominated more by compartmentalized concepts of engineering than by holistic environmental science.

**Table 3. Shortcomings of the US performance assessment program for a geological repository at Yucca Mountain, Nevada**

- Omits the biosphere as a component of the whole environment.
- Does not use environmental simulation.
- Ignores impacts to the environment and how they could feedback to affect repository performance.
- Avoids radiological consequence analysis for ecosystems and man.
- Time span assessed is too short.
- Attempts to rely on performance assessment as a means of evaluating quantitative regulatory standards while at the same time increasing emphasis on judgmental approaches as components of the methodology.

Conceptual limitations inherent in the approach to performance assessment taken for the Yucca Mountain Project may discourage some from viewing the concept as a means of addressing long-term environmental impacts of persistent pollutants like nuclear waste and other genotoxic materials that can cause human cancer, cellular injury, and fetal injury. The principle challenges that must be met with respect to application of performance assessment to environmental problems can be summarized as follows:

- Methods are needed for quantifying uncertainties associated with parameters characterizing natural systems.
- A rigorous objective approach is needed for developing complete scenarios.
- Means are needed for estimating probabilities of occurrence for phenomena and scenarios and for measuring associated uncertainty.
- Systematic approaches for judgmental methods must be developed that lend themselves to peer review and replication.
- Validated computational models are needed for quantitative and predictive analyses of complex natural processes and their interactions.
- Uncertainties need to be better understood and reduced with respect to the behavior of natural systems over long time periods.
- An accepted means is needed for demonstrating and evaluating a total performance assessment methodology, especially before performance assessment is used as a regulatory concept or tool.

Now is an appropriate time for consideration to be given to repository performance assessment with a view to facilitating the development of a methodology that has potential for application to broader environmental issues. Additionally, it may be that other forms of project appraisal such as environmental and technology assessments can contribute to the development of repository performance assessment. Judging from the limitations discussed herein to achieving an accepted method for the US Yucca Mountain Project such interaction has not occurred thus far.

## References

J W Bartlett (1988), "HLW repository siting: getting from here to there with the issues", in R Post (editor), *Waste Management '88: Proceedings of the Symposium on Waste Management*, vol 2 (University of Arizona, Tucson) pages 423-25.

R E Berlin and C C Stanton (1989), *Radioactive Waste Management* (John Wiley and Sons, New York).

E J Bonano and R M Cranwell (1988), "Treatment of uncertainties in the performance assessment of geologic high-level radioactive waste repositories", *Mathematical Geology*, 20, pages 543-565.

E J Bonano, S C Hora, R L Keeney, and D von Winterfeldt (1989), "The use of expert judgements in performance assessment of high-level waste repositories" (Sandia National Laboratories, Albuquerque, NM) SAND89-0495C.

A Brandstetter and B E Buxton (1989), "The role of geostatistical, sensitivity, and uncertainty analysis in performance assessment", in B E Buxton (editor), *Geostatistical, Sensitivity and Uncertainty*

*Methods for Ground-Water Flow and Radionuclide Transport Modeling* (Battelle Press, Columbus, OH) pages 89-110.
L J Carter (1987), *Nuclear Imperatives and Public Trust: Dealing with Radioactive Waste* (Resources for the Future, Washington, DC).
L J Carter (1989), "Nuclear waste policy and politics", *Forum for Applied Research and Public Policy*, 4(3), pages 5-18.
N A Chapman and B Come (1989), "Long-term predictions: making proper use of geological evidence", *International Symposium on the Safety Assessment of Radioactive Waste Repositories* (CEC, OECD/NEA, and IAEA, Paris) 9-13 October.
N A Chapman and I G McKinley (1987), *The Geologic Disposal of Nuclear Waste* (John Wiley & Sons, Chichester, UK).
P A Davis, L L Price, K Wahi, M Y Goodrich, D Gallego, E J Bonano, and R Guzowski (1990), "Components of an overall performance assessment methodology" (US Nuclear Regulatory Commission, Washington, DC) NUREG/CR-5256.
L P Duffy (1989), "Briefing on the status of the DOE civilian high level waste program" (US Nuclear Regulatory Commission, Rockville, MD) transcript, 20 December.
D J Egan, R L Clark, F L Galpin, and W F Holcomb (1989), "Re-promulgation of US EPA's environmental standards for disposal of spent nuclear fuel and high-level and transuranic radioactive wastes", in R Post (editor), *Waste Management '89: Proceedings of the Symposium on Waste Management*, vol 1 (University of Arizona, Tucson) pages 155-159.
A L Garcia (1989), "Repository programs in Europe", *Transactions of the American Nuclear Society*, 58, pages 94-101.
R L Hunter (1988), "The importance of scenario development in meeting 40 CFR Part 191, in R Post (editor), *Waste Management '88: Proceedings of the Symposium on Waste Management*, vol 2 (University of Arizona, Tucson) pages 643-646.
R L Hunter and C J Mann (1989), "Techniques for determining probabilities of events and processes affecting the performance of geologic repositories: literature review" (US Nuclear Regulatory Commission, Washington, DC) NUREG/CR-3964.
T O Hunter and F W Bingham (1989), "Systems performance assessment for a Yucca Mountain repository", in R Post (editor), *Waste Management '89: Proceedings of the Symposium on Waste Management*, vol 1 (University of Arizona, Tucson) pages 545-549.
G Kirchner (1990), "A new hazard index for the determination of risk potentials of disposed radioactive wastes", *Journal of Environmental Radioactivity*, 11, pages 71-95.
J A Lieberman and W W Lee (1986), "Mathematical modeling of waste repository performance: a peer review", in H C Burkholder (editor), *High-Level Nuclear Waste Disposal* (Battelle Press, Columbus, OH) pages 749-758.
C McCombie, T Papp, and S Coplan (1989), "The development and status of performance assessment in radioactive waste disposal", *International Symposium on the Safety Assessment of Radioactive Waste Repositories* (CEC, OECD/NEA, and IAEA, Paris) 9-13 October.
National Board on Spent Radioactive Fuel (1988), "Ethical aspects of nuclear waste" (Statens Karnbransle Namnd, Stockholm) SKN Report 29.
B Ross (1986), "Disruption scenarios for a high-level waste repository at Yucca Mountain, Nevada", in R Post (editor), *Waste Management '86: Proceedings of the Symposium on Waste Management*, vol 2 (University of Arizona, Tucson) pages 403-409.
B Ross (1989), "Scenarios for repository safety analysis", *Engineering Geology*, 26, pages 285-299.
I S Roxburgh (1987), *Geology of High-Level Nuclear Waste Disposal* (Chapman and Hall, London).
J C Stepp and R F Williams (1989), "Need for performance- based approach to characterize and license the Yucca Mountain HLW repository", in *Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone — Focus '89* (American Nuclear Society, Inc, La Grange Park, IL) pages 188-193.
US Department of Energy (1988), "Site characterization plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada" (US DOE, Washington, DC) DOE/RW-0199.
US Department of Energy (1989), "Report to Congress on reassessment of the Civilian Radioactive Waste Management Program" (US DOE, Washington, DC) DOE/RW-0247.
US Environmental Protection Agency (1985), "Environmental standards for the management and disposal of spent nuclear fuel, high-level and transuranic radioactive waste: 40 CFR 191", *Federal Register*, 50, pages 38066-38089.
US Nuclear Regulatory Commission (1983), "Disposal of high-level radioactive wastes in geologic repositories", *Federal Register*, 48, pages 28194-28229.
F van Dorp, H Grogan, and C McCombie (1989), "Disposal of radioactive waste", *Radiation Physics and Chemistry*, 34, pages 337-347.

ATTACHMENT P

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# ENVIRONMENTAL PERFORMANCE ASSESSMENT: A CASE STUDY OF AN EMERGING METHODOLOGY

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ABSTRACT

The emerging methodology of environmental performance assessment offers a potential means by which the future consequences of new technologies can be evaluated. A pilot effort to create a nuclear waste repository at Yucca Mountain, Nevada, however, has yet to adequately address biological and societal components of the environment that will evolve at the site following closure and abandonment of a repository. The nonphysical components of environmental systems cannot be ignored in performance assessment studies and are likely to be no more recalcitrant to analysis than physical components such as the geologic and hydrologic characteristics of a site. If environmental performance assessment is to contribute to understanding the risks and uncertainties associated with technologies like nuclear waste disposal, the methodology must address all components of environmental systems in a comprehensive and integrated manner. A methodology that recognizes only physical factors stands little chance of predicting the future outcome of actions that will affect the environment for thousands of years.

The rapid development and complexity of modern technology assure that decisions made by society will increasingly risk affecting environmental systems far into the future. This raises questions about how to deal with the long-term consequences of actions that may threaten generations to come. Nuclear waste disposal is the first of these dangers to come under wide scrutiny. It has been suggested that the manner in which this problem is approached could serve as a model for dealing with other long-term consequences of technological change [1, 2]. High-level nuclear waste poses a threat to the environment for thousands of years; steps are being taken by the United States Department of Energy (DOE) to dispose of the waste in deep geologic repositories meant to be reasonably safe for at least 10,000 years. The concept of geologic disposal of nuclear waste pursued by the DOE is based on a dual-barrier approach to waste isolation that involves an engineered barrier and a natural environmental barrier. Long-term containment and isolation of radionuclides primarily is to be accomplished by the environmental barrier, subsequent to a 300- to 1000-year period during which the engineered barrier in the form of a cladding and canister combination may have corroded and released the waste into the repository environment [3, 4]. Ultimate containment and isolation of radionuclides from the biosphere is primarily to be attained by virtue of the natural setting of the repository. Thus, geologic isolation in the United States will rely ultimately on a site's natural environmental characteristics and features to confine radioactive waste to the vicinity of the repository and therby protect future environmental systems and generations.

The environmental uncertainties posed by disposing of nuclear waste in geologic repositories are recognized in probabilistic, risk-based regulatory requirements, compliance with which is to be demonstrated through the use of performance assessment [4-7]. "Performance assessment" means an analysis that identifies the processes and events that could affect a repository setting, models the associated uncertainties, and evaluates potential consequences to the environment. As the major available tool for making informed decisions regarding repository siting and licensing [8], performance assessment is an aspect of the nuclear waste disposal issue most likely to serve as a model for how long-term aspects of technological development may affect future environmental systems. The emerging methodology of environmental performance assessment, as applied to geologic disposal of nuclear waste, is reviewed here.

## GEOLOGIC DISPOSAL AND PERFORMANCE ASSESSMENT IN THE UNITED STATES

The U.S. program for geologic disposal of high-level nuclear waste is set forth by the Nuclear Waste Polity Act of 1982 (NWPA) and the 1987 amendments to the act. As amended, the act requires that Yucca Mountain, located adjacent to the Nevada Test Site in southwestern Nevada, be evaluated as a suitable natural setting for a repository. Before authorization can be granted by the Nuclear Regulatory Commission (NRC) for constructing the repository and licensing it for operation, an environmental performance assessment must be carried out to demonstrate that the environment is likely to be protected from migrating radionuclides for at least 10,000 years [4]. A performance assessment methodology does not exist. The assessment program being developed by the NRC and the DOE is at an early stage and requires considerable evolution before it can be applied in other than simple bounding calculations of radionuclide releases to the accessible environment [8]. Because the regulations do not spell out how performance assessment is to be carried out, there is a need for agreement within the United States nuclear waste program on the methodology to be applied, especially regarding establishment of probabilities for risk assessment [9].

Much of the work relative to performance assessment for the Yucca Mountain Project has concentrated on constructing scenarios for future environmental systems [10-12]. The principal focus of scenario development for the Yucca Mountain environment has been on aspects of the physical environment such as geohydrology, geochemistry, and rock characteristics that are to comprise the primary barrier to radioactive waste migration. Once the components of the physical system are understood, plausible events will be postulated that could influence specific components of the system and lead ultimately to breaching of the repository and release of wastes to the biosphere [10]. Table 1 lists the physical components of the natural environment system believed to be important to the Yucca Mountain site.

The DOE and NRC performance assessment program for a geologic repository is based on the assumption that the most likely route for radionuclides released from a repository to take to the accessible environment is via ground water [3, 7, 13, 14]. Consequently, emphasis has been placed on environmental processes and scenarios that could lead to breaching the repository and releasing nuclear wastes to ground water. Other modes of repository breaching and mechanisms of transport of waste to the biosphere such as extrusive magmatic activity and denudation of the natural overburden also are considered but generally to a

Table 1. Physical Processes and Events Being Considered in Assessing the Environmental Performance of the Yucca Mountain Site for 10,000 Years

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|---|
| Geohydrology and ground-water hydraulics [3, 10, 11, 12] |
| Geochemistry [3, 12] |
| Tectonics and faulting [3, 10, 11, 12] |
| Volcanism [3, 10, 11] |
| Rock properties (e.g., thermodynamics and strength) [10, 11] |
| Site geometry and geology (stratigraphy) [3] |
| Occurrence of mineral and energy resources [3, 10, 11, 12] |
| Dissolution of rocks [12] |
| Formation of inorganic colloids [12] |
| Erosion and denudation of overburden [3, 10, 11] |
| Climatic change [12] |
| Surface hydrology and flooding [12] |

lesser extent than components of the environmental system that affect ground-water transport. This is evident from Table 1 which largely considers physical processes and events such as geohydrology, geochemistry, tectonics, rock dissolution, climatic change, and flooding that affect ground-water transport scenarios.

Table 2 lists the non-physical components of environmental systems that are being addressed for the Yucca Mountain site. The paucity of biological processes and events considered reflects the early stage of development of the environmental performance assessment concept. The only biological process considered has been microbial growth which has only recently been brought to the attention of researchers [12]. The hypothesis is that microbes naturally present in the host rock formation could render radionuclides more mobile and readily accessible to the environment. Some emphasis has been placed on human activities that might influence repository site performance, in particular on irrigation, intentional ground-water and climatic manipulation, and intrusion from resource exploration and mining [12]. War, sabotage, chemical waste disposal, and archeological exhumation have been discounted as potential influences on the future environmental performance of the Yucca Mountain site. For those societal factors considered, the emphasis has been on the likelihood of natural conditions and resources at the site being such that in the future an activity could occur. Thus, the likelihood of future society itself being such that an event might occur has not been addressed. For example, the possibility of human intrusion into a repository is based on the probability of extractible natural resources occurring at the site and not on the likelihood of the nature of a future society being such that resource exploration might or might not occur.

Scenarios under study for repository performance assessment are shown in Table 3. Hunter *et al.* describe the procedure as one of constructing event trees that depict the alternative courses that various processes could take [10]. The result is a hypothetical sequence of future events that might allow radionuclides to breach the natural barrier and escape from a repository. For both the engineered barrier and the natural barrier, the events, in combination with the rock types (e.g., welded tuff, alluvium, argillite) composing the natural barrier

Table 2. Non-Physical Processes and Events Being Considered in Assessing the Environmental Performance of the Yucca Mountain Site

| |
|---|
| Natural microbial activity [12] |
| Human intrusion in search of natural resources [3, 10, 11, 12] |
| Future irrigation [12] |
| Ground-water recharge or withdrawal [12] |
| Climate control [12] |

Table 3. Scenarios Being Considered for Environmental Performance Assessment of the Yucca Mountain Site

| |
|---|
| Hydrological alterations, increased underground water flow, and water-table rise [10, 11, 12] |
| Formation of new ground-water discharge points [12] |
| Tectonic disturbance, faulting, and rock fracturing [3, 10, 11] |
| Alteration of rock properties and geochemical changes [10, 11, 12] |
| Advance of a dissolution front [3, 12] |
| Extrusive magmatic activity [3, 10, 11, 12] |
| Erosion and overburden denudation [3, 10, 11] |
| Climatic control or change [3] |
| Migration of inorganic colloids [12] |
| Accelerated natural microbial activity [12] |
| Human intrusion by exploratory drilling [3, 10, 11, 12] |

at the Nevada Test Site and Yucca Mountain led initially to 21,000 scenarios [10]. These next were narrowed to 4,000 scenarios, only 400 of which were considered sufficiently probable to pursue in the performance assessment program for the Yucca Mountain site [11]. Currently, eighty-four different scenario sequences (grouped in seventeen categories) are being analyzed by the DOE Yucca Mountain Project. The environmentally-based categories, listed in Table 3, are used as a basis for further analysis of disruptive event and process scenarios for Yucca Mountain [12], and include both physical and non-physical environmental factors influencing site performance. Table 3 also displays scenarios analyzed for the NRC in a demonstration of a hypothetical performance assessment methodology for a nuclear waste repository [14]. In the demonstration the objective was to show for a simple, idealized case that, in conformity with regulations and standards [4-6], performance assessment can be used to predict transport of radionuclides from a repository to the accessible environment. The constraints that ultimately will be posed by data limitations and uncertainties were recognized in the numerous assumptions made [14]. Nonetheless it was concluded that when perfected performance assessment methodology could serve to evaluate and demonstrate environmental performance of a repository site.

The scenarios shown in Table 3 assume that ground water poses the most likely route by which the environment and humans could be exposed to radioactive wastes in the future. For example, the environmental standards [4-6] assume that the principal risk to future individuals would be very small except for the possibility that individuals one day might use ground water from the vicinity of a repository. This risk also was recognized by the National Academy of Sciences [13], which concluded that for a site like Yucca Mountain water resources probably would be limited in the future as they are now and consequently any water available at the site would most likely be used by future generations. Despite these concerns, no attention in the environmental performance assessment program for the DOE Yucca Mountain Project is being given to the likelihood of future societal factors at Yucca Mountain being such that ground water there would be used. Instead, the focus is on that gound water itself and the likelihood of radionuclides reaching the biosphere via that route during the next 10,000 years. Scenarios of this sort depend more on information on environmental events and processes like those shown in Table 1 than those in Table 2. This is because it is accepted that food chains, ways of life, and population distributions over 10,000 years, unlike geologic and hydrologic factors, cannot be usefully predicted over such long periods of time [5, 12]. As a consequence no serious attempt is being made in the United States repository program to understand biologic and societal factors with respect to future environmental systems and the intergenerational consequences of nuclear waste disposal.

Once events, processes, and plausible future scenarios are well-defined, probabilistic and deterministic models must be developed to perform the complex computations that will be necessary for analyzing possible interactions among climates, geohydrologic regimes, tectonic disturbances, volcanism, geochemical alterations, and resource exploration. The analytical models for the Yucca Mountain site [15, 16] are in a rudimentary stage of development and are limited by existing knowledge of the geologic and hydrologic environment [8]. The work will try to incorporate alternative conceptual models and mathematical structures into the environmental performance assessment. Significant progress in developing definitive models to predict the behavior of the physical environment at Yucca Mountain will require much new information on how the geologic and hydrologic systems function and interact. This level of understanding will come only after five to seven years of planned field studies at the site are completed by DOE [17]. In the interim, the performance assessment program will continue developing plausible scenarios for the Yucca Mountain environmental system.

## SOME METHODOLOGICAL LIMITATIONS AND UNCERTAINTY

Many difficulties stand in the way of understanding the complex environmental processes at Yucca Mountain. As noted, the focus to date has been on understanding the nature of the physical system. The DOE has developed detailed plans to characterize the geologic and hydrologic environment at the site [17]. The efficacy of the performance assessment program depends on the ability of science to "interrogate" the site's environment successfully enough to warrant probabilistic and/or deterministic predictions of events and processes in at least the next 10,000 years. Several reviews have been undertaken of the ability of existing study methods and techniques to provide the data and information needed for constructing models of the Yucca Mountain geology and hydrology. For example, Jones, *et al.* found that seismic reflection profiling and electromagnetic methods are of little use in determining the deep internal geologic structure due to the complexity of the site [18]. It also was concluded that seismic refraction techniques require further development to overcome existing limitations with respect to Yucca Mountain's geology. Other efforts have found an absence of commonly agreed upon techniques and theory for characterizing and modeling ground-water movement in unsaturated fractured rock media like that at Yucca Mountain [19-21]. These findings for both the geologic and geohydrologic environment at the Yucca Mountain site were endorsed by an oversight review of the DOE Project [22].

Difficulties also exist with respect to understanding subsurface geochemistry and the combined radionuclide-fluid-rock interactions. Only now are preliminary efforts being made to model geochemical phenomena with respect to radionuclide transport and repository performance assessment. Many difficulties have arisen [23]. For example, it has recently come to light that colloids in the subsurface environment play an important role in the migration of radionuclides [23, 24]. Failure to account for colloidal movement can lead to significant underestimates of the distances that radionuclides will migrate in ground-water systems. McCarthy and Zachara discuss instances where waste plutonium and americium have, over short periods of time, unexpectedly traveled in excess of thirty miles below ground due to colloidal mechanisms, when laboratory analyzes indicated that movement of only a few millimeters would be expected [24]. The occurrence and properties of below-ground colloids are poorly understood, so the insights necessary for predictive modeling of this mode of transport are not well developed. Relevant to the Yucca Mountain site are concerns that colloids may be important to mobilizing radionuclides in both the vadose and the saturated ground-water zones. It is further suspected that in combination with naturally occurring microbes, biocolloids could be formed [24], which would further complicate understanding ground-water transport of radionuclides from a geologic repository to the accessible environment. This possibility would significantly complicate performance assessment for Yucca Mountain and emphasizes the uncertainties that exist with respect to biological components of the environmental system.

The complexity of Yucca Mountain's physical setting and the absence of reliable data, techniques, and models for predicting future tectonics, seismicity, volcanism, and geohydraulics that will govern transport of radionuclides from a geologic repository to the biosphere limits existing scientific and technological capabilities and results in considerable uncertainty with respect to performance assessment for the Yucca Mountain Project [19, 25]. Because of the long half-lives of radionuclides involved and the need to accurately predict their fates in the environment for at least 10,000 years, best or conservative estimates will not suffice. In the face of large uncertainties in characterizing the geology and geohydrology of a site like Yucca Mountain and the uncertainties inherent in long-term prediction it is imperative to quantify the uncertainties in predicting repository performance in order to establish levels of confidence in assessing the performance of a site [19]. This limitation was recognized conceptually in the NWPA and the applicable environmental radiation standards [4-6], and must be dealt with in the course of environmental performance assessment for the Yucca Mountain site. Consequently, considerable attention is now being devoted to the task of characterizing and analyzing probabilities and environmental uncertainties [19, 26].

Table 4 lists the broad classes of uncertainty that apply to a geologic repository site like Yucca Mountain. At this stage most attention is being devoted to the uncertainty related to the geosciences where the need for validated probabilistic and conceptual models is clearly recognized as being critical [19]. Some attention has been turned to the future state of the non-geologic environment in terms of predictions, probabilities, and uncertainties associated with future climate. This is critical not only to future hydrologic regime at a repository site but also to the biological and societal components of the environmental system that may develop there, possibly enhancing radionuclide accessibility to the environment. Unfortunately no definitive methods exist for predicting climates over thousands of years and no study has addressed all the environmental processes and events necessary to predict future conditions at the resolution needed for evaluating repository sites and conducting performance assessments [26].

Limited effort has been devoted to date to predictions and uncertainties associated with non-physical components of environmental systems (as in Table 2). In the United States repository program, human intrusion is considered one of the most likely of the occurrences that might compromise repository integrity [26]. Consequently, this possibility has been addressed somewhat,

Table 4. Types and Sources of Uncertainty that Apply to Environmental Performance Assessment for a Geologic Repository Site (Based on Buxton [19])

| |
|---|
| Variation in the natural environmental setting and choice of parameters |
| Conceptual and probabilistic modeling (definitions and calculations) |
| Future evolution of the environmental system (physical, biological, and societal) |
| Measurement errors (systematic, random, bias, arbitrary) |

especially in the resource exploration scenario, which is particularly applicable to Yucca Mountain because the site is located in a region characterized by extractible mineral resources. Hunter and Mann concluded that objective estimates of the future mineral resource potential of an area cannot be made with known techniques [26].

Another human intrusion issue centers around the possibility of unintentional intrusion. Gillis reported on the findings of the DOE Human Interference Task Force [27], which evaluated modes of unintentional human intrusion into a nuclear waste repository. The study concluded that the probability of human intrusion could satisfactorially be reduced by using comprehensive communication systems at the repository site in the form of permanent markers. This conclusion was reached without the use of scenario, probability, or uncertainty analyses. Nonetheless, the results of the study have been used in the Yucca Mountain Project to largely dismiss the issue of human intrusion. Thus, this and other uncertainties associated with societal components of future environmental systems at Yucca Mountain are not being aggressively pursued.

Uncertainty also is introduced in environmental performance assessment of a repository site by errors associated with measuring environmental parameters. These can result from inaccurate instruments, inferences made from erroneous data, and from bias and arbitrariness introduced into assumptions made in data analysis and interpretation [19]. Crowe has recognized intentional bias built into the Yucca Mountain Project as a result of mounting pressure to "prove" the site in the face of increased funding and political realities [28]. This concern appears increasingly valid in light of the fact that Yucca Mountain represents the sole site being considered for a high-level nuclear waste repository in the United States. With no alternative to Yucca Mountain, the success of the DOE repository siting program rests on the correct assumption having been made that Yucca Mountain is an acceptable, licensable site.

As has been argued, at this stage in the environmental performance assessment program for the Yucca Mountain site, there seems to be little effort devoted to non-physical components of the environmental system in constructing future scenarios. Instead, there is a tacit assumption that biologic and societal factors cannot be usefully predicted [5, 12]. Rather than (say) trying to assess the likelihood of a future society taking some action at Yucca Mountain that will interfere with the performance of the natural environment as a barrier to radionuclide movement to the biosphere, the approach is to focus on the physical component of the environmental system that would be altered either by direct manipulation or as the indirect consequences of manipulation. Exploitation of the ground-water system as a water supply source is an example. As a result there is no attempt to construct and assess scenarios that embody plausible alternative courses of society and ecosystems that might develop at and affect the performance of the Yucca Mountain site in terms of nuclear waste isolation. Nowhere does there appear to have been a serious effort made to identify the sources of such uncertainty and consider how these uncertainties may be addressed or resolved by insights into future development of biological and societal components of environmental systems.

## DISCUSSION AND CONCLUSIONS

The extent of information and analysis needed to carry out a 10,000-year environmental performance assessment is immense, on a scale never before attempted, and challenges the ability of science to comprehend the complexities and uncertainties involved. This is particularly true when the comprehensive physical, biological, and societal nature of environmental systems is considered. The importance of societal components of environmental systems to the integrity of a repository system was considered in part by the Swedish National Board for Spent Nuclear Fuel [1], which recognized that the nuclear waste issue may become a model for dealing with long-term consequences of other technologies. Their study found it essential to the success of the Swedish geologic repository program that means be sought for addressing risks and uncertainties from societal components of the environmental system. Similarly, the Canadian Nuclear Fuel Waste Management Program considers biosphere modeling essential for estimating the range and probabilities of environmental effects of geologic disposal of nuclear wastes [29].

In the performance assessment program for the Yucca Mountain site it is understandable that initial attention would be given to aspects of the physical environment such as those in Table 1. Not only are events and processes involving geologic and hydrologic factors easier to portray than those involving biological and societal ones, but the non-physical factors appear more likely to pose limits to the site's ability to perform as required and isolate nuclear wastes for at least 10,000 years. Soon, however, the more difficult task of identifying and understanding non-physical events, processes, and scenarios that could characterize future environmental systems at Yucca Mountain must be undertaken. The importance of this is underscored by postulated scenarios [5, 13], suggesting that the distant future use of ground water from the vicinity of a repository in an arid region like southwestern Nevada could result in substantial health risks to individuals. These preliminary analyses were based on limited information on ground-water travel time, radionuclide migration, the assumption that water will continue to be limited in the distant future, and the further assumption that, as is the case now in the Yucca Mountain region, ground water will be used by humans for potable water and irrigation. Thus, the generally arid nature of the Yucca Mountain site suggests that potentially contaminated ground water is likely to be used and that individual radioactive dose rate criteria may not be met [13].

Another example of the need to address future societal scenarios concerns inadvertent human intrusion. Efforts to date have focused only on means of marking a repository so that future generations would detect and avoid or manage its hazards [27]. In the same light it bears noting that lack of a means of assessing the potential of a future society to explore a given site for natural resources led only to the simplistic recommendation that a repository not be sited where any natural material occurs in greater abundance that the average for the Earth [26].

While uncertainties with respect to the physical environment may be dealt with separately in the initial stage of an environmental performance assessment for a repository, the large uncertainties posed by biological and societal factors cannot be set aside without further consideration. Within the various scenarios analyzed for Yucca Mountain must be what really will occur at the site during the next 10,000 years. Otherwise, the entire performance assessment exercise will be for naught, despite the sophistication of the analytical methodologies used. Incorrect scenario specification may result in a nuclear waste repository not performing as intended. It has been pointed out that incorrect specification of repository performance scenarios is likely to be the most significant source of error in trying to assess how the environmental system will behave [19].

There is some reason to believe that currently perceived limitations to dealing with the uncertainties posed by non-physical factors can be overcome. Recent applications of risk and uncertainty analyses to environmental assessment holds the promise of quantifying biological and societal factors [30, 31]. Adequate knowledge of the non-physical components of the environment seems to exist. The constraints that remain to successful application of risk and uncertainty analyses to them appear to be:

1. Adapting existing models to express output in terms of probabilities; and
2. Expressing data in terms that allow uncertainties to be quantified.

A category of recently developed computer programs referred to as "expert systems" also may help overcome some of the limitations of traditional assessments based on subjective judgement. For example, Lein has argued that expert systems encoded with the knowledge of biological and societal factors affecting the course of a future technology can provide solutions to specialized problems previously thought not to be amenable to more traditional risk and uncertainty analysis [32]. Prototype expert systems appear to suggest that artificial intelligence can be used to screen comprehensive alternative scenarios reflecting both physical and non-physical events and processes. If so, it is possible that tools may soon exist for evaluating and assessing the importance of cultural, societal, and other non-physical factors in environmental systems. Certain parameters that can be documented, characterized, compared over time, and used to predict trends have been identified [33, 34]. Conceptual means of formulating these issues are available [35], as are the rudiments of an information base [36]. New ways of addressing heretofore unmanagable issues within performance assessment models thus may be within reach. This suggests that uncertainties posed by biological and societal factors may be no greater and no more recalcitrant to resolution that those associated with the physical aspects of environmental systems. They simply are receiving less attention than geologic, hydrologic, and related factors in the United States repository program.

## REFERENCES


1. National Board on Spent Nuclear Fuel, *Ethical Aspects of Nuclear Waste*, Report 29, Statens Kambransle Namdn, Stockholm, Sweden, 1988.
2. J. Lemons and C. Malone, Siting America's Geologic Repository for High-Level Nuclear Waste: Implications for Environmental Policy, *Environmental Management, 13*, pp. 435–441, 1989.
3. U. S. Department of Energy, *Mission Plan for the Civilian Radioactive Waste Management Program*, DOE/RW-0005, Washington, D.C., June 1985.
4. U. S. Nuclear Regulatory Commission, Disposal of High-Level Radioactive Wastes in Geologic Repositories, 10 CFR Part 60, *Federal Register, 48*, pp. 28194-28229, 1983.
5. U. S. Environmental Protection Agency, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes, 40 CFR Part 191, *Federal Register, 50*, pp. 38066-38089, 1985 (remanded 17 July 1987, U. S. Court of Appeals, First Circuit).
6. D. Egan and R. Clark, Amended Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes, 40 CFR Part 191: Working Draft I, U. S. Environmental Protection Agency, Washington, D.C., June 2, 1989.
7. U. S. Department of Energy, Nuclear Waste Policy Act of 1982: General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories, 10 CFR Part 960, *Federal Register, 49*, pp. 47714-47770, 1984.
8. J. A. Lieberman and W. W. L. Lee, Mathematical Modeling of Waste Repository Performance: A Peer Review, in *High-Level Nuclear Waste Disposal*, H. C. Burkholder (ed.), Battelle Press, Columbus, Ohio, pp. 749-758, 1986.
9. R. L. Hunter, R. M. Cranwell, and C. J. Mann, Determining Probabilities of Geologic Events and Processes, in *High-Level Nuclear Waste Disposal*, H. C. Burkholder (ed.), Battelle Press, Columbus, Ohio, pp. 637-646, 1986.
10. R. L. Hunter, G. E. Barr, and F. W. Bingham, *Preliminary Scenarios for Consequence Assessments of Radioactive-Waste Repositories at the Nevada Test Site*, SAND82-0426, Sandia National Laboratories, Albuquerque, New Mexico, 1982.
11. ———, *Scenarios for Consequence Assessments of Radioactive-Waste Repositories at Yucca Mountain, Nevada Test Site*, SAND82-1277, Sandia National Laboratories, Albuquerque, New Mexico, 1983.
12. B. Ross, *A First Survey of Disruption Scenarios for a High-Level-Waste Repository at Yucca Mountain, Nevada*, SAND85-7117, Sandia National Laboratories, Albuquerque, New Mexico, 1987.

13. National Academy of Sciences. *A Study of the Isolation System for Geologic Disposal of Radioactive Wastes.* National Academy Press, Washington. D.C., 1983.
14. E. Bonano. P. Davis. L. Shipers. K. Brinster, W. Beyeler, C. Updegraff, E. Shepherd, L. Tilton, and K. Wahi. *Demonstration of a Performance Assessment Methodology for High-Level Radioactive Waste Disposal in Basalt Formations.* U. S. Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-4759. 1989.
15. M. Board, *Examination of the Use of Continuum versus Discontinuum Models for Design and Performance Assessment for the Yucca Mountain Site.* U. S. Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-5426. 1989.
16. A. Dudley, R. Peters. J. Gauthier, M. Wilson, M. Tierney, and E. Klavetter, *Total Systems Performance Assessment Code (TOSPAC) Volume 1: Physical and Mathematical Bases.* SAND85-0002, Sandia National Laboratories, Albuquerque, New Mexico, 1988.
17. U. S. Department of Energy, *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada.* DOE/RW-0199, Washington, D.C., 1988.
18. G. Jones, M. Blackey, J. Rice, V. Murphy, E. Levine, P. Fisk, and R. Bromery, Survey of Geophysical Techniques for Site *Characterization in Basalt, Salt, and Tuff,* U. S. Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-4957, 1987.
19. B. E. Buxton, *Geostatistical, Sensitivity, and Uncertainty Methods for Ground-Water Flow and Radionuclide Transport Modeling,* Battelle Press, Columbus, Ohio, 1989.
20. National Academy of Sciences, *Ground-Water Models: Scientific and Regulatory Applications,* National Academy Press, Washington, D.C., 1989.
21. National Water Well Association, Vadose Zone Investigations at a Potential Nuclear Waste Repository Site, in *Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone,* National Water Well Association, Dublin, Ohio, pp. 396-563, 1986.
22. Nevada Nuclear Waste Project Office, Geologic and Hydrologic Issues Related to Siting a Repository for High-Level Nuclear Waste at Yucca Mountain, Nevada, USA, *Journal of Environmental Management, 28,* in press, 1989.
23. M. D. Siegel and C. D. Leigh, *Progress in Development of a Methodology for Geochemical Sensitivity Analysis for Performance Assessment: Parametric Calculations, Preliminary Databases, and Computer Code Evaluation,* U. S. Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-5085, 1989.
24. J. F. McCarthy and J. M. Zachara, Subsurface Transport of Contaminants, *Environmental Science and Technology, 23,* pp. 496-502, 1989.
25. C. R. Malone, The Yucca Mountain Project: Storage Problems of High-Level Radioactive Wastes, *Environmental Science and Technology, 23*:12, pp. 1452-1453, 1989.

26. R. L. Hunter and C. J. Mann, *Techniques for Determining Probabilities of Events and Processes Affecting the Performance of Geologic Repositories: Literature Review*, U. S. Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-3964, 1989.
27. D. Gillis, Preventing Human Intrusion into High-Level Nuclear Waste Repositories, *Underground Space*, 9, pp. 35-43, 1985.
28. B. M. Crowe, Volcanic Hazard Assessment for Disposal of High-Level Radioactive Waste, in *Studies in Geophysics: Active Tectonics*, National Academy Press, Washington, D C., pp. 247-260, 1986.
29. J. M. Barnard, Biosphere Model for the Interim Assessment of the Canadian Concept for Nuclear Fuel Waste Disposal, in *High-Level Nuclear Waste Disposal*, H. C. Burkholder (ed.), Battelle Press, Columbus, Ohio, pp. 659-670, 1986.
30. L. W. Barnthouse and G. W. Suter, *User's Manual for Ecological Risk Assessment*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-6241, 1986.
31. G. W. Suter, L. W. Barnthouse, and R. V. O'Neill, Treatment of Risk in Environmental Impact Assessment, *Environmental Management*, *11*, pp. 295-303, 1987.
32. J. K. Lein, An Expert System Approach to Environmental Impact Assessment, *International Journal of Environmental Studies*, *33*, pp. 13-27, 1989.
33. L. W. Milbrath, Culture and the Environment in the United States, *Environmental Management*, *9*, pp. 161-172, 1985.
34. D. Alexander (ed.), Culture and the Environment, *Environmental Management*, *9*, pp. 95-177, 1985.
35. A. Miller, Technological Thinking: Its Impact on Environmental Management, *Environmental Management*, *9*, pp. 179-190, 1985.
36. R. DeYoung and S. Kaplan, On Averting the Tragedy of the Commons, *Environmental Management*, *12*, pp. 273-283, 1988.

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ATTACHMENT Q

# THE YUCCA MOUNTAIN PROJECT AS AN EXAMPLE OF UNREPLICATED ECOLOGICAL EFFECTS STUDIES

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Abstract

Sampling the same ecosystem over time to evaluate the impacts of human disturbance or changes resulting from prescribed management practices commits pseudoreplication. Frequentist analysis of studies lacking true replication is improper, gives rise to uncertainty, and raises questions regarding the precautionary principle. A review of the literature on unreplicated studies and an assessment of postmodern statistical approaches sheds some light on the dilemmas encountered without true replicates and controls. As a solution to such problems, attention is called to the Bayesian statistical approach increasingly being applied to investigations concerning single, large ecosystems. The postmodern development of Bayesian inference compliments the ongoing transition to ecosystem-based approaches to environmental impact assessment and management. Thus, ecosystem management and Bayesian statistics appear to compliment each other with respect to monitoring, understanding, and managing environmental impacts in single, large ecosystems. These issues are illustrated by the Yucca Mountain Project in Nevada where ecological effects studies are underway for developing a nuclear waste repository.

## Introduction

In studies concerning either human induced ecological impacts or investigations to understand how natural resources respond to management, investigators traditionally prefer having suitable numbers of replicate treated and control sites. This is a requirement for long-used "optimal impact study design" (Green 1979, Hurlbert 1984, Stewart-Oaten et al. 1986). Without adequate replication, the result is a "suboptimal impact study design" in which natural variation (the stochastic factor) can be confused with human distrubances (Green 1979, Hurlbert 1984, Stewart-Oaten et al. 1992 Underwood 1994). Although the use of frequentist statistics is known to be uncertain and misleading for unreplicated ecological effects studies, alternatives have not been available (Hurlbert 1984, Smith et al. 1993, Stewart-Oaten et al. 1992, Underwood 1994). In this situation, controversies can arise because of questions about uncertainty, Type I and Type II errors, and the precautionary principle (Eberhardt and Thomas 1991, Hilborn and Ludwig 1993, Jassby and Powell 1990, Lemons et al. 1997).

To resolve problems resulting from the lack of replication, ecosystem and watershed levels of assessment and management increasingly are being encouraged and implemented (e.g., Malone 1998, Mongomery et al. 1995, Underwood 1994). This evolution is part of the change in postmodern ecological science and statistical paradigms that researchers such as Maurer (1998) and Underwood (1995) believe are needed for ecosystem management and environmental management.

The need for changes in statistical approaches to suboptimal unreplicated impact studies can be illustrated by examining an ongoing controversial study. At the Yucca Mountain site in southern Nevada, the U.S. Department of Energy (DOE) plans to dispose of the nation's high-level nuclear waste in a geological repository Initially in the Yucca Mountain case, there was only one ecosystem to study and no predisturbance baseline ecological information. This is the worse case for evaluating ecological effects (Green 1979) because it is unknown when, where, and to what extent impacts may have occurred before the study began. Five years after initiating the suboptimal impact studies, the DOE added a single far-field control site. However, neither the new "control" site nor the Yucca Mountain "treated" site were replicated. At both locations sampling over time was performed resulting once more in pseudoreplication but in two sites as opposed to one. Additionally, frequentist inference methods continue to be misapplied. The reproach bears restating simply because many investigators remain unaware of or fail to acknowledge that their field investigations face uncertainties that can affect subsequent decision making. Correctly understanding ecosystem conditions and responses to disturbance is essential to the effectiveness of decisionmaking regarding the postmodern approach to ecosystem management.

Objections to unreplicated studies still are made, but authors such as Hilborn and Ludwid (1993), Shrader-Frechette and McCoy (1994), Stewart-Oaten (1995), and Underwood (1995) realize that better approaches to teaching statistical inference to ecologists is needed because so few of us are more than "cookbook" students who lack sufficient training in probability, the need for replication and controls, and frequentist and Bayesian theorems. The absence of sufficient training in statistical procedures impedes ecologists particularly regarding studies in unreplicated ecosystems (Dennis 1996, Dixon and Ellison 1996, Stewart-Oaten 1995, Underwood 1994).

If ecosystem and watershed level approaches are coupled with suitable inference methods, it appears that many of the uncertainties arising from unreplicated impact study design could be resolved. This proposition is discussed below in the context of the Yucca Mountain ecological impact studies. Actual field data from the ecological studies are not used because the DOE has chosen not to make such information available before an environmental impact statement for the project is finalized no earlier than 2001.

**Pseudoreplication and Suboptimal Impact Study Designs**

Environmental impact assessment became popular following passage of the National Environmental Policy Act (NEPA) and has led to wide-spread use of suboptimal impact study designs for interpreting the effects of human-induced disturbances in single ecosystems. Hurlbert (1984) was among the first to call attention to the dilemma of using traditional frequentist analyses for unreplicated ecological studies. His insights led Stewart-Oaten et al. (1986) to recommend a version of the "Before-After-Control-Impact" (BACI) study design using two ecosystems, one disturbed and one undisturbed, to be interpreted by traditional frequentist approaches. Because there was no true replication for either ecosystem, sampling through time before and after one site was perturbed still committed pseudoreplication. Similar difficulties trouble natural resources manager faced with evaluating the response of a single large ecosystem to prescribed management (Walters 1986, Walters and Holling 1990).

It was not long before other investigators (e.g., Eberhardt and Thomas 1991, Jassby and Powell 1990, Reckhow 1990, Walters and Holling 1990) became involved with the issues raised by false replication. As a result, some ecologists concluded that such studies are highly problematic and have no ready solution for coping with stochastic environmental variations (e.g., Dennis 1996, Hilborn and Ludwig 1993, Pitelka and Pitelka 1993, Smith et al. 1993, Stewart-Oaten 1995, Underwood 1994). In other words, if true replication is not possible, it remains erroneous to use classical frequentist statistics to derive conclusions (Stewart-Oaten et al. 1992, Underwood 1994 and 1995).

This explains why some pioneers in postmodern environmental impact assessment and natural resources management (e.g., Canter 1985, Reckhow 1990, Walters 1986, Westman 1985) have not accepted pseudoreplication and traditional frequentist approaches as a solution to interpreting suboptimal impact study designs. Among them are Walters and Holling (1990) and Shrader-Frechette and McCoy (1994) who question whether such problems are irresolvable with respect to classical state-of-the-art statistical analysis. Eberhardt and Thomas (1991) doubt whether such ecological effects studies should even be attempted. Smith et al. (1993) and Underwood (1994), on the other hand, believe that new statistical approaches can yet be developed, and this is where Maurer's (1998) views fit on the challenges presented to the need for new practices and philosophies regarding postmodern ecological science and statistical paradigms.

As emphasis expands on conserving biodiversity through ecosystem management (Maurer 1998, Underwood 1995, Vogt et al. 1997), investigators must meet the challenges posed by understanding how entire ecosystems and landscapes respond to both natural and human-caused changes. In this regard, Holling and Meffe (1996) recognized the quandry of studying single, large ecosystems and argured for new approaches to understanding natural variation and its influence on discerning and managing ecosystem impacts. Gunderson et al. (1997) and Vogt and collaborators traced the development of the postmodern ecosystem management and natural resources protection and Montgomery (1995) and Montgomery et al. (1995) discuss its implementation in the western U.S. On these and other bases, an argument has been made (Malone 1998a, 1998b, 1998c, 1999) for adopting the ecosystem-based approach at Yucca Mountain that is being implemented in the surrounding region (DOE 1996, USAF 1997, TKC 1996, TNC, 1996).

Wiens and Parker (1995) have shown that where disturbed sites cannot be replicated, consideration of methodological limitations and hidden ecological assumption can be helpful. At issue are concerns regarding sampling for characterizing levels of environmental disturbance. Additional concerns arise from common assumptions that are seldom verified regarding spatial and temporial variation in biotic parameters and their interactions with human-caused disturbances. Wiens and Parker present several suboptimal designs that compensate for pseudoreplication by considering stochastic factors. However, each requires before-and-after comparisons, a condition not met when baseline information is lacking, such as at Yucca Mountain.

An approach to traditional BACI studies where the "Before" condition (pre-disturbance baseline ecological data) is missing was presented by Osenberg et al. (1994). Their "After-Impact" procedure alone assesses ecological effects on post-impact sites in comparison with control sites distant from the disturbed site. Osenberg and colleagues conclude that such study designs can be an effective approach to assessing ecological impacts . However, the authors note that if frequentist analysis is to be used, true replication of both the disturbed condition and the far-field sites is essential. Otherwise, Bayesian inference is needed to distinguish between the effects of the disturbance natural natural variability over time, the ultimate delimma with pseudoreplication.

Thus, the solution to unreplication ecosystem impact studies well may rest with the premise of Walters (1984) and Walters and Holling (1990) involving more wide-spread use of Bayesian analysis to understand natural variation. A fresh look is being taken at Bayesian inference for interpreting trends over time in single, non-replicated ecosystems (e.g., see Dixon and Ellison 1996 and other authors in a Special Section of Ecological Applications 6: 1034-1103, 1996). In a study of ecological effects in a single, unreplicated ecosystem, Crome et al. (1996) analyzed the same body of data both by the suboptimal experimental design/frequentist method and the Bayesian approach. The comparison demonstrated that traditional statistical methods are illogical and that Bayesian methods are strong and correct.

The goal is to develop a study design to replace classical frequentist statistics in unreplicated ecosystem-level studies. Presently, Bayesian approaches often are not used because many ecologists fail to understand the significant differences between them and traditional frequentists analysis where subjectivity is hidden. Bayesianists, on the other hand, know that in unique, one-of-a-kind ecosystems subjectivity is handled openly and transparently (Crome et al. 1996). The rapidly developing Bayesian approach is a general one adaptable as an integrated package for site-specific situations of ecological impact assessment. For non-replicated studies, Bayesian statistical inference provides an attractive alternative to frequentist inference because the latter rests on too many assumption that often cannot be satisfied (Eberhardt and Thomas 1991, Reckow 1990, Smith et al. 1993, Underwood 1994, Wiens and Parker 1995).

## Ecological Effects Studies at Yucca Mountain

In 1979, the DOE began investigating Yucca Mountain in southern Nevada for the site's environmental suitability as a deep repository for disposing of the nation's high-level nuclear waste. Disturbance of 480 ha of habitat in the 190 km$^2$ site has resulted from construction of roads, drillpads, pads for tunneling, trenches, pipelines, and powerlines through 1997. Seventy-nine percent, or 370 ha, of the habitat ultimately lost had been destroyed prior to initiation of environmental impact studies in 1989. Since then, habitat on another 110 ha of land has been destroyed (Wade 1996). To assess ecological impacts, 24 pairs of 4 ha plots were established at the Yucca Mountain site in 1998 (Green et al. 1991). One of each pair of the ecological study plots was established adjacent to a disturbed area with the second plot sited 200-300 m from the disturbed area. It was subjectively assumed that the distant plot was not influenced by ecological disturbance (habitat destroyed by construction activities) and that if plots nearer to a disturbance were similar to the one 200-300 m distant, no impact has resulted from habitat destruction.

Using paired plots constitutes a "split-plot" study design (Steel and Torrie 1980). The DOE had assumed that the Yucca Mountain ecological effects study design was an acceptable variation of Green's (1979) "optimal impact study design," despite committing pseudoreplication, missing pre-disturbance ecological baseline data, and interpreted with classical analysis of variance, multiple regression, and correlation analysis (Green et al. 1991, Sokal and Rolf 1981, Stewart-Oaten et al. 1986). As discussed in the previous section, pseudoreplication is incompatible with frequentist analysis because there is no way to account for stochastic, natural variation, especially of the magnitude that occurs in arid mountains.

Yucca Mountain can experience a hundred-fold change in productivity from year to year due to pronounced variation in climate, elevation, topography, and substrate conditions (EGG 1991, Malone 1991). Where the range of natural variability is this large, Type II errors, i.e., not detecting impacts when in fact they exist, especially are difficult to elude (Osenberg et al. 1994, Underwood 1994, Wiens and Parker 1995). For this and other reasons, the strategy for the DOE's study was weak (Table 1) in that (1) during the first five years the treated and untreated plots were collocated, (2) effects that might have occurred before 1989 were disregarded, and (3) frequentist analyses was applied to data obtained through pseudoreplication.

Table 1. Weaknesses in the environmental study design and the statistical approach tc the Yucca Mountain ecological impact investigations.

- Absence of true spatial replication commits pseudoreplication by using time-series samples as replicates.
- Treatment and control plots collocated during 1989-1994 and not demonstrated to be independent of habitat disturbances on the site.
- Absence of predisturbance ecological baseline information before commencing the investigation after 10 years of habitat destruction.
- Misapplies standard frequentist statistical analysis to non-replicated data.
- Degree of variability not quantitatively demonstrated between Yucca Mountain site and the far-field control site adopted in 1995.
- No spatial replication for the single disturbed (Yucca Mountain) site and the single far-field control site adopted in 1995.

- Time-series sampling in the disturbed (Yucca Mountain) site and the far-field control commits pseudoreplication.

- Use of the 1989-1994 information from the previously disturbed Yucca Mountain site as an unverified ecological baseline for comparing to the far-field control site.

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After the initial five years, an effort was made to compensate for the absence of baseline data. Thus, in 1995, the DOE altered the initial study design by reducing the number of ecological study plots at the Yucca Mountain site from 48 to 12 and adding six plots to a single far-field control site located 22 km from Yucca Mountain. The plan now is to use the results obtained 1989 through 1994 as a baseline for discerning effects caused by the post-1994 site characterization activities (DOE 1996, TRW 1996, Wade 1996). The "baseline" information subsequently will be compared to the 12 plots remaining at Yucca Mountain and the six new plots in the far-field ecosystem.

The changes made by the DOE in the Yucca Mountain ecological study design result from the lack of baseline information prior to initiation of the impact study in 1989. Originally, 24 paired plots were sampled at Yucca Mountain from 1989 through 1994. In 1995, the study design was altered when sampling was discontinued in all but 12 of the initial 48 plots. At the same time, six new plots were established at the far-field location. Due to the initial absence of baseline information, the DOE has elected to use data from the 1989-1994 studies at Yucca Mountain as the baseline for comparing results of the revised study design. This strategy assumes that the habitat destruction at Yucca Mountain prior to 1989 (79% of the total during 1979-1997) had no effect on the 12 study plots retained at the site since the end of 1994. Thus, if an effect is subsequently detected, it will be supposed to have resulted from the the 21% of the site disturbance that has occurred since 1994.

There is no assurance that the 12 remaining plots at Yucca Mountain are a sufficient number to characterize the stochastic factor. The same is true for the six study plots established at the new control site. In redesigning the experiment, the DOE should have measured the variability in the disturbed site and the control site and asked how many replicates of each are needed in view of the observed variability among them (Table 2). The DOE apparently has no evidence to answer the question of whether or not the two different sites are sufficiently similar for one to be used for the disturbed situation and the other as a comparable control (DOE 1996, TRW 1996, Wade 1996). Demonstrating the alikeness of ecosystems visually judged similar always is open to doubt because separate ecosystems can always be shown to be different if adequately sampled (Eberhardt and Thomas 1991, Smith et al. 1993, Stewart-Oaten et al. 1992).

Table 2. Statistical weaknesses in the two phases of the Yucca Mountain ecological effects studies.

PHASE ONE (1989-1994)

- Absence of spatial replication.
- Commits pseudoreplication by using repeated sampling as replication.
- Treatment and control plots collocated and not shown to be independent.

PHASE TWO (1995-1998)

- Similarity between treatment and control site not tested.
- Treatment and control site unreplicated.
- Commits pseudoreplication by using repeated sampling as replication.
- Absence of predisturbance ecological baseline information.
- Misapplied frequentist analysis to non-replicated data.

An ecological impact study design, such as that being pursued now for the Yucca Mountain Project, involving two independent sites where one is disturbed and the second one is not indeed is a credible version of the BACI model (Wiens and Parker 1995, Osenberg et al. 1994). However, treating time-series samples from each location as independent replicates by applying standard frequentist statistics remains erroneous (Smith et al. 1993, Stewart-Oaten et al. 1992, Underwood 1994). Thus, the DOE has returned full circle to the dilemma posed by lacking true replication. All that has been accomplished is having located an independent, undisturbed site to use as a lone control. Also problematic now is the adequacy of the new concept for obtaining baseline information. Interpreting such results correctly would require using Bayesian methods such as those discussed by Reckhow (1990) and Ellison (1996).

## Conclusions

In the past, dilemmas of the Yucca Mountain sort arose because adequate analytical approaches did not exist for interpreting unreplicated ecosystem investigations. Traditional statistical approaches lack empiricism and are fraught with subjective judgement, particularly where there is an absence of baseline ecological information. Consequently, some researchers have suggested abandoning hypothesis testing in such cases and resorting to purely descriptive studies and subjective judgement. However, this action is too drastic in view of the recent advances being made in analyzing and interpreting unreplicated field studies. Some promising methods attemp to cope with single-ecosystem studies by identifying and substantiating inherent ecological assumptions associated with spatial and temporal variation. Other methods use after-only studies in comparison with far-field controls with but depend on adequate replication for determining the stochastic factor. The most promising solutions to the problems of pseudoreplication seem to rest with empirical Bayes methods and hierarchical models that are rapidly being developed.

In some respects, the challenges presented by postmodern ideas regarding biodiversity conservation through ecosystem management appear to be ahead of the capacity of ecological science to support. New approaches to old problems of natural complexity and uncertainty are needed more than ever for the new paradigm of managing natural resources. The ideal of sustaining both ecosystems and the human economies linked to them places a burden of precaution on decisions regarding ecosystems and landscapes. Past emphasis in ecology has been placed on traditional study designs, methods of data collection, and analysis of the results. Now, increased attention is needed regarding decisionmaking in the context of ecosystem management.

These problematic issues apply in the case of the Yucca Mountain ecological impact studies. However, time remains for the DOE to explore alternative approaches such as Bayesian inference to improve the validity of its environmental impact assessment. Clearly, nothing stands to be lost by the DOE from attempting to validate information from what otherwise may prove to be unproductive ecological data. Without doing so, interpreting the ecological effects investigations now underway will remain at risk with regards to complying with the National Environmental Policy Act for developing a nuclear waste repository in southern Nevada.

**References**

Canter, L.W. 1985. Impact prediction auditing. The Environmental Professional 7(3): 255-264.

Crome, F.H.J., M.R. Thomas, and L.A. Moore. 1966. A novel Bayesian approach to assessing impacts of rain forest logging. Ecological Applications 6(4): 1104-1123.

Dennis, B. 1996. Discussion: should ecologists become Bayesians? Ecological Applications 6(4): 1095-1103.

Dixon, P. and A.M. Ellison. 1996. Introduction: ecological applications of Bayesian inference. Ecological Applications 6(4): 1034-1035.

DOE (U.S. Department of Energy). 1995. Site environmental report for calendar year 1994. June. DOE, Las Vegas, NV.

DOE (U.S. Department of Energy) 1996a. Framework for the resource management plan. Volume 2 of Final environmental impact statement for the Nevada Test Site. DOE/EIS 0243. DOE, Las Vegas, NV.

EGG (EG&G Energy Measurements). 1991. Yucca Mountain biological resources monitoring program: annual report FY89 & FY90. EGG 10617-2084. January. EGG, Goleta, CA.

Eberhardt, L.L. and J.M. Thomas. 1991. Designing environmental field studies. Ecological Monographs 61(1): 53-73.

Green, R.H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. John Wiley & Sons, New York, NY.

Green, R.A., M.K. Cox, T. Doerr, T.P. O'Farrell, W.K. Ostler, K. Rauthestrauch, and C. Willis. 1991. Assessing impacts on biological resources from site characterization activities of the Yucca Mountain Project. pp. 1456-1460, in High-Level Radioactive Waste Management. American Nuclear Society, La Grange Park, IL.

Gunderson, L.H., C.S. Holling, and S.S. Light (eds.) 1997. Barriers & Bridges to the Renewal of Ecosystems and Institutions. Columbia University Press, New York, NY.

Holling, C.S. and G.K. Meffe. 1996. Command and control and the pathology of natural resources management. Conservation Biology 10(2): 328-337.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54(2): 187-211.

Jassby, A.D. and T.M. Powell. 1990. Detecting changes in ecological time series. Ecology 71(6): 2044-2052.

Lemons, J., K. Shrader-Frechette, and C. Cranor. 1997. The precautionary principle: scientific uncertainty and Type I and Type II effors. Foundations of Science 2: 207-236.

Malone, C.R. 1991. The potential for ecological restoration at Yucca Mountain, Nevada. The Environmental Professional 13(3): 216-224.

Malone, C.R. 1995. Ecology, ethics, and professional environmental practice: the Yucca Mountain Project as a case study. The Environmental Professional 17(3): 271-284.

Malone, C.R. 1998a. The federal ecosystem management initiative in the United States. In, J. Lemons, L. Westra, and R. Goodlane (eds.) Ecological Sustainability and Integrity: Concepts and Approaches. Kluwer Academic Publishers, Boston, MA.

Malone, C.R. 1998b. Implications of resources management at the Nevada Test Site. Federal Facilities Environmental Journal 9(1): 51-62.

Malone, C.R. 1998c. The Southern Nevada Initiative: A case of federal ecosystem management in the U.S. Environments 26(2): 1-15.

Malone, C.R. 1999. Integrated weapons-site cleanup. Forum for Applied Research and Public Policy 14(2): in press.

Maurer, B.A. 1998. Ecological science and statistical paradigms: at the threshold. Science 279(5350): 502-503.

McBride, G.B., J.C. Lostis, and N.C. Adkins. 1993. What do significance tests really tell us about the environment? Environmental Management 17(4): 423-432.

Montgomery, D.R. 1995. Input- and output-oriented approaches to implementing ecosystem management. Environmental Management 19(2): 183-188.

Montgomery, D.R., G.E. Grant, and K. Sullivan. 1995. Watershed analysis as a framework for implementing ecosystem management. Water Resources Bulletin 31(3): 369-386.

NWTRB (Nuclear Waste Technical Review Board). 1995. Report to the U.S. Congress and the Secretary of Energy: January to December 1993. NWTRB, Arlington, VA.

NWTRB (Nuclear Waste Technical Review Board). 1996. Report to the U.S. Congress and the Secretary of Energy: 1995 Findings and

Recommendations. NWTRB, Arlington, VA.

Osenberg, C.W., R.J. Schmitt, S.J. Holbrook, K. Abu-Saba, and A.R. Flegal. 1994. Detection of environmental impacts: variability, effect size, and power analysis. Ecological Applications 4(1): 16-30.

Pitelka, L.F. and F.A. Pitelka. 1993. Environmental decision making: multidimentional dilemmas. Ecological Applications 3(4): 566-568.

Reckhow, K.H. 1990. Bayesian inference in non-replicated ecological studies. Ecology 71(6): 2053-2059.

Shrader-Frechette, C. and E.D. McCoy. 1994. Ecology and environmental problem solving. The Environmental Professional 16(4): 342-348.

Smith, E.P., D.R. Orvos, and J. Cairns, Jr. 1993. Impact assessment using the Before-After-Control-Impact (BACI) model: concerns and comments. Canadian Journal of Fisheries and Aquaitic Sciences 50: 627-637.

Sokal, R.R. and F.J. Rolf. 1981. Biometry: The Principles and Practice of Statistics in Biological Research. W.H. Freeman and Co., New York, NY.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. Second edition. McGraw-Hill, New York, NY.

Stewart-Oaten, A. 1995. Rules and judgement in statistics: three examples. Ecology 76(6): 2001-2009.

Stewart-Oaten, A., W.M. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? Ecology 67(4): 929-940.

Stewart-Oaten, A., J.R. Bence, and C.W. Osenberg. 1992. Assessing effects of unreplicated pertubations: no simple solutions. Ecology 73(4): 1396-1404.

TKC (The Keystone Center). 1996. Dialogue on a DoD biodiversity management strategy. Final Report, January 23. TKC, Keystone, CO.

TNC (The Nature Conservancy). 1996. Conserving biodiversity on military lands. TNC, Arlington, VA.

TRW (TRW Environmental Safety Systems, Inc.) 1996. The vegetation of Yucca Mountain: description and ecology. B00000000-01717-5705-00030 REV 00. March 29. DOE, Las Vegas, NV.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications 4(1): 3-15.

Underwood, A.J. 1995. Ecological research and (and research into) environmental management. Ecological Applications 5(1): 232-247.

USAF (U.S. Air Force). 1997. Integrated natural resources management plan: Nellis Air Force Base/Nellis Air Force Range. March 1997 Draft. Nellis Air Force Base, NV.

Vogt, K.A. and collaborators. 1997. Ecosystems: Balancing Science with Management. Springer-Verlag New York, Inc., New York, NY.

Wade, S.A. 1996. Yucca Mountain site characterization project environmental protection process. November 6. Presentation by the Yucca Mountain Project Office to the Mojave-Southern Great Basin Resource Advisory Council, Las Vegas, NV.

Walters, C.J. 1986. Adaptive Management of Renewable Resources. McMillian Publ. Co., New York, NY.

Walters, C.J. and C.S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71(6): 2060-2068.

Westman, W.E. 1985. Ecology, Impact Assessment, and Environmental Planning. John Wiley & Sons, Inc., New York, NY.

ATTACHMENT R

Appendix A

## BASE CASE SCENARIO - HIGH LEVEL TRANSPORTATION

**Emergency Response Vans**

The number of emergency response vans may be affected by the routes chosen. It therefore would be premature to specify how many and at what intervals the response vans should be placed. Ideally, they should be located so as to have a maximum response time of one hour. The alternative to this would be to assign one response van to each Port of Entry.

Based upon a minimum of two (2) Port of entries design for inspection of nuclear shipments, two (2) emergency response vans with crews, would be required. An additional nine (9) emergency response personnel would be required to staff the Port of Entry and still maintain sufficient personnel for routine inspection should the response van be called out. The cost projection for an equipped emergency van was estimated to be $350,000. The cost for two (2) (one for each Port of Entry) would be approximately $700,000. Again, the two Ports of Entries would be a minimum. Replacement vehicles would be based upon State requirements of mileage.

Response to area's on railroad routes would require specialized equipment such as military type (Hummer, etc.) Vehicle or helicopter. Costs of these are not reported here within as this would most probably be the responsibility of another agency other than the highway patrol.

**Safe Escorts**

Safe escorts should be required should high-level shipments commence through Nevada. A minimum of 2 two-man units would be required per shipment. During the first year it is estimated that there will be seven (7) legal weight shipments per day. This would require 8, two-man teams to escort two shipments per day under ideal conditions. This equates to the following costs using new positions rather than existing positions.

**Personnel Initial Cost**

32 Troopers

| | |
|---|---|
| Hire, Train, Equipment = | $ 94,000 |
| Escort Vehicle - Commercial type = | $ 32,400 |
| Total | $ 126,400 |
| | x 32 troopers |
| | $4,044,800 Initial |

**Personnel Annual Costs**

| | |
|---|---|
| 32 Troopers | $1,429,600 |
| Benefits | $ 590,304 |
| Total | $2,019,904 |

**Training**

Until such time that specific needs for training are determined which can not be done until routes and the commitment level is established, only a rough projection can be given regarding needed training.

Based upon a 40 hour course conducted in conjunction with the Fire Marshall' Office and given at the P.O.S.T. academy as a money-saving factor, the following is projected. The dorm at P.O.S.T. is reserved to house 22 NHP personnel. The need to train 274 troopers which do not line in Carson City (location of the dorm) would be required. With an estimated $2,000 per week overhead cost. Approximately 25 to 28 weeks of overhead would be required. Supervisors from the rank of Sergeant and above (approximately 64) would need an additional week of command/advanced training. As taken from the 1988 report from Dr. Mushkatel of State Costs, training would need to include Port of Entry and Escort Troopers 60 to 120 troopers).

The training for all troopers, the necessary Supervisors, Port of Entry personnel and Escort personnel would require the total P.O.S.T. overhead to fall between 25 weeks minimum to an approximate maximum of 28 weeks. The monetary amounts for overhead would be a minimum of $45,000.00 with an estimated maximum of $60,000. State per diem should be added to the above figure based upon $26.00 per day. Per diem costs figure to be at a low of $35,070.00 and an approximate high of $41,370.00. Per diem for supervisors is estimated at $4,550.00 bringing the totals to a low of $39,620.00 and a high of $45,920.00.

Loss of time from regular duties due to training requirements should be accounted for as follows:

| | | | | | | Training | | Training Time |
|---|---|---|---|---|---|---|---|---|
| 3 - | Majors - | $7,734.58 x 3= | $23,203.75 | per month | or | 11,601.88 | / | 80 hrs |
| 5- | Captains- .... | $7,085.83 x 5= | $35,429.17 | per month | or | 17,714.58 | / | 80 hrs |
| 15- | Lieutenants- | $6,498.92 x 15 = | $97,483.75 | per month | or | 48,741.88 | / | 80 hrs |
| 44- | Sergeants- | $5,717.83 x 44 = | $251,584.67 | per month | or | 125,792.33 | / | 80 hrs |
| 207- | Troopers | $5,260.17 x 207= | $1,496,555.83 | per month | or | 5,986,223.32 | / | 40 hrs |

Estimates for port of Entry personnel and Escort personnel would range from a minimum of $468,646 to an estimate high of $973,292.

For ease of figuring, reimbursement for loss of regular duties, due to required training, would for one month's time be at a minimum of $3,158,674.00 and estimated maximum of $3,695,649.00.

## ATTACHMENT A

Projected Construction Costs for Ports of Entry

To assist with determining construction costs with establishing a "Port of Entry", contact was made with Russ Hall of the Nevada Department of Transportation and David K. Nakao, P.E. of the State of California's Department of Transportation, Office of Permits and Truck Studies.

The state of California has currently developed a plan for the construction of a 4 bay facility on I-15 near the Nevada/California border with construction beginning in the year 2001.

Site location is important with respect to construction costs. Generally, straight and flat terrain is the most economical. Consideration is given to the terrain as approximately 75% of construction costs are attributed to paving and lighting. Approximately 1 mile of deceleration and acceleration lanes are required to enter and leave the site. Nevada, with raised speed limits, may be required to lengthen the deceleration/acceleration lanes.

The following information is supplied by California for construction costs of actual and projected sites:

I-15 @ Mountain Pass = $17,880,000
I-40 near Needles = 19,200,000
I-5 So. Of Redding = $12,840,000

Construction costs per monitoring station based upon the State of California's average cost for constructing Port of Entry's would be $16,560,000.00. The cost for two would be $33,120,000.00. This estimate is based upon providing:

Signs, lighted at night, on the roadway directing all trucks transporting high-level radioactive waste to exit.

Paved heavy-duty freeway two-lane ramps leading into and out of the weight-in-motion scales.

Computer-assisted weigh scales that allow individual axle weights and gross vehicle weights to be recorded and the vehicle to be classified while the truck continues to move.

Over-dimensional detectors.

A building that includes office space, reception area, restrooms, showers, locker room, Hazardous Material locker room for self-contained Haz Mat examining protective suits, break room, computer and electronic reader area,

A signal system that, when necessary, directs the trucks and drivers to an inspection area or into the facility.

An all weather vehicle inspection facility complete with high intensity lights, automatic bay doors, fire suppression equipment, Haz Mat detection and monitoring equipment, generator.

A high-level radioactive materials containment area for leaking of ruptured containers and a decontamination area for personnel.

A paved parking and vehicle impoundment area, equipped to transfer data to NHP stations, other state, local and federal law enforcement and public safety agencies and other haz mat responder teams.

Each monitoring station would be operated 24 hours a day, 7 days a week. This would require 15 commercial troopers, one sergeant and one lieutenant.

PERSONNEL ANNUAL COSTS:

| | |
|---|---|
| 60 Troopers | $2,680,500 |
| Benefits | $1,106,820 |
| 4 Sergeants | $ 195,484 |

| | |
|---|---|
| Benefits | $ 78,972 |
| 4 Lieutenants | $ 224,120 |
| Benefits | $ 87,828 |
| 12 Clerical | $ 351,300 |
| Benefits | $ 8,495 |
| 2 Dispatchers | $ 75,420 |
| Benefits | $ 18,452 |
| TOTAL PERSONNEL EXPENSES | $4,827,391 |
| Overtime would be estimated at 5% of total personnel costs. | $ 241,370 |
| TOTAL PERSONNEL COSTS INCLUDING OVERTIME | $5,068,761 |

OPERATING COSTS: ANNUAL

| | |
|---|---|
| Vehicle operating costs 68 vehicles | $ 121,176 |
| Utilities | $ 144,000 |
| Supplies | $ 192,000 |
| Maintenance | $ 96,000 |
| Contracts | $ 72,000 |
| Personnel driven operating costs | $ 675,451 |
| TOTAL OPERATING COSTS | $1,300,627 |

EQUIPMENT:

| | |
|---|---|
| Furniture | $ 240,000 |
| High-level radioactive monitoring equipment and personal protective attire | $ 600,000 |
| 68 vehicles | $1,713.600 |
| Computers | $ 166,900 |
| 68 new positions, equipment | $1,070,214 |

TOTAL EQUIPMENT COSTS .................................... $3,790,714

Sworn officers assigned this duty will, over and above the normal training cost, receive specialized training in the detection and containment of Radioactive Waste.

TRAINING:

68 sworn ............................................................ $2,093,203

Specialized training ............................................... $ 300,000

TOTAL TRAINING COSTS ........................................ $2,393,203

TOTAL MONITORING STATION COSTS FIRST YEAR .................. $43,280,120

SECOND YEAR COSTS would not include construction costs or new equipment costs or initial training costs associated with academy training and Radioactive specialized training.

TOTAL SECOND YEAR COSTS ................................... $ 6,369,387

**RAILROAD INSPECTION OF THE TRANSPORTATION OF HIGH-LEVEL RADIOACTIVE WASTE**

These inspections of high-level radioactive waste transported via railway could be conducted by monitoring station personnel. Specialized training would be provided by the Federal Railroad Administration. Inspection areas are restricted to the following:

- Tracks
- Haz Mat
- MP & E Inspector
- Operating Procedures
- Signal and train control

This Division has no information to base a cost statement.

To monitor the transportation of high-level radioactive waste, it would be recommended that as permit restriction, the commercial carriers of this cargo be required to have a Global Positioning System transmitter on the vehicle. This would allow for the continuous monitoring of the vehicle as it travels to it destination. Included here are the costs to the state of this program. For detailed information on equipment and quantity, see the attached memorandum, subject GPS.

TOTAL COST OF THE GPS MONITORING SYSTEM . . . . . . . . . . . . . . . . . . $ 195,984

FIRST YEAR COSTS . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $66,683,826

SECOND YEAR COSTS . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $ 7,024,188

Question: Could less expensive mobile units be constructed for Ports of Entry?

We currently deploy mobile inspection stations statewide on a random basis for the purposes of conducting safety inspections and weighing activities. These are designed for short term use for the following reasons:

1. Inadequate lighting at the facilities, as well as around the inspection station.
2. There are no facilities or running water at these sites.
3. There is no emergency decontamination facilities to handle exposure to hazardous materials.
4. There is no shelter to conduct inspection activities during inclement weather.
5. The inbound and outbound access ramps are not designed for continuous operation.
6. The current sites are not large enough to handle high volume traffic 24 hours per day, 7 days per week
7. The current sites are not large enough to place more than two or three vehicles out of service at any given time.
8. There are no buildings to operations. We currently use a converted recreational vehicle that could not handle the rigors of continuous 24-hour use and cannot hold more that about five (5) people.

ATTACHMENT S

## Appendix B

The following chart was published in the newsletter NHTSA, published by the U.S. Department of Transportation, National Highway Traffic Safety Administration. (DOT808 952)

Involvement in Fatal and Injury Crashes and involvement rates for large trucks. 1998-1998

| Year | Number of large trucks involved in fatal crashes | Number of large trucks registered | Vehicle involvement rate* | Vehicle miles traveled (millions) | Vehicle involvement rate ** |
|---|---|---|---|---|---|
| 1988 | 5,241 | 6.136.884 | 85.4 | 137,985 | 3.8 |
| 1989 | 4,984 | 6.226.482 | 80.0 | 142,749 | 3.5 |
| 1990 | 4,776 | 6.195.876 | 77.1 | 146,242 | 3.3 |
| 1991 | 4,347 | 6.172.146 | 70.4 | 149.543 | 2.9 |
| 1992 | 4,035 | 6,045.205 | 66.7 | 153,384 | 2.6 |
| 1993 | 4,328 | 6.088.155 | 71.1 | 159,888 | 2.7 |
| 1994 | 4,644 | 6,587,885 | 70.5 | 170,216 | 2.7 |
| 1995 | 4,472 | 6,719,421 | 66.6 | 178,156 | 2.5 |
| 1996 | 4,755 | 7,012,615 | 67.8 | 182,971 | 2.6 |
| 1997 | 4,917 | 7.083.326 | 69.4 | 191,345 | 2.6 |
| 1998 | 4,935 | ———— | ———— | ———— | ———— |
| **Year** | **Number of large trucks involved in injury crashes** | **Number of large trucks registered** | **Vehicle involvement Rate*** | **Vehicle miles traveled (millions)** | **Vehicle involvement rate**** |
| 1988 | 96,000 | 6.136.884 | 1,562 | 137,985 | 69 |
| 1989 | 110,000 | 6,226.482 | 1,770 | 142,749 | 77 |
| 1990 | 107,000 | 6.195.876 | 1.730 | 146,242 | 73 |
| 1991 | 78,000 | 6.172.146 | 1.264 | 149,543 | 52 |
| 1992 | 95,000 | 6.045.205 | 1,567 | 153,384 | 62 |
| 1993 | 97,000 | 6,088.155 | 1,585 | 159,888 | 60 |
| 1994 | 96,000 | 6.587.885 | 1.452 | 170,216 | 56 |
| 1995 | 84,000 | 6.719.421 | 1.244 | 178,156 | 47 |
| 1996 | 94,000 | 7.012.615 | 1,339 | 182,971 | 51 |
| 1997 | 96,000 | 7.083.326 | 1,349 | 191,345 | 50 |
| 1998 | 89,000 | ———— | ———— | ———— | ———— |

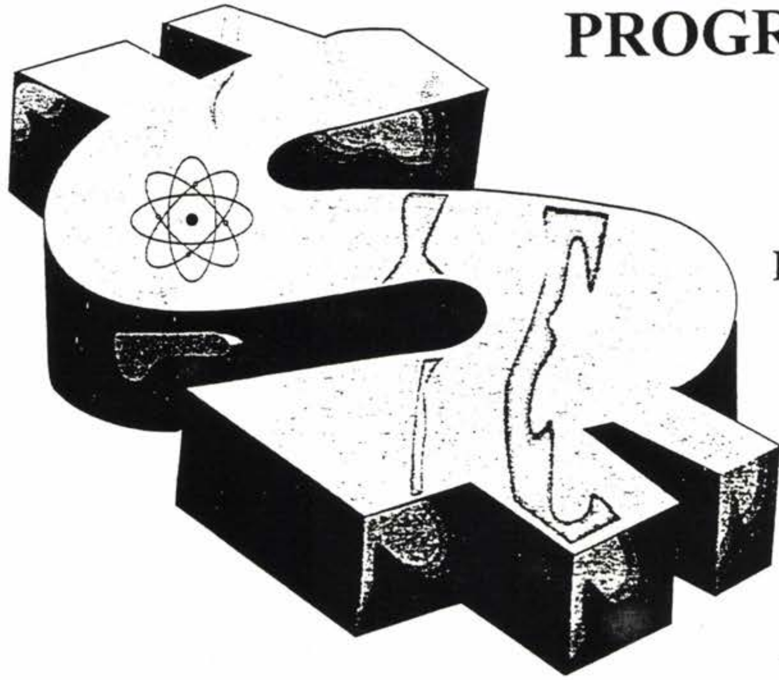
- * Rate per 100,000 registered vehicles.
- ** Rate per 100 million vehicles miles traveled.

———— = not available

Source: Vehicle miles traveled and registered vehicles - Federal Highway Administration.

# ATTACHMENT T

# AN INDEPENDENT COST ASSESSMENT OF THE NATION'S HIGH-LEVEL NUCLEAR WASTE PROGRAM



February
1998

By

*PLANNING INFORMATION CORPORATION*
*THOMPSON PROFESSIONAL GROUP*
*DECISION RESEARCH INSTITUTE*

**Review of Findings By**
**KPMG Peat Marwick**

## Preface

In 1996, the U.S. Department of Energy (DOE) announced plans to prepare, by late 1998, a "Viability Assessment" as a tool for managing and making decision about the federal high-level radioactive waste program, in particular the proposed Yucca Mountain nuclear waste repository. One component of the Viability Assessment was to be an assessment of the total cost of the federal program, something that has been and continues to be plagued by great uncertainty due to the changing and evolving nature of the program since 1983.

In order to effectively evaluate the accuracy and appropriateness of the Viability Assessment's findings, the State of Nevada commissioned an independent study of likely costs associated with accepting spent fuel and high-level radioactive wastes at generator sites, transporting the material to Nevada, and ultimately disposing of it in a repository. The report which follows grew out of this effort. However, as the project progressed, it became apparent that the data and findings have applicability and importance far beyond the narrow confines of DOE's Viability Assessment.

To undertake this project, it was necessary to make determinations about what the reference waste management system would consist of and how it will operate. Toward that end, the waste management system prescribed in pending congressional legislation was used as the report's guiding framework. Consequently, the assumptions in this independent cost assessment report reflect the legislation's provisions regarding schedules and time frames, DOE responsibility for at-reactor storage pending shipment, waste acceptance activities, transportation planning and emergency preparedness, shipping assumptions and intermodal transportation, centralized interim storage, repository disposal, and other related aspects of the system.

To assure that the report's contents and finds would be as accurate and objective as possible, a team of independent consultants was employed to gather information, analyze the data, and develop the ultimate cost conclusions. The accounting firm of KPMG Peat Marwick was commissioned to provide expert peer review for the effort.

The result of this extraordinary independent undertaking is a comprehensive and timely evaluation of the real costs to the nation of the federal high-level nuclear waste program - not just the Yucca Mountain repository component - and the potential taxpayer liability the country will incur as that program moves forward.

KPMG Peat Marwick LLP

725 South Figueroa Street
Los Angeles, CA 90017

Telephone 213 972 4000

Telefax 213 622 1217

April 23, 1998

Mr. Robert R. Loux
Executive Director
Nevada Agency for Nuclear Projects
1802 N. Carson Street, Suite 252
Carson City, Nevada 89701

Re: Peer Review of "An Independent Cost Assessment of the Nation's High-Level Nuclear Waste Program", February 1998

Dear Mr. Loux:

Pursuant to your request, KPMG Peat Marwick LLP ("KPMG") has completed its review of "An Independent Cost Assessment of the Nation's High Level Nuclear Waste Program", February 1998 ("Study"), prepared by Planning Information Corporation, Thompson Professional Group and Decision Research Institute, and hereby submits this summary letter describing work performed and conclusions reached.

KPMG was retained to provide the agreed upon procedures of "Peer Review" of the Study, pursuant to the engagement letter dated June 4, 1997. Of the limited tasks set forth below, the calculations tested were found to be accurate, the Study's assumptions appear to be supportable, and KPMG's peer review is complete.

The agreed upon procedures which constitute the peer review include the following:

a. Review the reasonableness of Study assumptions
b. Review the cost categories and cost components for completeness
c. Review the supporting documentation
d. Test selected mathematical calculations for accuracy
e. Review the Study for internal consistency
f. Review the Study for overall consistency

To complete the above described agreed upon procedures, KPMG performed certain tasks including the following:

1. Detailed review of Study
2. Site visits and interviews with authors of various Study components including: Planning Information Corporation, Thompson Professional Group and Decision Research Institute
3. Verify calculations/assumptions in narrative and charts to underlying data
4. Verify assumptions/citations in narrative to source documents (i.e. DOE Reports)
5. Review literature and supporting materials outside the body of the Study

The procedures performed do not constitute an audit, examination or review in accordance with standards established by the American Institute of Certified Public Accountants and therefore, we do not make any representations regarding the sufficiency of the procedures performed for your informational needs. The term "review" has a defined meaning in U.S. accounting and auditing literature; however, the term "review" as used in this letter is intended to refer to obtaining and analyzing information, and does not encompass the term or scope of engagement defined in the accounting and auditing literature.

Should you have any questions or comments regarding KPMG's completion of these services, please call me at (213) 955-8994.

Sincerely,

KPMG Peat Marwick LLP

Joseph S. D'Antoni
Principal

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## LIST OF FIGURES

# 1. EXECUTIVE SUMMARY

This report presents the findings of a new, comprehensive and independent assessment of the Total System Life Cycle Costs (TSLCC) for the nation's high-level nuclear waste (HLNW) program and the proposed repository at Yucca Mountain, Nevada. This study finds that the costs will be $53.9 billion in constant 1996 dollars.

The study bases its cost evaluation on current plans by the U.S. Department of Energy, recent federal court decisions, and pending federal legislation that has the support of a majority of members in Congress. The costs include expenditures to date and estimated costs for the study, licensing, development, and operations necessary to implement the federal program.

The HLNW is produced or stored at 80 locations including commercial nuclear power stations, nuclear weapons facilities and temporary storage sites. Moving these wastes to Yucca Mountain requires an unprecedented national waste transportation program. Since the majority of the HLNW is produced or stored east of the Mississippi River, rail and highway transportation will affect residents in 43 states and more than 500 communities. This report fully takes account of the national scope of the federal government's HLNW program.

The assessment for future activities, events, and behaviors depends upon the quality of the data and the assumptions made about future conditions. This 1998 Independent Report provides details of how this new study was conducted, including the important assumptions, data sources, calculations, and considerations that have significant effects on the total cost estimate. The total cost reported here is a conservative estimate that includes a contingency margin for ordinary complications but *does not include* estimates for uncertainties that could add significant additional costs to this first-of-a-kind, century-long, and historically-troubled effort. These uncertainties—which range from the cost of extended at-reactor storage, to accidents in cross-country transportation, to the technologies of emplacement, retrieval or closure—are summarized in Table 2 and described in the body of this report.

The goal of the HLNW program is to permanently dispose of these wastes in a facility that provides geological safety for humans and the environment as long as necessary, a period of 10,000 years or more. Faced with these requirements, no country in the world has developed a HLNW disposal facility. The stringent technical requirements, the lack of any precedent in scientific, engineering, and management experience, and the need to obtain public support make any program very costly. From the very beginning of the current program during the Carter administration, up to the present day, concerns about costs have been expressed in Congress, by the nuclear power industry, and by officials of the Reagan, Bush, and Clinton administrations. In authorizing the program, Congress reserved to itself the right to annually appropriate funds for the program and it imposed requirements on the program administrators to estimate costs and revenues.

## Background to a Total System Life Cycle Cost Estimate

The Nuclear Waste Policy Act (NWPA) requires the U.S. Department of Energy (DOE) to "estimate, on an annual basis, . . . the costs required to construct and operate the repositories to be needed . . . and to carry out any other activities under this Act" (Section 310 (a) (10)) and to "evaluate whether collection of the fee [authorized in the Act] will provide sufficient revenues to offset the costs . . ." (Section 302 (a) (4). The requirements are generally referred to as the analysis of "total system life cycle costs" (TSLCC) and the Fee Adequacy Assessment. During the 15 years that the Nuclear Waste Policy Act has been in effect, DOE has prepared three reports to meet these requirements. The 1986 report estimated TSLCC for a program using a single repository in tuff (at Yucca Mountain) at $30.0 billion; the 1990 estimate was $33.5 billion; and the 1995 estimate was $34.0 billion (in constant 1996 dollars).*

## Focus on Yucca Mountain

In the Nuclear Waste Policy Act of 1982, Congress outlined a program for studying three sites simultaneously as potential locations for the nation's first HLNW repository and then developing a second repository. This would have allowed the government to choose the best of the three sites for the first repository and to achieve geographical equity by eventually developing both a western and an eastern site. Both these goals were abandoned as program requirements when the Nuclear Waste Policy Act Amendments of 1987 directed the DOE to study only the potential repository site at Yucca Mountain, Nevada. The amendments also prohibited location of an interim storage facility in Nevada. This shift in policy responded to widespread public opposition to the original program and saved the costs of site characterization studies at Hanford, Washington and Deaf Smith County, Texas. DOE estimated the savings at $7.4 billion (in constant 1996 dollars).

Progress at Yucca Mountain has been slow and difficult. Meeting U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency licensing and permitting requirements even within time lines that were extended several times appeared impossible. Therefore, DOE suggested, and Congress authorized, a preliminary judgment about the suitability of this site in the form of a "viability assessment," which is due for release by the end of September, 1998. It now appears that this viability assessment will not include a TSLCC estimate. A presentation of the viability assessment cost estimate made to the 94th meeting of the Advisory Committee on Nuclear Waste on September 25, 1997 stated that this estimate will address only the "mined geologic disposal system" and will exclude "historical costs, licensing, waste acceptance, storage, national transportation, and other costs." The preliminary estimate for this portion of the repository work was $14.8 billion. This figure does not represent a comparable base for reference with past DOE estimates of a TSLCC or the 1998 independent assessment described in this report.

Also, it should be noted, the legislation now in Congress would remove the existing prohibition and establish an interim storage facility adjacent to Yucca Mountain on the assumption that prompt removal of wastes from civilian reactors is needed and that Yucca Mountain will eventually serve as a disposal site.

---

* DOE estimates have been adjusted for changes in the inventory requiring permanent disposal, as well as changes in the value of the dollar.

## The Independent Cost Assessment by Major Category

The work done for this estimate of the TSLCC for the nation's high-level nuclear waste program can be summarized in seven categories, as shown in Table 1, below.

**Table 1. Overview of Total System Life Cycle Cost by Major Cost Categories**

| Major Cost Categories | Cost (bil FY'96$) | |
|---|---|---|
| Expenditures Through Fiscal Year 1996 | | 6.1 |
| Estimated Future Costs | | 47.8 |
| 1. Onsite Storage | 4.3 | |
| 2. Cross-Country Transportation | 6.0 | |
| 3. Nevada Transportation | 3.2 | |
| 4. Centralized Interim Storage Facility | 9.2 | |
| 5. Geological Repository | 23.0 | |
| 6. Other Development and Evaluation Costs | 0.4 | |
| 7. Other Program Costs | 1.7 | |
| Total | | $53.9 |

Each of these categories requires a brief summary description.

1. **Onsite Storage**: These are costs incurred at the nuclear power reactors for onsite storage due to an estimated delay in pickup of spent nuclear fuel of 5 years assuming that DOE pickup begins in 2003 instead of the contractual date of 1998.

2. **Cross-Country Transportation**: This includes costs of equipment and services for highway and rail transport of all HLNW from civilian, nuclear weapons, and temporary storage facilities to Yucca Mountain.

3. **Nevada Transportation**: This includes costs to receive and transport HLNW in heavy rail casks within the State of Nevada including the development and operation of an intermodal transfer facility at Caliente, heavy-haul operations to the centralized storage facility at Area 25 near Yucca Mountain, and the construction and operation of a government-owned railroad between Caliente and Yucca Mountain.

4. **Centralized Storage Facility**: This includes the costs of site development, facility construction, and operations. It also includes the cost of metal and concrete storage systems for spent fuel arriving by legal-weight truck and by rail, and for rail shipments using dual-purpose canisters or single-purpose canisters to transport spent fuel.

5. **The Geologic Repository**: This includes the costs of design, licensing, constructing, equipping, operating, and closing the repository.

6. **Other Development and Evaluation Costs**: This includes fees paid to the U.S. Nuclear Regulatory Commission and the costs of the Nuclear Waste Technical Review Board.

7. **Other Program Costs**: This includes payments equal to taxes and benefits as provided for under the Nuclear Waste Policy Act.

All estimates in Table 1, above, include contingency, project management, and program management costs, as well as the direct costs for personnel, equipment, materials, and sub-contractor expenses.

## Summary of Assumptions for the Independent TSLCC Assessment

Where possible, this TSLCC cost assessment is similar to the 1995 DOE TSLCC report. The most notable differences are in the waste management assumptions, which reflect recent court decisions and pending Congressional legislation. This cost assessment study takes into account the similar legislative proposals of Senate Bill 104 and House Bill 1270, both of which have been passed and now await actions by a conference committee in the current Congress, and the recent court decision on DOE's contractual obligations to nuclear power utilities (Northern States Power, et al., versus USDOE. November 14, 1997).

## Uncertainties

Cost estimates for complex projects and programs traditionally include a contingency factor to allow for a range of conditions and performance within the planning parameters. This was done in the case of the 1995 DOE TSLCC estimate and in the 1998 independent TSLCC study reported here. These contingency allowances assume that the waste disposal program proceeds as expected with no major surprises or complications, and are included in the Table 1 figures, above.

In fact, as the history of the selection and site characterization process shows, many things could go wrong and produce additional costs or reduced revenues. More importantly, there are many major components to the waste program that have no precedent, and adverse conditions or events could create large potential costs. Some areas of uncertainty that could add significant costs to the program, but which are not included as in this TSLCC assessment are listed in Table 2, below. The disqualification of Yucca Mountain as a suitable site, which could occur because of adverse site conditions, or for regulatory, political, or technological reasons, would be the most dramatic, unaccounted for outcome.

## Costs and Revenues

The estimates of revenues from civilian nuclear power plants are based upon projected electric generation of existing stations, which are expected to operate in gradually reduced numbers until the year 2033, when all currently operating reactors will have completed their license terms. There is some uncertainty about operating projections since several plants already have shut down early. Early shutdowns reduce revenues on a one-to-one basis for each kilowatt of power not produced, but the reduced amount of spent fuel reduces costs only at the margin of a program that must be developed in any case. The effects of early shutdowns in reducing nuclear waste fund revenues are likely to be substantially greater than their effects in reducing program costs.

Through fiscal year 1996, the program spent $6.1 billion, 11.4 percent of the total estimated program costs. This means that expenditures to date—the "sunk costs"—are just over one-tenth of the total estimated program costs.

**Table 2. Uncertainties in the Federal Government's HLNW Program**

| Uncertainty | Commentary |
|---|---|
| 1. Inventory of HLNW | Nuclear power stations may produce less spent fuel due to early shutdowns, thus producing less revenue. Weapons complex wastes may be greater than currently estimated. |
| 2. Pickup of Spent Fuel | Pickup start dates or schedules may be delayed adding costs to the program. Courts could allocate costs to the disadvantage of the Nuclear Waste Fund. Defense waste disposal could be delayed to accommodate commercial spent fuel. |
| 3. Onsite storage | Onsite storage of spent fuel could result in a different mix of dry-cask and pool storage with costs in operations, repackaging, and ability to operate reactors. |
| 4. Canisters and Casks | Problems with the construction, performance, and maintenance of canisters and casks could introduce additional direct costs and significant indirect costs through program delays. |
| 5. Cross-Country Transportation | Transportation capacity, performance, and public or community responses could adversely affect the cross-country transportation costs. Accidents (or sabotage incidents) involving waste shipments could add direct costs for response and cleanup, and cause delays in the shipment schedule. |
| 6. Regulatory and Oversight | Licensing and permitting may delay the program. The site characterization program itself may encounter technical, budgetary, management, or personnel performance delays. |
| 7. Construction | Delays for numerous reasons are possible at the intermodal transfer facility, and in heavy-haul and rail construction, or due to unexpected conditions at the repository, adjustment of the design to meet revised HLNW demand, management and contractor performance, and Congressional funding, |
| 8. Operations | Discovery of adverse conditions not predicted during site characterization, natural events such as earthquakes, complications with the performance of advanced technologies (e.g., robotics), personnel, contractor organizations, or program managers could introduce additional costs. |
| 9. Retrieval | A retrieval option for wastes already emplaced is required. If conditions at the site or with the wastes required retrieval the costs could be very significant. |
| 10. Closure | Estimate of the TSLCC is based upon closure of the repository and termination of the costs. If the planned techniques for closure do not prove to be adequate, ongoing costs could extend indefinitely. |

The costs of managing and disposing of the nation's high-level radioactive wastes have been a central concern since the late 1970s when the original terms of the Congressional program were first negotiated. The primary purpose of resulting legislation, The Nuclear Waste Policy Act of 1982, was to dispose of spent fuel from nuclear power plants and establish the Nuclear Waste Fund as the means to pay for the federal program (Section 111 (b)(4); Section 302 (a)(3)). The principle was to have the beneficiaries of nuclear power pay the costs of spent fuel disposal. The Secretary of Energy is required to annually evaluate and see whether the existing fee "will provide sufficient revenues to offset the costs" of the program (Section 302 (a)(4). If the fee is not adequate, the Secretary is directed to propose an adjusted fee and immediately inform Congress.

Costs for federal government use of the high-level nuclear waste repository to dispose of wastes from the nation's nuclear weapons complex, for example, are funded by taxpayers through Congressional appropriations. The expected use of the nation's proposed repository at Yucca mountain is about 80 percent for civilian spent nuclear fuel and about 20 percent for the nation's nuclear weapons wastes.

Congress, on its part, has the authority to modify the program, as it did in selecting Yucca Mountain, Nevada as the only site to be studied as a potential repository. This action prohibited further study of other sites (NWPA Amendments Act of 1987) and thereby cut costs for the program. Reductions in annual Congressional appropriations for the program, which are typically less than the administration's budget requests, can delay progress and impose increased costs in the long run.

The most recent estimate by the U.S. Department of Energy is that the Nuclear Waste Fund (current balance and future revenues) will produce $28.1 billion in constant 1996 dollars, about half (52 percent) of the $53.9 billion dollar projected cost for implementing the nation's HLNW program, leaving the general taxpayer with a liability of $25.8 billion.

### Implications

The cost-revenue condition of the nation's HLNW program and the potential for costly uncertainties are causes for concern. The key implications are that the probable costs of managing the nation's HLNW and the liability for the general taxpayer are substantially greater than have been estimated. The Nuclear Waste Fund under its current fee structure will not meet its share (approximately 80 percent) of the costs of permanent disposal of the nation's high-level nuclear wastes.

# 2. THE RESULTS, UNCERTAINTIES AND IMPLICATIONS OF THE INDEPENDENT COST ASSESSMENT

## Introduction

Escalating costs in the U.S. Department of Energy's (DOE) High-Level Radioactive Waste Management Program have been a matter of concern since the early days of the program. Initial estimates of the costs for characterizing three potential repository sites under the original Nuclear Waste Policy Act of 1982 were in the neighborhood of $80 million per site. The currently estimated cost of characterizing just one site - Nevada's Yucca Mountain - exceeds $5 billion.

Recognizing the importance of cost as a factor in determining the feasibility of continuing with the program, DOE initially included an assessment of program costs as one of the four components to its Yucca Mountain "Viability Assessment" (VA) that is being prepared for submission to the President and Congress in September, 1998. The VA was initially conceived by DOE in 1996 as part of a revised Program Plan for the Yucca Mountain project. The VA is intended to provide a basis for an assessment, by Congress and the Administration, of the overall feasibility of moving ahead with the federal high-level waste program. As proposed by DOE, the VA will have four components: (1) a preliminary Total System Performance Assessment (TSPA), (2) a conceptual design for the proposed repository and support facilities, (3) a plan for obtaining a license to construct and operate the repository from the Nuclear Regulatory Commission, (4) and an assessment of program costs. In 1997, DOE revised its concept of the VA to include only an assessment of the current and future costs associated with constructing and operating a repository - not the total costs for the program. DOE subsequently announced plans to issue a Total System Life Cycle Cost report in mid-September, 1998, but this will not be part of the VA.

Together with the ability of the site to isolate highly radioactive wastes from the environment for tens of thousands of years, the overall cost of the effort is a major determinant of the program's scope, direction, and impacts to states and communities. It is also a crucial ingredient for determining whether the program can, in fact, be implemented. The State of Nevada embarked on an independent system-wide cost assessment when it became known that the cost estimates in the VA would not be reflective of the total costs involved with implementing the federal high-level waste program. This independent cost assessment effort has two interrelated objectives: (1) to serve as the basis for critically and substantively evaluating DOE's conclusions about project costs as they are presented in the VA and in any associated TSLCC assessment and (2) to provide an objective and complete picture of the costs of the federal high-level waste program and the implications for impact assessment and for national high-level nuclear waste policy. Given the history of cost overruns and schedule delays not only for the Yucca Mountain program but also for a variety of other DOE programs nationwide,* a credible assessment of total system life cycle costs for the high-level waste program is indispensable for determining whether or not the federal program is, in fact, viable.

* See USGAO: "Department of Energy: Opportunity to Improve Management of Major System Acquisitions" (GAO/RCED-97-17), November 1996.

Since 1987, contractors for the State of Nevada's Yucca Mountain socioeconomic impact assessment studies have been collecting data on program costs as major factors that will drive project impacts in Nevada. At the same time, Nevada technical contractors have been closely monitoring DOE's site characterization activities and the design processes for the repository and related facilities. These efforts have generated significant amounts of information directly relevant to the issue of total system costs. In order to effectively and adequately evaluate the cost projection component of the DOE's VA, independent contractors have been engaged to compile available information on current and projected inventory requiring disposal, the costs of continued on-site (at reactor) storage, the costs of cross-country transportation, the costs of heavy haul and rail transportation in Nevada, the costs of centralized storage, and the costs of repository evaluation, licensing, construction, operations, and closure. Independent contractors also estimated contingency, and project and program management costs.

All of this information was then rolled up into a total system life cycle cost for the DOE program, as that program is defined by DOE's revised Program Plan, the requirements of currently-proposed legislation (e.g. S.104/H.R. 1270), the rulings of the U.S. Circuit Court of Appeals for the District of Columbia in litigation brought by utility companies (Northern States Power Company et al. v DOE), and recent DOE policy shifts. A prominent national accounting firm, KMPG Peat Marwick, was engaged to ensure that the independent cost analysis used reasonable and accurate assumptions, costing procedures, and cost factors.

This independent assessment draws on source data assembled by DOE and NRC, previous TSLCC and fee adequacy assessments by DOE, U.S. General Accounting Office (GAO) reports dealing with costs of DOE's high-level radioactive waste program (especially the 1990 report that reviewed DOE's findings with regard to Waste Fund adequacy),* and related assessments by special interest groups to support particular positions**.

## 2.1 TOTAL SYSTEM COST RESULTS

This section reviews the results of the independent cost analysis. Unless otherwise noted, cost estimates include contingency and project and program management as well as direct costs. Following sections address the uncertainties that suffuse the high-level nuclear waste program and their potential cost effects, and the key implications that flow from the findings of the assessment. Chapter 3 of this report discusses the basis for the cost analysis in greater detail—the assumptions regarding the inventory requiring permanent disposal, the strategy for waste management and the schedule for its implementation, the cost categories themselves and the cost analysis procedures.

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* "Nuclear Waste: Changes Needed in DOE User-Fee Assessments to Avoid Funding Shortfall," U.S. GAO, June 1990 (GAO/RCED-90-65).

** For example, the Nuclear Energy Institute's 1997 assessment of the costs of extended at-reactor dry storage and the 1997 Public Citizen analysis of on-site storage costs.

## Total and Projected System Costs

The independent cost assessment for the DOE/OCRWM program estimates total system costs at \$53.9 billion (FY'96\$), about 54.1 percent greater than DOE's estimate in September 1995 (see Figure 1). Projected expenditures after FY 1996 are estimated at \$47.8 billion, about 66.8 percent greater than the DOE 9/95 estimate for this period. Of the total system cost, about 88.6 percent is projected expenditure and only 11.4 percent is "sunk costs" through FY 1996 (see Figure 2).

As mentioned, future expenditures are estimated at \$47.8 billion, of which 9.0 percent is the cost of onsite storage due to delay in DOE pickup, about 12. 5 percent is cross-country transportation, about 6.8 percent is Nevada transportation, about 19.2 percent is centralized storage, about 48.0 percent is the cost of the repository, and about 4.5 percent is other program components (see Figures 3 and 4). About \$38.5 billion (80.7 percent) is costs attributable to the disposal of commercial spent nuclear fuel, for which the Nuclear Waste Policy Act anticipates full recovery from the Nuclear Waste Fund.

**Figure 1. Total Cost is Estimated at \$53.9 Billion (FY'96\$)**

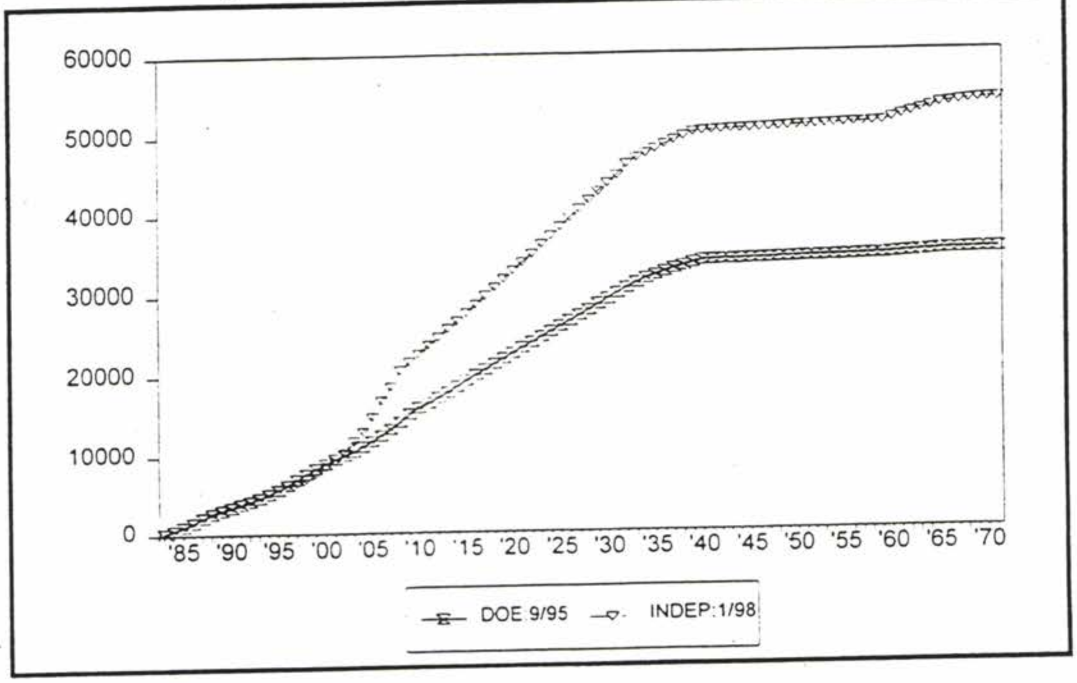


**Figure 2. About 11 Percent of the Total Has Been Spent**

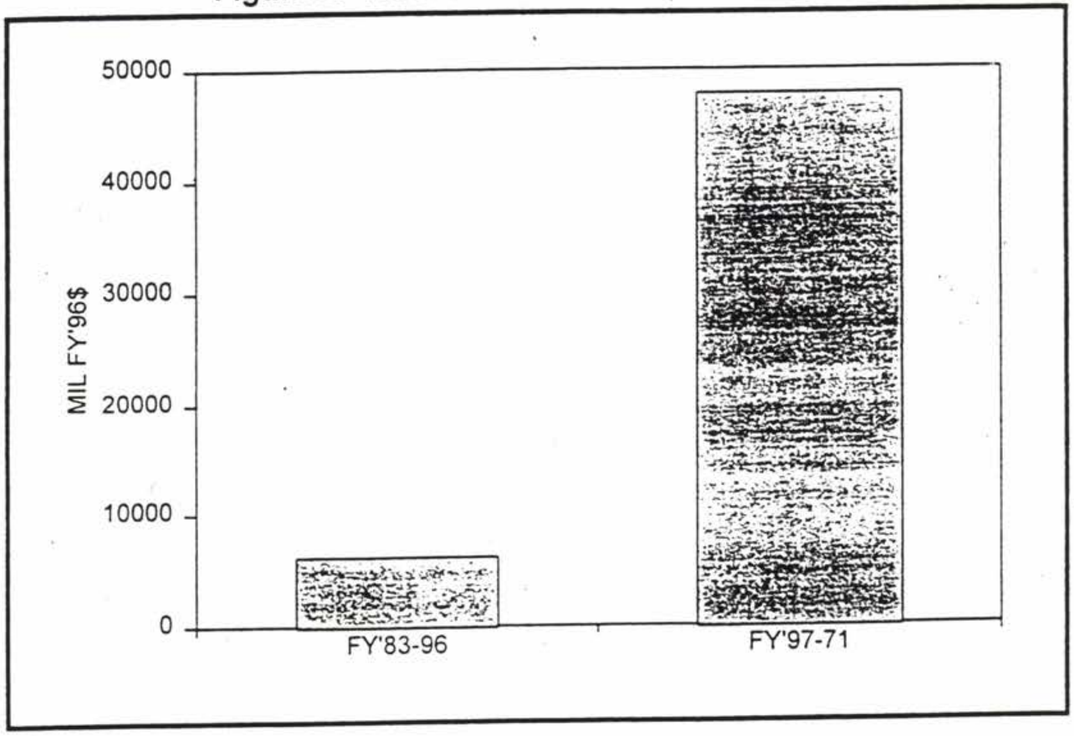
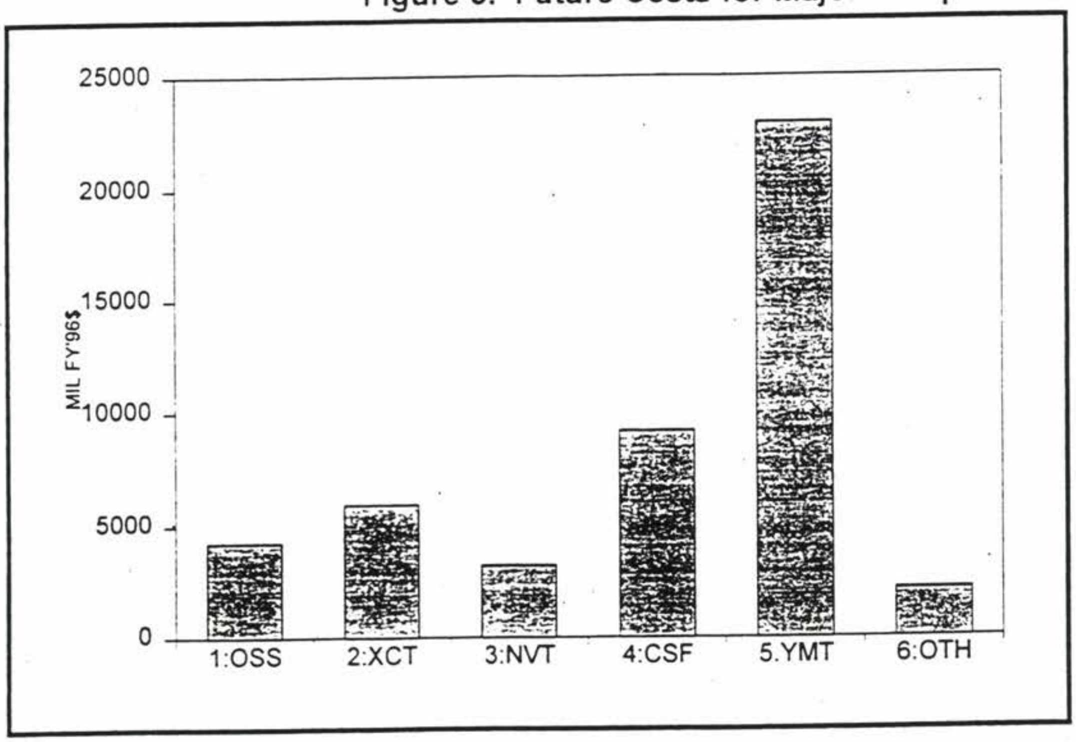



**Figure 3. Future Costs for Major Components**



## Figure 4. Sunk and Future Program Costs (FY'97 - FY'71; MIL '96$)

| | | Total | %FY'83+ | %FY'97+ | %categ |
|---|---|---|---|---|---|
| GRAND TOTAL: FY 1983FY 2071 | | 53905.4 | 100.0% | NA | NA |
| EXPENDITURE THROUGH FY 1996 | | 6128.0 | 11.4% | NA | NA |
| FUTURE COSTS: FY 1997 FY 2071 | | 47777.4 | 88.6% | 100.0% | NA |
| 1.0 | ONSITE STORAGE COSTS | 4278.9 | 7.9% | 9.0% | 100.0% |
| 1.1 | Commercial SNF in Que | 3886.1 | 7.2% | 8.1% | 90.8% |
| 1.2 | DOE SNF & SNF not in Que | 392.8 | 0.7% | 0.8% | 9.2% |
| 1.3 | DOE High-Level Waste | NA | 0.0% | 0.0% | 0.0% |
| 2.0 | X-COUNTRY TRANSPORTATION | 5968.2 | 11.1% | 12.5% | 100.0% |
| 2.1 | Commercial SNF in Que | 4269.3 | 7.9% | 8.9% | 71.5% |
| 2.2 | DOE & Other SNF not in Que | 590.1 | 1.1% | 1.2% | 9.9% |
| 2.3 | DOE High-Level Wastes | 505.1 | 0.9% | 1.1% | 8.5% |
| 2.4 | Technical Assist Trng: 180(c) | 603.7 | 1.1% | 1.3% | 10.1% |
| 3.0 | NEVADA TRANSPORTATION | 3244.7 | 6.0% | 6.8% | 100.0% |
| 3.1 | Intermodal Transfer Facility | 92.3 | 0.2% | 0.2% | 2.8% |
| 3.2 | Heavy-Haul to CSF | 437.2 | 0.8% | 0.9% | 13.5% |
| 3.3 | Rail Spur to CSF/YMP | 2715.1 | 5.0% | 5.7% | 83.7% |
| 4.0 | CENTRALIZED STORAGE FACILITY | 9179.3 | 17.0% | 19.2% | 100.0% |
| 4.1 | Misc Upfront Costs | 65.2 | 0.1% | 0.1% | 0.7% |
| 4.2 | Construction | 429.7 | 0.8% | 0.9% | 4.7% |
| 4.3 | Major Equipment | 8469.2 | 15.7% | 17.7% | 92.3% |
| 4.4 | Operations | 215.2 | 0.4% | 0.5% | 2.3% |
| 5.0 | REPOSITORY | 22955.1 | 42.6% | 48.0% | 100.0% |
| 5.1 | Site Characterization | 2553.8 | 4.7% | 5.3% | 11.1% |
| 5.2 | Design & License Application | 1079.2 | 2.0% | 2.3% | 4.7% |
| 5.3 | Surface Facilities | 6142.5 | 11.4% | 12.9% | 26.8% |
| 5.4 | Underground Facilities | 7158.2 | 13.3% | 15.0% | 31.2% |
| 5.5 | Waste Containers | 6021.4 | 11.2% | 12.6% | 26.2% |
| 6.0 | OTHER DEVEL & EVAL COSTS | 433.6 | 0.8% | 0.9% | 100.0% |
| 6.1 | NRC Fees | 400.0 | 0.7% | 0.8% | 92.3% |
| 6.2 | NWTRB | 33.6 | 0.1% | 0.1% | 7.7% |
| 6.3 | Nuclear Waste Negotiator | 0.0 | 0.0% | 0.0% | 0.0% |
| 7.0 | OTHER PROGRAM COSTS | 1717.8 | 3.2% | 3.6% | 100.0% |
| 7.1 | PETT Payments | 1233.0 | 2.3% | 2.6% | 71.8% |
| 7.2 | Benefits | 484.8 | 0.9% | 1.0% | 28.2% |

**Extended Onsite Storage**

As implied in the November 14, 1997 decision of the District of Columbia Circuit Court in Northern States Power et al versus USDOE, this assessment assumes that the federal government and the Nuclear Waste Fund (not individual utility ratebases) have an obligation to pay for the costs of onsite storage of SNF which would have been removed from commercial reactor sites had DOE pickup begun in 1998 (as anticipated in the NWPA) and proceeded at rates specified in proposed legislation. These include costs for onsite dry storage, for operation of spent fuel pools as interim storage facilities after reactor shutdown, and for limited upgrades at spent fuel pools needed to load casks for cross-country transportation.

This assessment assumes that DOE pickup of commercial SNF will be delayed from 1998 to 2003, during which time centralized storage, intermodal transfer and other needed facilities might be designed, licensed and constructed. The projected cost (FY'97+) to the nuclear waste program for onsite storage associated with a five-year delay is $4.3 billion, of which $3.9 billion is for onsite storage of SNF at commercial reactor sites, and $0.4 billion is for onsite storage of SNF located elsewhere. Of the $3.9 billion, about $0.6 billion (14.8 percent) is for dry storage, and about $3.3 billion (84.2 percent) is for the operation of pools as interim storage facilities after reactor shutdown. Since this assessment bases transportation choices on the current loading capabilities of spent fuel pools, the estimated cost for upgrading pool dimensions or lifting apparatus is only $37 million (1.0 percent).

**Cross-Country Transportation**

For legal-weight truck shipments, cross-country transportation includes the cost of shipment from origin sites to Yucca Mountain or Nevada Test Site (NTS) Area 25. These include the shipment costs, the shipment escort and inspection costs, the cost of the high-capacity cask and special truck trailer, and the operations, maintenance, replacement and decommissioning costs of this equipment.

For rail shipment, cross-country transportation is the cost of shipment in dedicated trains to Caliente (NV), where such shipments would be transferred to heavy-haul trucks or continue along a 365-mile government-owned and operated rail spur. Equipment purchases include cask and buffer cars; shipment costs are based on the loaded cask and the ballast in the buffer cars. Some rail shipment sites which lack or no longer have a rail spur require heavy-haul to a nearby railhead.

The total cost of cross-country transportation is estimated at $6.0 billion, of which $4.3 billion is for transport of SNF from commercial reactor sites, $0.6 billion is for SNF transport from other sites, $0.5 billion is for HLW transport from four sites in the DOE complex, and $0.6 billion is for emergency management training for affected states, counties and Tribes. Of the $4.3 billion, about $3.1 billion (71.9 percent) is for rail and truck carrier costs for 24,400 cask shipments over 56 million miles, about $1.0 billion (22.7 percent) is for purchasing, maintaining and decommissioning transportation casks and equipment, and $0.2 billion (5.4 percent) is for shipment escort and inspection.

**Nevada Transportation**

In this assessment, Nevada transportation is included to enable transportation (cross-country and in Nevada) by rail as well as by legal-weight truck. Intermodal transfer and heavy-haul are included (consistent with directives in proposed legislation) to enable *early* cross-country shipment by rail as well as by legal-weight truck. Nevada transportation costs are estimated at $3.2 billion, of which $0.5 billion (16.3 percent) is for the intermodal transfer facility at and heavy-haul from Caliente, while $2.7 billion (83.7 percent) is for the construction and operation of a 365-mile government-owned and operated rail spur from Caliente to Yucca Mountain.

Consistent with DOE's 1991 conceptual plan, the direct construction cost for the Caliente-Yucca Mountain rail route is estimated at $1.2 billion (FY'96$). Contingency and project and program management costs increase this figure to $1.9 billion. Upfront design and right-of-way costs, the construction of ancillary facilities, the purchase and maintenance/replacement of major equipment, and operations costs account for the remainder of the $2.7 billion estimate for the rail spur.

### The Central Storage Facility at NTS Area 25

Under the assumptions of this assessment, the centralized storage facility receives and stores SNF until it is emplaced in the nearby geologic repository at Yucca Mountain. About two-thirds of the SNF arrives at the centralized storage facility in dual-purpose rail canisters. Under normal circumstances, these canisters need not be opened at the central storage facility; they are removed from transportation casks and placed in concrete bunkers or vaults for onsite storage. This assessment assumes that, at 16 rail shipment sites, utilities choose to purchase dual-purpose canisters as an onsite storage cost in order to limit the operation of spent fuel pools as interim storage facilities after reactor shutdown. At 31 other rail shipment sites, utilities choose to use storage-only canisters for dry storage; the cost of dual-purpose canisters for transportation and central storage of SNF from these sites is included as a central storage cost.

About one-third of the SNF arrives at the centralized storage facility uncanistered in high-capacity casks for legal-weight truck transport. Under the assumptions of this assessment, this SNF is removed from the transportation cask and held in a reinforced concrete fuel transfer facility until a sufficient number of PWR or BWR assemblies have accumulated to fill a metal cask for onsite storage.

The total cost for centralized storage is estimated at $9.2 billion, of which $2.4 billion (26.3 percent) is the direct cost of purchasing, replacing and decommissioning metal casks for storage of SNF arriving by legal-weight truck, about $2.7 billion is the direct cost for dual-purpose canisters for rail shipment of SNF which has been stored onsite in pools or storage-only canisters, and about $0.4 billion (4.4. percent) is the direct cost of concrete storage for all SNF arriving by rail or heavy-haul. Other direct costs include upfront and construction costs (about $0.3 billion, 3.4 percent) and operations (about $0.14 billion, 1.5 percent). Contingency and project/program management costs account for the remaining non-direct portion of centralized storage costs.

### The Repository

Under the assumptions of this assessment, the geologic repository would dispose of the nation's entire current and projected inventory in 11,000 waste containers for SNF and 19,234 canisters* for HLW, emplaced in 94 miles of drifts bored in parallel rows at a single emplacement level through the fractured

* Purchased by the DOE Office of Environmental Restoration and Waste Management as containers for onsite storage (and transportation, emplacement) of HLW; costs not included in estimates for the DOE/OCRWM program.

tuff beneath Yucca Mountain. Major challenges include the design of the emplacement drifts and the movement and emplacement of waste packages within and among them, the monitoring and possible retrieval of flawed or damaged packages, and the backfill and decommissioning of the facility* late in the 21st century.

The projected cost of the Yucca Mountain repository is estimated at $23.0 billion, of which the completion of site characterization is $2.6 billion (11.1 percent). Licensing and design (upfront and ongoing during construction and operations) is $1.1. billion (4.7 percent). The cost of surface facilities at the repository (their construction, equipping and operation throughout emplacement, care-taking and decommissioning) is estimated at $6.1 billion (26.8 percent of projected repository costs). Underground facilities are estimated to cost $7.2 billion (31.2 percent). The direct cost of waste emplacement containers for SNF is estimated at $6.0 billion (26.2 percent), of which $3.9 billion is the direct purchase cost at an estimated $350,000 per container.

## 2.2 UNCERTAINTIES IN THE DOE/OCRWM PROGRAM

The projected costs described above include estimated contingency costs to address the potential for ordinary complications in scheduling, regulatory compliance, design, construction, procurement or hiring. However, any large, long-term, first and only-of-its-kind project is subject to uncertainty over and above standard contingency factors. This section reviews some of the uncertainties in the DOE/OCRWM program, and suggests how they could affect program costs and/or the implementation of the waste management strategy implicit in current directions and proposed legislation.

### The Inventory Requiring Permanent Disposal

A Reagan administration decision in 1985 required collocated geologic disposal for high-level defense wastes as well as SNF from commercial and DOE reactors. However, the disposition of GTCC** and other wastes (e.g., decommissioned nuclear weapons) remains uncertain. Also, the estimates of high-level wastes are not finalized and are increasing; DOE's estimates in December 1996 are 45 percent greater in volume and 39 percent greater in canisters than its estimates 15 months earlier in September 1995. Additional waste streams could increase costs for cross-country and Nevada transportation, complicate the design and emplacement strategy for the repository, and increase repository construction and operations costs.

### The NWF Obligation Due to Delay in DOE Pickup of SNF

In its November 14, 1997 decision in Northern States Power et al versus USDOE, the US Court of Appeals for the District of Columbia Circuit concluded that the federal government has an obligation

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* Some studies suggest that the repository might be "ventilated" that is—not closed or decommissioned, but continued in caretaker operation into the 22nd century and beyond.

** Greater-than-class-c low-level wastes, much of which is expected to be generated in the decommissioning of nuclear reactors.

under its standard contract* with utilities to remediate costs attributable to delays in pickup and/or reductions in pickup rates. However, it declined to specify a remedy until delays actually begin, and it did not determine whether the costs of delay should be drawn from the Nuclear Waste Fund or from the general fund.

In the absence of a court-approved formula, this assessment allocated the costs of delay based on an estimate of the projected inventory at each site (assuming pickup beginning in 2003 and proceeding at rates specified in proposed legisilation) compared to the inventory had pickup begun in 1998. The uncertainties are a) the Court could specify a remedy more advantageous to utilities and less advantageous to DOE and the NWF or general taxpayer, and b) DOE could fail to begin pickup in 2003 and/or fail to proceed at S-104 rates. These contingencies could increase onsite storage costs and/or the portion of onsite storage costs allocated to the NWF or general taxpayer. If not anticipated and very effectively managed, delays in pickup (start date or rates) could result in unused capacity in cross-country and Nevada transportation, and in additional costs of systems developed but not fully used. Delays in the SNF pickup start date and rate could result in delay in pickup of high-level defense wastes, which the DOE Office of Environmental Restoration and Waste Management must vitrify and store while awaiting shipment to a geologic repository for permanent disposal.

### Dry Storage for Discharges in Excess of Pool Capacity

The assessment assumes that dry storage can be developed at any site at which it may be required. However, at some sites physical limitations or community concerns could complicate the licensing and development of dry storage facilities. The consequence could be a more costly solution to dry storage and/or a utility decision to shutdown before license term, thus depriving the NWF of currently anticipated revenues.

### Defective Canisters and/or Transportation Casks

This assessment assumes no defective storage canisters or transportation casks. If canisters are found to be defective, they would need to be repaired or replaced—increasing costs for onsite storage, transportation or centralized storage, depending on the point at which the defect is discovered. Defective transportation casks may or may not require repair or replacement, since transportation choices and schedules could result in an excess cask inventory in some shipment years. The major cost consequences, however, depend on the management of defects by utilities and/or DOE as they occur. Ineffective management could have major cost consequences.

### Canister and Cask Standardization

Our estimates assume all SNF will be shipped in a standard LWT cask and one of two rail casks, each matched with a standard canister for storage and/or transportation. If the container delivery "system" (DOE, NRC, vendors, fabricators) fails to deliver an adequate quantity of standard casks and canisters, as required by shipment schedules, system efficiency would go down and costs would go up. Under a privatized transportation system, such as DOE is now proposing, market-driven decisions could result in

* Paragraph B of NWPA Section 302(a)(5) says that "in return for payment of fees," DOE will dispose of commercial spent nuclear fuel, beginning not later than January 31, 1998.

use of a variety of unstandardized casks, perhaps with reduced cask purchase costs, but with increased costs for handling, repackaging and storage at the centralized facility.

### Shipment Costs for Cross-Country Transportation

Transportation carrier costs for 30,400 cask shipments and 65 million cask shipment miles on the nation's Class A railroads and interstate highways are not yet negotiated. Rail carriers and USDOE disagree on the need for and cost of shipping SNF in dedicated trains. Given speed, route and operating restrictions for shipments of SNF and HLW—and the implications of these restrictions for other rail or highway freight traffic—shipment costs per ton-mile or per ton-originated may be higher than assumed in this assessment.

### Concerns in Transportation Corridor Communities

The willingness of corridor communities to accept a shipment campaign of this type and magnitude—the ability of our political system to produce and maintain acceptance when such a large portion of affected communities see themselves as corridors for dangerous materials originating elsewhere and benefitting others—has not been demonstrated. Resistance could come from state-local-tribal governments along corridors or from grassroots activism. Some believe that concerns with early shipments will rapidly diminish after the initial shipments along various routes; others anticipate the concerns could build as the campaign proceeds.

It is conceivable that concerns among corridor communities, as expressed through participatory state and local politics, could shutdown or greatly complicate parts of the nationwide campaign for cross-country shipment of high-level wastes. DOE could build a central storage facility and/or repository, and be able to ship only parts of the projected inventory to these Nevada facilities.

### Accidents in Cross-Country Transportation

Our assessment assumes no accidents in a cross-country shipment campaign involving 16,920 legal-weight truck shipments and 37.6 million cask shipment miles on often-congested public highways, plus 4,500 dedicated train shipments over 9.1 million miles of heavily-used rail corridors. Accidents in cross-country transportation are likely. Such accidents could require substantial emergency response, as well as evacuation, road closure or other measures resulting in losses for corridor businesses. The associated costs are not included in this assessment. Nor are the costs of potential radiation releases, should such occur, which would be paid under guidelines established by the Price-Anderson Act of 1957, as amended in 1988. The major costs of accidents in cross-country transportation, however, are likely to be subsequent to the accident itself, in the management and operation of the shipment campaign.

### NRC Review for Shipment Staging or Switching Locations

Our assessment assumes that NRC review and/or licensing is not required for staging or switching locations required in the cross-country shipment campaign—e.g., major rail yards in Chicago, St. Louis, Kansas City. Should such be required (e.g., if an accident or a security breakdown occurred in a rail switching yard), significant additional cross-country transportation costs could result.

### NRC Licensing for the Intermodal Transfer Facility

Our assessment assumes, based on Senate Bill 104, that NRC licensing is not required for the intermodal transfer facility at Caliente (NV). Should safety or security considerations (or litigation, or political action by affected parties) require NRC licensing, the result would be a delay in the pickup start date, with consequent implications for onsite storage costs at commercial reactor sites. Licensing could also require additional construction and operations costs at the intermodal transfer facility itself.

### Delays in Heavy-Haul Operations

Heavy-haul operations could be delayed due to complications in negotiating or funding the necessary improvements in the public highways along the 365-mile route, and/or due to concerns in local communities along such routes. The result could be increased costs for heavy-haul construction and operations, and (more significantly) increased upstream costs for onsite storage and cross-country transportation.

### Delays in Rail Spur Construction and Operation

Delays in procuring the required right-of-way and/or environmental permits along the 365-mile rail spur route could increase construction costs. Indirect effects could include an extension of heavy-haul operations (and the associated intermodal transfer and heavy-haul costs) and/or increased upstream costs for extended onsite storage or cross-country transportation.

### Seismic Activity at NTS and the Central Storage Facility

Seismic activity is expected to be a major concern in the licensing of a centralized storage facility for up to 24,000 MTU of SNF at NTS Area 25. These or other concerns could lead to increased costs to meet NRC licensing requirements regarding the spent fuel transfer building, storage procedures and equipment, or decontamination facilities. If such requirements delay the operations of the centralized storage facility or reduce its throughput capacity, there could be significant additional upstream costs in onsite storage and/or excess transportation capacity developed but not fully used.

### Delays in Site Characterization at Yucca Mountain

Several contingencies not addressed in this assessment could delay the completion of Yucca Mountain site characterization: e.g., a seismic event which damages surface or underground facilities and equipment at the exploratory studies facility; an unexpected geologic condition (e.g., a large body of perched water, a highly fractured unstable zone) encountered by the east-west tunnel currently under construction; discovery or confirmation of a health hazard for workers underground;* a major equipment failure which damages the heater test or causes an electrical fire or rock fall within the ESF. Any such contingency would increase site characterization costs and could indirectly increase costs in other components of the waste management program.

* For example, cristobalite dust detected in 1996 in the original five-mile ESF was found to exceed OSHA limits and required respirators to worn by all personnel, thus reducing productivity.

### Repository Construction and Operation

The construction and 60-year operation of a permanent repository in the heavily fractured tuff of Yucca Mountain involves many contingencies not addressed in this assessment: e.g., defects in the repository block (faulting, fracturing, perched water) which were undetected during characterization and which reduce capacity or require reconfiguration; variations in rock quality in the repository block which complicate thermal loading and affect capacity, ventilation or emplacement layout; escalating surface facility construction costs due to seismic events or NRC license requirements; complications in the operation of robotic equipment within emplacement drifts; the cost of waste containers fabricated from exotic materials to meet stringent performance standards.

### Retrieval of Emplaced High-Level Waste

Performance standards require that SNF be retrievable for 50 years after initial emplacement. The feasibility of retrieval at any cost is uncertain at best. The costs, should retrieval be required, are not included in this assessment—very rough estimates are in the billions or tens of billions of dollars, depending on the complexity and extent of retrieval required. Also not included are the costs of dealing with the waste retrieved, should the retrieval be occasioned by hazards detected in the emplaced wastes.

### Permanent Closure of the Geologic Repository

In closing the repository, the federal government warrants that the materials it contains will be safely isolated from the human environment, without further government involvement, in perpetuity. Yet the backfilling techniques proposed for closure are unproven as to feasibility or effectiveness. Some argue that the repository should remain unclosed or ventilated, implying that the government responsibility (and costs) could extend indefinitely.

## 2.3 IMPLICATIONS OF THE COST ESTIMATES

The implications of the total system cost estimates, and of the uncertainties not reflected in the cost estimates, are wide ranging. The key implications are that the probable cost of managing the nation's SNF and HLW is substantially greater than has been estimated by DOE, that the general taxpayer stands to bear about half of the projected cost.

While there are and will continue to be substantial uncertainties inherent in projecting the costs and revenues of a complex program over many years, two things are apparent—the Nuclear Waste Fund as currently constituted is woefully inadequate to meet the long-term costs of implementing current DOE plans and proposed legislation, and this shortfall is likely to increase rather than decrease over time.

This section of the report briefly elaborates on these and related implications of the independent assessment of total system costs.

### Waste Management is More Costly than Estimated by DOE

The projected cost of managing SNF and HLW in accordance with the NWPA (as revised by the Amendments of 1987 and legislation proposed in Senate Bill 104 and House Bill 1270) and recent US

Appeals Court decisions is \$53.9 billion—a figure about 18.9 billion (54.1 percent) greater than estimated by DOE in September 1995. The projected cost of managing SNF and HLW in fiscal years 1997-2071 is \$47.8 billion—a figure \$19.1 billion (66.8 percent) greater than DOE's estimates for the same period.

#### Program Uncertainties Could Further Increase Costs

The above estimates do not include the cost implications of uncertainties in a program that involves many scientific and technical challenges, difficult equity and perceptual issues, and consequent demands on our regulatory and political systems. Should any or some combination of these uncertainties materialize, they could significantly increase the above estimates of costs required to see the nation's high-level nuclear waste program through to a satisfactory conclusion. Even more difficult, perhaps, they could require a rethinking of the nation's waste management program at a point when even more funds have been expended and wastes are partly emplaced, partly in central storage, and partly at commercial reactor and other DOE sites.

#### NWF Revenues will Likely Further Contract

This assessment assumes that all commercial nuclear plants operating in 1997 will continue to operate (and generate revenues to the Nuclear Waste Fund) through their license term. DOE's fee adequacy assessment makes a similar assumption.* In recent months, however, several utilities have announced that they intend to or are considering early shutdown of several plants—e.g., Big Rock, Oyster Creek, Maine Yankee, Zion 1 and 2.

Early shutdowns would reduce the expense of waste management under the NWPA, by reducing the amount of spent fuel which must be stored on an interim basis, transported or emplaced. However, the reductions in NWF revenues as a consequence of early shutdowns will likely be much greater than the corresponding reductions in expenses. Early shutdowns reduce revenues on a one-to-one basis for each kilowatt of expected nuclear power not generated by a commercial reactor. Early shutdowns reduce waste management costs at the margins of an overall program which must be fully developed in any case. The effects of early shutdowns in reducing Nuclear Waste Fund revenues are likely to be substantially greater than their effects in reducing program costs. The assumptions of this assessment (all reactors operating in mid-1997 continue to operate through license term) represent the "best case" scenario of revenues and expenses for the NWF.

#### Fund Management Could Diminish Investment Revenues

Nuclear utilities, frustrated by prospective delays in DOE pickup of spent nuclear fuel and by the inclusion of the Nuclear Waste Fund in the general federal budget, have proposed that annual fee collections be limited to the amounts actually appropriated by Congress for implementation of the

* "The 1.0 mil per KWh fee revenue used in this analysis was derived from the no-new-orders end of reactor life projection of net electricity generation prepared in 1994 by the EIA. It is assumed in this projection that commercial units will operate for 40 years from the issuance of their operating licenses without extension, reactor performance will not be affected by aging, and the equilibrium-cycle capacity factor will increase slightly from 74 percent in 1995 through 2014 to between 75 and 76 percent until 2034." DOE/RW-0490, pg. 5.

DOE/OCRWM program. This would place the program on a current cost basis, and reduce the projected balance in the Nuclear Waste Fund, the investment of which was intended by the Nuclear Waste Policy Act to support the implementation of the program over the decades after nuclear reactors shut down.

### The General Taxpayer Stands to Pay $26 Billion

DOE's most recent assessment of the one-mil per kilowatt hour fee on sales of nuclear generated power, established by the NWPA to meet the costs of permanent disposal of commercial SNF, estimates that the fee provides a revenue base of $28.1 billion (FY'96$) from which to meet projected program expenditures.* The independent cost assessment estimates program costs at $53.9 billion (FY'96$), suggesting that the general taxpayer liability is about $25.8 billion, or about half (48 percent) of total program expenditure.**

### A Small Portion of Total Costs are "Sunk"

Though the DOE/OCRWM waste management program is now in its fifteenth year, only 11.3 percent of estimated TSLCC have been incurred through FY 1996; 88.7 percent will be incurred in future years. Thus, despite the huge investment at Yucca Mountain and the large investments in investigating sites at Hanford, Deaf Smith County and elsewhere, just over ten percent of the costs which the nation should expect to spend for permanent disposal of HLNW have been "sunk." In determining future directions for the program, sunk costs should be relegated to a lesser role than they seem to have been in many policy determinations to this point.

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* Nuclear Waste Fund Fee Adequacy: an Assessment (October 1996) DOE/RW-0490; Analysis of the Total System Life Cycle Cost (September 1995) DOE/RW-0479. The fee adequacy assessment (pg 11) estimates that the fund balance at the end of FY'94, plus projected income from fee payments and investments, will generate $22.8 billion ($24.1 billion in FY'96 dollars), sufficient to offset the civilian share of TSLCC as estimated by DOE in September 1995. DOE's September 1995 analysis of TSLCC (pg 39) estimates the civilian share at $26.6 billion ($28.1 billion in FY '96 dollars). Our discussion assumes that the fund will generate the higher figure—noting, however, that higher estimates of annual costs would draw down the fund balance more rapidly than assumed in DOE's fee adequacy assessment, thus reducing investment income to the NWF.

** As mentioned, the Nuclear Waste Fund (and the one-mil per kilowatt hour fee) created by the Nuclear Waste Policy Act (Section 302) was intended to pay for the disposal of only those wastes generated in the production of commercial nuclear power. The independent assessment estimated the costs attributable to commercial SNF, distinguishing these from the costs attributable to DOE SNF and HLW. Comparing the costs attributable to commercial SNF ($43.5 billion, FY'96$) against DOE's estimate of revenues generated in the Nuclear Waste Fund ($28.1 billion, FY'96$), we estimate a shortfall of $15.4 billion—that is, expenses attributable to commercial SNF that will not be met by the Nuclear Waste Fund as currently constituted. The $43.5 billion estimate of costs attributable to commercial SNF is 80.68 percent of projected costs (see Appendix D), plus a like percentage of actual expenditures through FY 1996 (see Appendix B).

## 2.4 SOURCES FOR TOTAL SYSTEM COST ASSESSMENT

Several sources were consulted in preparing the independent assessment of total system costs for the permanent disposal of the nation's SNF and high-level waste.

### USDOE Assessment of Total System Costs

The Nuclear Waste Policy Act requires DOE to prepare "an estimate, on an annual basis, of the costs required to construct and operate the repositories anticipated to be needed . . . and to carry out any other activities under this Act" (Section 301 (a) (10)). Based on the estimate of costs, the Act requires that DOE "shall annually review the amount of the fees (on sales of civilian nuclear power). . . to evaluate whether collection of the fee will provide sufficient revenues to offset the costs. . ." (Section 302 (a) (4)). The former requirement is generally referred to as the assessment of "total system life cycle costs" and is part of DOE's responsibility to develop and maintain a mission plan for management of the nation's high-level nuclear waste. The latter requirement is referred to as the "fee adequacy assessment," and is part of DOE's responsibility to manage the nuclear waste fund established by the NWPA.

This assessment included a thorough review of DOE's most recent analysis of total civilian costs (published in September 1995), and a comparative review of estimates prepared in 1986, 1989 and 1990. DOE's assessments describe waste management assumptions (e.g., projected inventory, number of repositories, repository media, etc.) but do not describe their cost analysis procedures or cost factors.

Our review compared DOE estimates of total system costs, selecting comparable waste management assumptions (e.g., single repository, in tuff) and adjusting for changes in the projected inventory and for constant dollars. The key observation is that, in a program that has had many changes of direction and adjustments in cost, the DOE estimates of TSLCC have been very consistent. The 1995 estimate is only about ten percent above the initial estimate prepared in 1986, only seven to eight percent higher than the estimate from 1989, and virtually identical to the 1990 estimate prepared to reflect the effects of the 1987 amendments to the NWPA.

### USGAO Reports to Congress

In response to requests from Congress and its committees, the General Accounting Office (GAO) has made numerous inquiries into various aspects of DOE's program for management of the nation's high-level nuclear wastes and/or the site characterization project at Yucca Mountain. Some GAO inquiries have focused directly on program costs or revenues; other have focused on management issues which have a significant but indirect bearing on costs. The GAO has found numerous persistent causes for concern:

- A September 1994 report concluded that comprehensive review of the disposal program is needed.
- A December 1994 report expressed concerns about DOE's management and organization of the Nevada repository project.
- A September 1993 report inquired about funds spent to identify a monitored retrievable storage facility site.

- A May 1993 report observed that Yucca Mountain project was behind schedule and facing major scientific uncertainties.

- A May 1992 report concluded that DOE's repository site investigations would be a long and difficult task.

- A March 1992 report concluded that the development of casks for transporting spent fuel needs modification.

- A June 1992 report evaluated the status of actions to improve DOE user-fee assessments.

GAO's major review of total system costs in the DOE/OCRWM program was published in June 1990* and concluded that changes were needed in DOE user-fee assessments to avoid shortfalls in the Nuclear Waste Fund. The review evaluated DOE's estimates of total system cost, but did not investigate costs analysis procedures in detail, nor did it validate cost factors. Much of GAO's review focused on the one mil per kilowatt hour fee and the uncertainties regarding its adequacy to support projected expenses.

GAO has reviewed 80 projects designated by DOE as major systems acquisitions and identified many which suffered significant cost overruns or schedule slippages:** e.g.,

- The final cost of the Fuels and Materials Examination Facility at Hanford (WA) was 39 percent above the original estimate, and the completion schedule slipped 14 months. The $234 million facility is now used for storage and office space.

- The costs of the West Valley Demonstration Project in New York increased 226 percent from an original estimate of $446 million to a final cost of $1,008.5 million, and the originally estimated completion date slipped seven years and five months.

- The cost of the Super Conducting Supercollider in Texas increased from an original estimate of $5.9 billion to over $11 billion before the project was terminated in October 1993.

- The vitrification plant at the Savannah River Site in South Carolina was completed in November 1996—62 percent over original budget and 6½ years behind schedule.

GAO notes the many causes for cost overruns and schedule slippages in large and technically demanding projects, but finds several underlying causes (unclear or changing missions, incremental project funding, a flawed system of incentives, insufficient DOE personnel to effectively oversee contractor operations) common to many DOE major systems acquisitions.

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* USGAO: "Nuclear Waste: Changes Needed in DOE User-Fee Assessments to Avoid Funding Shortfall" (GAO/RCED-90-95, June 7, 1990).

** USGAO: "Department of Energy: Opportunity to Improve Management of Major System Acquisitions" (GAO/RCED-97-17, November 1996).

### DOE/NRC Management Information

This assessment included significant efforts to collect, organize and analyze information collected by DOE or NRC. Examples include:

- DOE expenditures, as reported in detail in "status of obligation authority" reports.
- DOE records of spent fuel discharges (by reactor, current location, number and type of assemblies, MTU) through 1995.
- NRC data on operating and shutdown commercial nuclear power reactors (Information Digest: Appendix A).
- DOE projections of spent fuels discharges under no-new-orders, end-of-license term assumptions (DOE/RW-0431, June 1995)
- DOE's Integrated Data Base Report (DOE/RW-006, December 1996) including estimates of high-level defense waste and DOE spent nuclear fuel.

### Other Sources for the Independent Assessment

Other information sources used in this assessment include data received from the American Railroad and American Trucking Associations, inputs from sources in the nuclear industry (e.g., the Nuclear Energy Institute and its consultant Energy Resources International), and construction industry standards.

The State of Nevada began the independent assessment in late 1996. Independent contractors were engaged to collect available information on the current and projected inventory requiring permanent disposal, the costs of continued onsite storage due to delay in DOE pickup, the costs of cross-country transportation, the costs of heavy-haul and rail transportation in Nevada, the costs of centralized storage, and the costs of repository characterization, licensing, construction, operations, and closure. Independent contractors were asked to estimate contingency, project management and program management costs—arriving at a total cost for the life-cycle of the DOE program. Waste management assumptions were specified so as to reflect a program which responds as practicable to initiatives currently underway as part of DOE's May 1996 revised program plan, the requirements of currently proposed legislation (e.g., S.104/HR.1270), the remedies resulting from the November 14, 1997 decision in Northern States Power Company et al versus USDOE, and recent DOE/OCRWM policy shifts. An outside contractor was engaged to ensure that the independent cost analysis used reasonable assumptions, costing procedures and cost factors.

Chapter 3 of this report describes the inventory requiring permanent disposal; the strategy for managing the waste inventory; the types of costs required by the waste management strategy; the schedules for storage, pickup and emplacement which determine cost streams over time; and the key cost analysis procedures used in this assessment.

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# 3. THE INDEPENDENT COST ANALYSIS: WASTE INVENTORY, WASTE MANAGEMENT ASSUMPTIONS, COST ANALYSIS PROCEDURES

In its September 1995 analysis of the total system life-cycle cost (TSLCC) of the civilian radioactive waste program, the US Department of Energy (DOE) describes its assumptions regarding waste management strategy—the inventory, the transportation requirements, the schedule for disposal. However, DOE's report does not describe its costing procedures or cost factors, or the rationale for the costing procedures and factors.

This section describes at a general level the waste management assumptions and cost analysis procedures and cost factors used in an independent assessment of total system cost. We discuss the inventory requiring permanent disposal; the strategy for managing the waste inventory; the types of costs required by the waste management strategy; the schedules for storage, pickup and emplacement which determine cost streams over time; and the key cost analysis procedures used in this assessment.

Throughout the independent assessment we have used the "best available" input data and cost assumptions. Much of the input data comes from DOE, and we have made particular efforts to locate and obtain the most recent DOE data available. Many of the cost assumptions come from nuclear industry sources or construction industry standards. Supplementary inquiries have been conducted to provide a basis for estimates of project and program management costs, additional PETT payments, and numerous other factors.

## 3.1 THE INVENTORY REQUIRING PERMANENT DISPOSAL: THREE GROUPS

This assessment divides the inventory requiring permanent disposal in a geologic repository into three broad categories:

a) Current and projected inventories of spent nuclear fuel stored at commercial reactor sites. This category includes all discharges of spent fuel assemblies from commercial reactors, less those which for various reasons have been shipped to other sites such as Morris (IL), West Valley (NY), and the Idaho National Engineering and Environmental Laboratory (INEEL)—i.e., the broad category of SNF for which utilities expected the federal government to begin taking responsibility on January 31, 1998.

b) Current and projected inventories of spent nuclear fuel at other sites—chiefly federal government sites, but also private sites such as the Morris facility and various universities with research reactors. The inventories include SNF from commercial reactors (e.g., Three Mile Island, Cooper Station, Dresden) which has been shipped offsite (e.g., to INEEL, Morris, West Valley), SNF from Navy and foreign research reactors which will be shipped to INEEL and the Savannah River Site (SRS) for storage while awaiting shipment to Yucca Mountain for disposal, and SNF generated at defense reactors—chiefly Hanford. In the que for DOE pickup, this category has second priority (in this assessment) to spent fuel stored at commercial reactor sites.

c) Projected HLW, which will be vitrified and canistered at four defense sites (Hanford, Savannah River, INEEL and West Valley) before being shipped* to Nevada for permanent disposal at Yucca Mountain.

### Current (1995) Discharges of SNF

This study included an assessment of spent fuel discharges through 1995, identifying the date, origin, current location, metric tons uranium (MTU) and assemblies of each discharge, and distinguishing discharges currently located at reactor sites (inventory group "a" above) from those at other sites (group "b"). At the end of 1995, 1,275 discharges totaling 31,747 MTU in 111,015 assemblies were stored at commercial reactor sites (inventory group "a"). Another 850 MTU originated at commercial reactors but had been shipped for storage at other sites (e.g., Morris, INEEL, West Valley); these form part of inventory group "b" in the current assessment.

### Projected Discharges (1996+) from Commercial Reactors

This study also included an assessment of projected spent fuel discharges from currently operating commercial nuclear reactors, through the end of their license term. Projected discharges are consistent with those presented in DOE's most recent projection of spent fuel storage requirements.** However, adjustments were made in the early projection years to account for actual discharges in 1994 and 1995, which are projection years in the DOE study. Also a random number method was used to prioritize projected discharges within a given year. Finally, projected discharges from four reactors included in the DOE projections (TVA's Bellefonte 1&2 and Watts Bar 1&2) were removed from this assessment—reflecting a judgement that, though NRC construction permits had been issued, these plants would not have commercial operation. Thus, inventory group "a" in this assessment reflects a no-new-orders, *modified* end-of-license-term projection of spent fuel discharges from commercial nuclear reactors.

The projected spent fuel discharges after 1995 total 50,598 MTU. Combined with the 31,747 MTU currently stored at commercial reactor sites, the total inventory in group "a" is estimated at 82,345 MTU. This is SNF which is or will be stored at commercial reactor sites, and which*** is the focus of the federal government's obligations for interim storage and pickup under the Northern States Power et al versus USDOE court decision of November 14, 1997.

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* Beginning in 2015, according to assumptions used in DOE's September 1995 TSLCC (pg. 8) and in this assessment.

** Spent Fuel Storage Requirements 1994-2042 DOE/RW-0431, June 1995.

*** Along with SNF stored at the General Electric Facility at Morris (IL).

### Spent Nuclear Fuel Not Located at Commercial Reactor Sites

Regarding inventory group "b", this study included an assessment of current and projected spent fuel *not* located at commercial reactor sites. One component in this group is SNF which originated at commercial reactors but which has since been shipped for storage at other sites such as Morris, West Valley, and INEEL. As mentioned, this component totals 850 MTU.* Another component is spent fuel discharges from DOE weapons reactors, Navy reactors, foreign research reactors and other fuel in the DOE/DOD complex. This fuel, which totals 2,666.5 MTU, has been grouped according to the probable locations from which it would be shipped to Yucca Mountain.

Combining both components, inventory group "b" includes 3,516.5 MTU (roughly similar to the spent fuel expected to be discharged from six BWR reactors.)** which would be shipped to Yucca Mountain from Hanford (2,132 MTU), INEEL (325 MTU), SRS (214 MTU), Morris (674 MTU), West Valley (147 MTU), or other sites (24 MTU).

### High-Level Waste at Four Defense Sites

Highly-radioactive wastes have accumulated at DOE defense sites (particularly Hanford, INEEL and Savannah River) in liquid, sludge, salt cake, slurry, calcine, capsule and other forms. DOE intends to stabilize these wastes in glass columns about 2 feet in diameter and 10 to 15 feet in length. The glass will then be canistered for storage onsite until it can be transported (beginning in 2015***) to Nevada for permanent disposal. This assessment assumes that 19,234 canisters of HLW will be produced.****

## 3.2 WASTE MANAGEMENT ASSUMPTIONS

Any estimate of total systems cost must reflect assumptions regarding how the current and projected inventory will be managed. The assumptions used in this assessment reflect current legislative proposals (primarily Senate Bill 104 and House Bill 1270), recent court decisions (e.g., Northern States Power et al versus USDOE, November 14, 1997), and DOE policies. The question posed is, what is the likely cost of a program which attempts to implement the directives in proposed legislation and the conclusions of recent court decisions? Some of the key waste management assumptions (which are summarized and compared with those of DOE's 9/95 TSLCC in Figure 5) include:

* It also includes very small amounts of spent fuel discharged from DOE research reactors which is included in DOE's acceptance priority rankings.

** E.g., Clinton, Cooper Station, Duane Arnold, Fitzpatrick, Monticello, Vermont Yankee.

*** DOE TSLCC 9/95, pg. 8.

**** DOE IDB December 1996 pp. 50-51. The estimate increased from 13,789 in IDB September 1995, pp 64-65.

## Figure 5. Waste Management Assumptions: Comparison

| | DOE TSLCC: 9/95 | | INDEP ASSESS: 1/98 | |
|---|---|---|---|---|
| # PERMANENT REPOSITORIES | Single repository for all SNF & HLW.<br>Exceed 70,000 MTU limit for repos #1. | | Same<br>Same | |
| INTERIM STORAGE | No monitored retrievable or centralized storage facility.<br>SNF stored at reactor sites (at utility expense) until shipped to YM, beginning 2010. | | Central storage facility at NTS Area 25.<br>SNF stored at reactor sites (at shared NWF/utility expense) until shipped to YM, beginning 2003. | |
| DOE PICKUP: SNF | Begins in 2010 & extends through 2040:<br>Year 1: 300 MTU<br>Year 2: 600 MTU<br>Year 3: 1,200 MTU<br>Year 4: 2,000 MTU<br>Year 5: 3,000 MTU<br>Year 6-30: 3,000 MTU<br>Year 31: 1,854 MTU | | Begins in 2003 & extends through 2033:<br>Year 1: 1,211 MTU<br>Year 2: 1,215 MTU<br>Year 3: 2,025 MTU<br>Year 4: 2,011 MTU<br>Year 5 2,704 MTU<br>Year 6-30: 3,021 MTU (Avg)<br>Year 31: 1,179 MTU | |
| DOE PICKUP: HLW | Begins in 2015 & extends through 2040:<br>Year 1-23 750 canisters<br>Year 24: 175 canisters<br>Year 25: 345 canisters<br>Year 26: 576 canisters | | Begins in 2015 & extends through 2040:<br>Year 1-23 750 canisters<br>Year 24: 750 canisters<br>Year 25: 750 canisters<br>Year 26: 484 canisters | |
| INVENTORY | SNF: 83,954 MTU<br>HLW: 18,346 Canisters | | SNF: 85,861 MTU<br>82,345 Comm reactor sites<br>3,517 DOE & other<br>HLW: 19,234 Canisters | |
| INTERIM STORAGE/ PERMANENT DISPOSAL | SNF is packaged & emplaced as received at the YM repository. | | Same | |
| NWF OBLIGATIONS: | | | | |
| Inventory | Commercial | | SNF at commercial sites | |
| Waste Mgt Activ | | | | |
| Interim strg | Not Applic | | Shared re pickup start and rate | |
| X-ctry transp | Yes, re SNF % | | Yes, re SNF % | |
| Nevada transp | Yes, re SNF % | | Yes, re SNF % | |
| Central strg | Not Applic | | Yes, re SNF % | |
| Repository | Yes, re SNF % | | Yes, re SNF % | |
| Program mgt | Yes, re SNF % | | Yes, re SNF % | |
| NEVADA TRANSP: | | | | |
| Intermodal Transf | Not Applic | | Yes, by 2003 | |
| Heavy-Haul | Not Applic | | Yes, 2003-2008 | |
| Rail Spur | Yes, 2010+, ______ miles | | Yes, 2008+, 365 miles | |
| TRANSP CASKS: | | | | |
| Rail | MPC @ 125/75 tons, as req. | | Same | |
| Hwy | High-capacity LWT cask, as req. | | Same | |
| TRANSP CHOICES: | Reactor Facilities | Cask Shipments | Sites | Cask Shipments |
| LWT: Comm SNF in Que | 4 | 1,441 | 26 | 14,769 |
| Other SNF | | | 4* | 2,151 |
| Small rail | 23 | 4,216 | 19 | 5,382 |
| Large rail | 92 | 9,189 | 28 | 4,256 |
| HLW rail | | | 4 | 3,847 |
| Sub-total | 119 | 14,846 | 81 | 30,405 |

* Multiple sites, grouped to 4 for analysis
Note: Some numbers may not add due to rounding.

### A Single Repository for All SNF and HLW

Our assessment assumes that all current and projected SNF and HLW is emplaced in a single repository at Yucca Mountain in Nevada. Implicitly, we assume that Section 114(d) of the NWPA would be changed to authorize DOE to exceed the 70,000 MTU limit for the first repository.* DOE's 9/95 TSLCC makes similar assumptions.

Previous DOE TSLCC assessments have assumed that the first repository would accommodate 62,907 MTU of SNF and 7,093 MTU of HLW.** Under our assumptions, about 22,954 MTU of SNF and about 40,984 MTU of vitrified HLW that would (under provisions of NWPA Section 114d) be stored in a second repository would instead be disposed at Yucca Mountain.***

### A Centralized Storage Facility at NTS Area 25

Our assessment assumes that a centralized storage facility, with capacity to store all SNF accepted and not yet emplaced, would be developed at Area 25 of the NTS. Implicitly, we assume that legislation would override the provisions of the NWPA that interim and permanent facilities should not be in the same state (Section 141(g)) and that the permanent facility must be authorized for construction before an interim facility can be authorized at all (Section 148(d)(1)).

DOE's 9/95 TSLCC, adhering to the provisions of the 1987 Amendments to the NWPA, assumes no Monitored Retrievable Storage or centralized storage facility. Implicitly, it assumes that SNF will be stored at reactor sites (at utility expense) until shipped to Yucca Mountain for permanent disposal.

### Early and Rapid DOE Pickup from Commercial Sites

Proposed legislation would require DOE pickup from commercial sites to begin in 2002 or 2003 (at 1,200 MTU) and rapidly increase (1,200 MTU in year two, 2,000 MTU in year three, 2,700 MTU in year four) to a plateau level of 3,000 MTU per year. Our assessment assumes that operation of a central storage facility begins in 2003, and that thereafter DOE pickup from commercial sites proceeds as specified in proposed legislation.

DOE's 9/95 TSLCC assumes that DOE pickup from commercial sites begins in 2010 (at 300 MTU) and increases gradually (600 MTU in year two, 1,200 MTU in year three, 2,000 MTU in year four) to a plateau level of 3,000 MTU, which extends to 2040. Our analysis accepts DOE's 9/95 assumption

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* An important uncertainty is whether Yucca Mountain can be shown to have the capacity to safely emplace SNF and HLW in such volume.

** E.g., DOE TSLCC May 1989 Tables A-3&4 (two-repository system).

*** SNF: 85,861 MTU projected inventory - 62,907 MTU in first repository = 22,954 MTU
HLW: 48,077 MTU projected inventory - 7,093 MTU in first repository = 40,984 MTU
19,234 canisters times estimated MTU per canister at Hanford, Savannah River, INEEL and West Valley = 48,077 MTU vitrified HLW.

that pickup of HLW from four defense sites begins in 2015 and extends (at a plateau rate of 750 canister shipments per year) until all canisters have been removed to Nevada.

#### Intermodal Transfer and Heavy-Haul

There is currently no rail link to Yucca Mountain. Our assessment assumes that the development of a long rail spur would begin in FY 2002 and would require at least five years. Furthermore, shipment of the volumes anticipated entirely on public highways is assumed to be unacceptable. Therefore, our assessment, consistent with proposed legislation, assumes that early shipment requires an intermodal transfer facility at Caliente and heavy-haul operation on Nevada's public highways. We further assume that heavy-haul through Las Vegas or across the NTS is infeasible; therefore, heavy-haul shipments are routed north of the Nellis Air Force Range to Tonopah, then south along US 95 to Yucca Mountain.

DOE's 9/95 TSLCC assumes that shipments begin in 2010, by which time a rail spur to Yucca Mountain would be available. Under these waste management assumptions, rail shipments would not require heavy-haul in Nevada to reach Yucca Mountain.

#### Central Storage at NTS Area 25

Consistent with provisions of proposed legislation (HR-1270), our assessment assumes that, as SNF is received in Nevada (beginning in 2003), it would be stored above-ground at a centralized facility at NTS Area 25 until the repository is ready for operation in 2010. We further assume that SNF which arrives uncanistered (by legal-weight truck) will be stored in metal casks, while SNF which arrives in dual-purpose canisters (by rail/heavy-haul) will be placed in concrete storage facilities.

DOE's 9/95 TSLCC assumes that SNF and HLW is packaged and emplaced (for permanent disposal) as it is received at the Yucca Mountain repository, which is assumed to begin operation in 2010.

#### Federal Government Obligation for Onsite Storage at Commercial Reactor Sites

As a result of the November 14, 1997 court decision in Northern States Power et al versus USDOE (and follow-on litigation to specify the implications of that decision), our assessment assumes that the federal government will have a financial obligation for continued onsite storage of SNF after it would have been picked up under an oldest-fuel-first priority ranking beginning in 1998. A calculation of the annual inventory at each site under the two cases (pickup beginning in 1998 and proceeding at S-104 rates versus pickup beginning in 2003) provides the basis for calculation of the federal government and NWF obligation for extended onsite storage at commercial reactor sites.

DOE's 9/95 TSLCC implicitly assumes that the federal government has no obligation for onsite storage of SNF at commercial reactor sites—even though pickup would not begin until 2010.

#### Canisters and Casks for Storage and Transportation

Our assessment assumes that a dual-purpose canister system for rail shipments (and storage onsite and/or at a centralized facility) would be made available. But utilities are under no obligation to use it in onsite dry storage, and, as long as early shipment is a prospect, may not, given the circumstances at particular reactor sites, have a financial incentive to do so. We have analyzed the circumstances at 77 sending sites and identified 16 which appear to have a financial incentive to use dual-purpose canisters for onsite storage in a program in which pickup begins in 2003. While a high-capacity LWT cask is currently not certified, we assume that such a cask would be made available in order to reduce (by a factor of four) the number of cask shipments on public highways.

DOE's 9/95 TSLCC assumes that a multiple-purpose canister system is developed by DOE and certified by NRC, as is the high-capacity cask for legal-weight truck shipment of uncanistered SNF. It further assumes that these federally-developed systems are used in preference to other storage/transportation systems.

**Transportation Mode and Cask Choices**

Based on a review of pool loading capabilities (e.g., operating crane capacity, cask set-down area, pool depth) at commercial reactor sites, our assessment assumes that as many as 26 sites (36 percent) will choose to ship by legal-weight truck. Utilities have no financial incentive to upgrade pool loading capabilities merely to facilitate rail shipment rather than shipment by LWT, which is legal under USDOT regulation.

Though DOE has made no commitment to transport rail casks by dedicated train, and has a long-standing challenge to rail carrier estimates of the cost of dedicated train shipment, we assume that SNF mixed with general rail freight would be unacceptable, and that dedicated trains would be used for all rail shipment.

DOE's 9/95 TSLCC assumes that, of 119 reactor facilities, only 4 (3.4 percent will ship by legal-weight truck. Further "all SNF rail shipments are assumed to be made by dedicated train."*

## 3.3 THE TOTAL SYSTEM COST CATEGORIES

The waste management assumptions described above require an analysis of total system cost in seven major categories, several of which have not been addressed in previous DOE TSLCC assessments.

**Extended Onsite Storage (Master Code 1.0)**

This assessment estimated the costs of extended onsite storage for 73 commercial reactor sites (master code 1.1), assuming DOE pickup beginning in 2003 rather than in 1998. Onsite storage costs include: the costs of dry storage for SNF discharges in excess of current pool capacity, the cost of operating spent fuel pools as interim storage facilities after shutdown of their associated reactors, and the cost of limited upgrades of pool loading capabilities to accommodate casks of a specified type, size and weight.**

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* DOE 9/95 TSLCC, pg. 8.

** The NWF obligation for these costs is based on the projected inventory at each site compared to the projected inventory had DOE pickup begun in 1998 and proceeded at S-104 rates.

This category also includes the costs of extended onsite storage of SNF not stored at commercial reactor sites (master code 1.2). For this analysis, multiple sites (Morris, Ft. St. Vrain, West Valley, DOE defense sites, university research reactors) are combined into four, and inventory estimates in MTU are translated into BTU assembly equivalents. The analysis assumes all such costs are supported by defense appropriations, except for those at Morris.

HLW at four defense sites will require vitrification, canistering and onsite storage while awaiting shipment to Yucca Mountain (master code 1.3). However, such costs are assumed to be the responsibility of the DOE Office of Environmental Restoration and Waste Management, not DOE/OCRWM.

### Cross-Country Transportation (Master Code 2.0)

Cross-country transportation includes the cost of high-capacity casks for LWT shipment of uncanistered SNF and the cost of rail casks for shipment of canistered SNF or HLW; the cost of trailers for LWT shipment and cask and buffer cars for rail shipment; the cost of operating, maintaining, replacing and decommissioning this equipment; the carrier, escort and inspection costs for LWT and rail shipments; and the cost of heavy-haul to a nearby railhead for rail shipment from sites which do not or no longer have a rail spur. These costs are estimated for transportation of commercial SNF stored at commercial reactor sites (master code 2.1), other SNF (master code 2.2), and HLW (master code 2.3).

Also included in cross-country transportation is an estimate of the costs of technical assistance training required of DOE/OCRWM under NWPA Section 180(c) (master code 2.4)

### Nevada Transportation (Master Code 3.0)

Cross-country transportation includes the cost of LWT shipment to Yucca Mountain, and of rail shipment to Caliente (NV). Nevada transportation includes the costs of moving rail casks from Caliente to the central storage facility at NTS Area 25 or the geologic repository at Yucca Mountain. These include the cost of an intermodal transfer facility at Caliente (master code 3.1), a heavy-haul operation between Caliente and the central storage facility (master code 3.2), and the construction and operation of a government-owned rail spur between Caliente and Yucca Mountain (master code 3.3).

### The Centralized Storage Facility (Master Code 4.0)

The costs of a centralized storage facility at NTS Area 25 include: the costs of designing and licensing such a facility (master code 4.1), the costs of site development and facility construction (master code 4.2), the costs of storage equipment (master code 4.3) and of facility operations (master code 4.4). The costs of storage equipment include the costs of metal casks for SNF arriving uncanistered by LWT and concrete storage for SNF arriving by rail in dual-purpose canisters. Storage equipment also includes the cost of dual-purpose canisters for rail shipments from 31 reactor sites at which onsite storage has used pools or dry-storage in storage-only canisters. The estimates reflect the projected inventory at the CSF, considering both the flows of SNF shipped to Nevada and those emplaced for permanent geologic disposal.

### The Geologic Repository (Master Code 5.0)

Repository costs include the actual expenditure for "first repository" development and evaluation through FY 1996, and the costs of completing site characterization at Yucca Mountain (master code 5.1), the design and license application costs at Yucca Mountain (master code 5.2); the cost of constructing, equipping and operating surface facilities (master code 5.3) and underground facilities (master code 5.4); and the cost of about 11,000 waste containers for emplacement of 85,861 MTU of SNF (master code 5.5).

### Other Development and Evaluation Costs (Master Code 6.1)

Other development and evaluation costs include fees paid to the Nuclear Regulatory Commission (master code 6.1), and support for the Nuclear Waste Technical Review Board (master code 6.2). These costs are not independently estimated. Estimates from the DOE 9/95 TSLCC (converted to FY'96$) are applied in this assessment.

### Other Program Costs (Master Code 7.0)

Other program costs include payments equal to taxes (master code 7.1) and benefits (master code 7.2) as provided for under NWPA Sections 116(c)(3) and 170-171. Estimates from the DOE 9/95 TSLCC (converted to FY'96 $) are applied in this assessment. However, an estimate of additional PETT related to components not included in the current DOE program (Nevada transportation and centralized storage) is included, based on the construction and major equipment costs of these facilities.

### Contingency Costs

Continency costs are estimated as a percentage of direct costs in the categories above. A review of projected costs in the DOE 9/95 TSLCC was conducted, relating contingency to base costs for various cost elements. The results were used as points of reference for estimating contingency costs in this assessment. A 15 percent contingency factor was used for onsite storage, cross-country transportation and the intermodal transfer portion of Nevada transportation. A 20 percent contingency factor was used for the heavy-haul and rail spur portions of Nevada transportation and for repository costs other than site characterization. Lower contingency factors were used for the completion of Yucca Mountain site characterization and for other development and evaluation and program costs. Overall in this assessment, contingency comprises 11.0 percent of total projected costs, and 16.3 percent of direct costs.*

Contingency addresses the potential for complications in the implementation of the program components as described—complications in scheduling, meeting state-local and federal regulations, construction, procurement or hiring. As applied in this assessment, contingency does not address the major uncertainties in the program—e.g., the potential for major accidents,** special construction

* By comparison, in DOE's September 1995 estimate of TSLCC, contingency comprises 14.1 percent of total projected costs and 18.6 percent of "base" costs.

** Contracted emergency response is included for two incidents (not involving releases or fatalities) in heavy-haul operations (master code 3.2) and nine incidents in rail spur operations (master code 3.3).

problems, unanticipated licensing requirements, etc. Such uncertainties are discussed in section 2.2 of this report.

**Project Management Costs**

This study included an assessment of project and program management costs in the DOE/OCRWM program in fiscal years 1988-1996. Using annual reports of DOE/OCRWM expenditures, selected budget and reporting codes were identified as "project" or "program" management, and tabulated for the relevant fiscal years, thus dividing total costs into three broad categories—direct costs, project management costs, and program management costs. Distinct from program management, which involves overall direction of the DOE/OCRWM program, "project management" is the management of specific activities for which direct costs have been estimated. This tabulation suggests that project management comprised 24.1 percent of direct costs over the nine-year period FY 1988-96, and 23.9 percent over the most recent five-year period FY 1992-96. Project management costs in the Yucca Mountain project (B&R category 1.2) have been higher than in the DOE/OCRWM program overall—31.2 percent in the FY 1988-96 period, and 28.3 percent in the FY 1992-96 period.

The above analysis was used as a point of reference in estimating project management costs associated with projected direct expenditure. In most categories, project management is estimated at 15 percent of direct costs plus one-third of contingency costs. In some categories (e.g, technical assistance training (master code 2.4), site characterization (master code 5.1.1), other development and evaluation (master code 6.0), and other program (master code 7.0) costs, project management is assumed to have been included in direct costs. Overall in this assessment, project management comprises 9.2 percent of total projected costs, and 13.6 percent of direct costs.

**Program Management**

The assessment described above also estimated program management costs in the DOE/OCRWM program, representing these as a percentage of all other (direct and project management) costs. Generally but not exclusively or necessarily conducted at DOE's headquarters in Washington, program management involves the overall direction, advocacy, coordination and financial management of the DOE/OCRWM program. The assessment suggests that program management costs comprised 8.3 percent of all other costs over the nine-year period FY 1988-96, and 15.1 percent over the more recent five-year period FY 1992-96.

The analysis of recent DOE/OCRWM expenditure was used as a point of reference in estimating program management costs associated with other projected expenditure. In most cost categories, program management was estimated at 15 percent of the subtotal of direct, contingency and project management. Overall, program management comprises 12.5 percent of total projected costs, and 14.2 percent of the direct, contingency and project management cost sub-total.

## 3.4 WASTE MANAGEMENT SCHEDULE: PICKUP, INTERIM STORAGE, EMPLACEMENT

Several schedules must mesh in a national waste management program—the schedules by which spent fuel is discharged from nuclear reactors (or HLW vitrified and canistered at DOE defense sites) and stored onsite while awaiting pickup, the start date and rate of DOE pickup of SNF and HLW for transport to the central storage facility or repository, and the rate at which SNF and HLW is emplaced in the geologic repository. These rates determine the inventory in onsite storage, the inventory in transit, the inventory in centralized above-ground storage, and the inventory emplaced in each year of the waste management program. These inventories, or their year-to-year changes, drive the cost streams in this assessment. The inventory assumptions are discussed in section 3.1, above. This section discusses the schedules for DOE pickup and emplacement.

#### Priority for Pickup of SNF

DOE pickup from commercial reactor sites is estimated on an oldest-fuel-first basis,* using the overall acceptance rates specified in currently proposed legislation, and summing for all storage locations at a particular site. This results in different pickup schedules at each commercial reactor site—depending on the start of commercial operations and the rate of discharges at each reactor relative to others across the nation. Thus, for example, pickup at Big Rock Point, which began commercial operation in March 1963, would start in year 1, while pickup at Callaway (commercial operations: December 1984) would begin in year 7, and pickup at Braidwood (commercial operations: July 1988) would begin in year 9.

#### Pickup Start Date and Schedule

If pickup begins in 2003 as assumed in this assessment, and proceeds at rates specified in current legislation (at least 1,200 MTU in years one and two, at least 2,000 MTU in year three, etc.), 81,683 MTU will have been picked up through 2031 (year 29 of the acceptance and transportation program). This assessment assumes that the remaining SNF at commercial reactor sites (662 MTU) would be picked up in 2032,** along with 2,338 MTU of SNF stored elsewhere. The remaining SNF not stored at reactor sites would be picked up in 2033.

Consistent with DOE assumptions in its 9/95 TSLCC, this assessment assumes that pickup of HLW begins in 2015 and proceeds at 750 canisters annually until all are removed from their current storage sites. At this rate, shipment of currently projected HLW canisters would extend through 2040.

This assessment prioritizes pickup of HLW based on the cumulative production and storage of canisters at each site (Hanford, INEEL, Savannah River, West Valley). This prioritization may not meet the terms of agreements between DOE and the host states for its facilities. For example, canister production at INEEL is projected (IDB December 1996) to extend through 2035 and pickup would extend through 2040.

* As described in the "standard contract" (10 CFR 961).

** Some SNF may not have been discharged from reactors. Shutdown at Comanche Peak 2, for example, is scheduled for February 2033. The study assumes that the final discharges from Comanche Peak, Limerick 2 and Vogtle 2 are available for pickup in year 30, and do not require a hiatus in a shipment campaign which proceeds at S-104 rates.

**Implications for Reactor Sites**

This assessment assumes that a central storage facility at the NTS (and the associated intermodal transfer facility at Caliente and heavy-haul around Nellis Air Force Range) begin operation in FY 2003, not in 1998 when the federal government obligations for commercial waste management begin. For example, given the priority of its discharges, the Beaver Valley site can expect pickup of 16.1 MTU in year four, 48.7 MTU in year five, and 35.2 MTU in year six—that is, 2006, 2007, and 2008 assuming DOE's first pickup year is 2003.

**Implications for the Nuclear Waste Fund**

In a November 14, 1997 decision, the US Court of Appeals for the District of Columbia Circuit concluded in Northern States Power et al versus USDOE that the federal government has an obligation under the standard contract (NWPA Section 302) to remediate utility costs attributable to delays in pickup start date or shortfalls in pickup rates. However, it declined to specify the remedy until delays actually begin, and it did not determine whether the costs of delay would be drawn from the Nuclear Waste Fund or from some other source such as the general fund.

In the absence of a court-approved formula, this assessment allocated the costs of delay based on an estimate of the projected inventory at each site (assuming pickup beginning in 2003 and proceeding at S-104 rates) compared to the inventory had pickup begun in 1998. The percentage of the projected inventory which would have been picked up had pickup begun in 1998 is applied to subtotal of costs for dry storage, pool operations after reactor shutdown and pool loading upgrades. The resulting estimated costs of delay are assumed to be an obligation of the Nuclear Waste Fund.

The estimated NWF obligation for onsite storage costs varies by site and by year. Overall, the NWF obligation is about 52.2 percent of the direct costs of dry storage, pool operations after reactor shutdown and pool loading upgrades at commercial reactor sties. The percentage is higher for sites that ship by legal-weight truck and sites that ship by rail after dry storage in storage-only canisters than for sites that ship by rail after storage in dual-purpose canisters.

## 3.5 COST ANALYSIS PROCEDURES: SITE-BY-SITE ANALYSIS

This assessment conducted a site-specific analysis for 73 commercial reactor sites, 4 sites* where DOE and other SNF is stored, and 4 HLW sites. The site-specific analysis estimates the annual inventory in pools and in dry storage; the DOE pickup from each site and the number of cask shipments by transportation mode and cask type; onsite storage costs (dry storage, pool operations after reactor shutdown, pool loading upgrades, additional dual-purpose canisters required for rail transport, and necessary heavy-haul to nearby rail heads); and the NWF obligation for onsite storage costs due to pickup delay. Site-by-site estimates of annual cask shipments (by transportation mode and cask type) provide the basis for estimates of transportation costs (cask shipment, escort and inspection; transportation cask and equipment purchases, operations and maintenance, and decommissioning), and (combined with assumptions regarding emplacement) the type, number and cost of storage equipment required at the central storage facility.

* Multiple sites, grouped as four for this assessment.

**Site-by-Site Information**

The following information was collected or developed for the reactors, pools and dry storage facilities at each site:

- The current (1995) inventory in each pool (joined or shared pools were treated as a single wet storage location) and existing dry storage facility.
- The projected additional discharges from each reactor to each pool. An analysis of the origin and storage location of SNF discharges through 1995 was used to allocate projected discharges from reactors to pools.
- The license shutdown date of each reactor and its associated pool. Information from the NRC Information Digest (1996 Edition) was used; joined or shared pools received the latter shutdown date among the reactors served.
- The maximum capacity (in assemblies ) of each pool, and the full core reserve to be added to that capacity upon shutdown of the associated reactor. This information was assembled from DOE's June 1995 projection of spent fuel storage requirements (DOE/RW-0431).
- The operating cost of each pool during reactor operations and after reactor shutdown. In absence of reliable data which distinguishes the cost of reactor and pool operations, we applied an average annual cost for pool operations, adjusted for the size of PWR and BWR pools at individual sites.
- The mode and cask for shipments from each storage location at each site. This study used the results of an assessment of "current capabilities" transportation choices published in July 1996.* (The second strategy option for onsite storage was associated with the "MPC Base Case" transportation choices developed in the same assessment.) As mentioned, under current capabilities transportation choices about 44 percent of storage locations ship by LWT, versus about 21 percent in the MPC base case assessment and 3.4 percent in DOE's September 1995 TSLCC.
- Requirements to upgrade pool loading capabilities in order to ship casks of the specified type. These requirements were based on a review of data collected in DOE's 1990 Facility Infrastructure Capacity Assessment, and an assessment to relate loading capabilities to the dimensions and loaded weight of the high-capacity LWT cask and the small and large rail casks assumed for this assessment.
- Requirements for heavy-haul to a nearby rail spur. The requirements were based on review of data collected in DOE's 1990 Near Site Transportation Infrastructure study, and an assessment to relate near-site infrastructure capabilities to transportation choices (i.e., rail or LWT) at each site.

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* The Transportation of Spent Nuclear Fuel and High-Level Waste, NV NWPO, July 1996, pg 39.

- The pickup schedule for spent fuel and HLW at each site, given a start date and pickup rate for all projected spent nuclear fuel stored at commercial reactor and other sites, as discussed in section 3.4, above.

**The Inventory Flow at Storage Sites**

The information described above was applied in a model of inventory flow for each of 73 commercial reactor sites.* In the model:

- Additional discharges (after 1995) from a reactor are stored in a designated pool until the pool capacity is reached. Discharges in excess of pool capacity require dry storage. It is assumed that dry storage could be provided at any site where it may be required, and would be provided to meet additional storage requirements in excess of pool capacity.

- Two strategies for onsite storage are available for each site: The first option assumes that at least one pool is retained in operation for interim storage and that necessary dry storage uses storage-only canisters. Pickup is prioritized among spent fuel locations in such a way that a pool (rather than dry storage is the last storage facility at a site to shutdown). An operating pool is used to load all legal-weight truck or rail transportation casks.

  In the second onsite storage strategy option, pool inventories are moved to dry storage in the years after reactor shutdown, and dry storage uses dual-purpose canisters. Pickup is prioritized in such a way that pools shut down prior to dry storage facilities; dual-purpose canisters are loaded dry to rail transport casks.

- In a preliminary run, the onsite storage costs for each option were compared for each site—given the assumptions for pickup start date, rate and priority in this scenario. The second option for onsite storage was assumed for 16 rail shipment sites for which onsite storage costs under option two are at least ten percent below those for option one. This assessment assumes that utilities select a strategy for onsite storage based on cost, given reasonably credible expectations for DOE pickup—not in order to facilitate a desirable overall plan for cross-country transportation or centralized storage, the costs for which are the obligation of the Nuclear Waste Fund, not individual utility ratebases.

**Dry Storage Costs (Master Code 1.1.1, 1.2.1)**

A May 1995 study by Energy Resources International, "Utility At-Reactor Spent Fuel Storage Requirements and Costs" estimated the costs of a 500 MTU dry storage facility operated over 20 years, considering the upfront, incremental, operating and decommissioning costs of such a facility. Total costs were estimated at 34 to 50 million, of which the incremental costs of metal storage canisters, concrete bunkers, loading and consumables comprise 60-65 percent.

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* Hope Creek and Salem reactors (owned by Public Service Electric and Gas Company) were combined as a single storage/shipment site. Fitzpatrick (owned by the Port Authority of New York) and Nine Mile Point (owned by Niagara Mohawk Power) were combined as a single storage/shipment site.

Using the framework of the ERI study, an analysis was conducted to apply the results in a model of inventory flow which estimates the annual inventory requiring dry storage at a particular site.

- Upfront costs (licensing, construction, equipment, engineering and startup testing) are incurred two years ahead of a projected need for additional dry storage. However. with the exception of equipment, all upfront costs are reduced by 25 to 33 percent for subsequent 500 MTU facilities that may be required at a particular site.

- Incremental costs (storage-only canisters, concrete overpack, pad extensions, loading) are incurred with increases in the dry storage inventory at a particular site. The ERI estimate of incremental costs for a 500 MTU dry storage facility are apportioned among the total PWR or BWR assemblies that could be stored at such a facility, and applied in this assessment as the needs occur.

- Annual operations costs (NRC fees, security, monitoring) are incurred in each year that a 500 MTU facility has inventory. For subsequent dry storage facilities that may be required at a particular site, operations costs are reduced 25 to 33 percent.

- Decommissioning costs are estimated at 12.5 percent of the initial (incremental) cost of storage-only canisters, concrete overpack and pads—i.e., the elements likely to be radioactively contaminated. These costs are incurred in the year after the facility's shutdown.

- Under the second option for dry storage at a rector site, the cost of canisters is increased by 50 percent to reflect the robust dual-purpose canister used, but the decommissioning costs attributable to storage-only canisters (about 12.5 percent of purchase costs under option 1) are eliminated as an on-site storage cost, since the dual-purpose canister would be used for transportation as well as on-site storage.

### Pool Operations After Reactor Shutdown (Master Code 1.1.2, 1.2.2)

In this assessment, pool operations are an onsite storage cost only in years after reactor shutdown. Otherwise, pool operations are considered a cost of operating the associated reactor. Data which reliably distinguishes the cost of reactor operations from those of associated pools were not available to this study. Industry sources have estimated pool operations costs at $8.0 million annually after shutdown. This assessment assumes that the average annual cost of pool operations is $6.3 million, a cost which is adjusted for the size of PWR and BWR pools at various reactor sites.

### Pool Loading Upgrades (Master Code 1.1.3)

Though the transportation choices assumed in this assessment conform to current pool loading capabilities at reactor sites, some improvements to operating crane capacity, cask set-down area or pool depth are nevertheless required at a few sites—based on the assessment of current conditions conducted in a recent transportation study.* Greater emphasis on rail over legal-weight truck transport, or on the

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* The Transportation of SNF and HLW: A Systematic Basis for Planning and Management at National, Regional and Community Levels (July 1996), Nevada NWPO.

use of large rail over small rail casks, would require greater investment to upgrade pool loading capabilities at more reactor sites.

**Cask Shipment (Master Code 2.1.1, 2.2.1, 2.3.1)**

Annual cask shipments by site and transportation mode/cask provide the basis for estimates of cask shipment miles and for truck or rail carrier costs, using revenues per ton-mile factors. Rail shipment miles are estimated based on default (least-time, using Class A railroads) routes from the origin site or the nearest railhead to Caliente. Highway shipment miles are based on the default (least-time, using interstate highways) routes from the origin site to Yucca Mountain. Each shipment includes a backhaul to the next pickup; backhaul milage is based on the average milage of one-way shipments for each cask type.

The tonnage includes the estimated weight of the loaded cask and its trailer or cask car, plus (in the case of rail shipments) the weight of buffer cars and ballast used in dedicated trains. The backhaul tonnage is adjusted for the weight of SNF or HLW removed at the central storage facility or repository. The revenues per ton-mile factors are based on an evaluation of information regarding the tonnage, revenue and average haul of general and hazmat rail and truck freight shipments received from the American Railroad Association and American Trucking Association. The rates for rail shipment used in this assessment are about five times general freight rates, and the rates for highway shipment are about three times general freight rates. These estimates may be conservatively low, given the special attention required in shipment of high-level radioactive waste, and the effects of dedicated train shipment on other freight traffic on Class A railroads.

**Shipment Escort (Master Code 2.1.2, 2.2.2, 2.3.2)**

This assessment assumes that each legal-weight truck cask shipment and each dedicated train is escorted. The costs are estimated on a per hour basis, considering the number of casks in the shipment and the average speed of the cross-country shipment.

**Shipment Inspection (Master Code 2.1.3, 2.2.3, 2.3.3.)**

This assessment assumes that each shipment is inspected twice—once en route at a designated crew change location or safe haven, and once on arrival at the central storage facility or repository in Nevada. Inspections include not only the casks but the shipment tackle, the truck trailers or rail cask cars, and the truck or locomotive. Inspection costs are estimated on a per inspection basis.

**Transportation Cask and Equipment Purchases (Master Code 2.1.4, 2.2.4, 2.3.4)**

This assessment assumes that casks and transportation equipment will be purchased for use exclusively in the shipment campaign. Purchases include transportation casks of the type and number required in a particular shipment year, the purchases of truck trailers and rail cask (or buffer) cars used in cross-country shipment, and the replacement of casks and equipment after 20 years—regardless of the level of use, but only if shipments continue to be made.

The requirement for casks-on-hand is the annual number of cask shipments of a particular type, divided by the annual number of round trips (turnover). We assume 15 round trips per year for all cask types, even though the particulars vary. (For example, the average one-way travel time is 49 hours for

LWT shipments versus 83 hours for small rail and 93 hours for large rail shipments. The shipment preparation and/or inspection for a dedicated train might be greater than for a LWT shipment). The estimated costs for casks and equipment are drawn from sources in the nuclear industry.

**Transportation Cask and Equipment Operations and Maintenance (Master Code 2.1.5, 2.2.5, 2.3.5)**

Annual operations and maintenance costs are estimated as a percentage of the initial purchase costs, but are applied only to the extent that the cask and equipment is in use in a particular year. The annual use of the cask and equipment inventory is estimated by comparing cask shipments with fleet capacity. The cask shipment capacity of the fleet is estimated by multiplying the number of casks in the inventory by annual turnover. Cask shipments divided by fleet capacity gives the fleet capacity in use. Except for HLW shipments, which are assumed to proceed (from four defense sites), at a steady 750 canisters per year, annual variation in cask shipments reduces the fleet capacity in use to under 50 percent.

**Transportation Cask and Equipment Decommissioning (Master Code 2.1.6, 2.2.6, 2.3.6)**

Decommissioning costs are incurred as the casks and equipment go out of service and are estimated as a percentage of original purchase costs. Rail cask cars and truck trailers are assumed to have some salvage value which offsets the decommissioning costs of the casks themselves.

**Heavy-Haul to Rail Head (Master Code 2.1.7)**

Several sites which, under the assumptions used in this assessment, would choose onsite storage option two do not or no longer have an onsite rail spur. The cost of heavy-haul to a nearby railhead is estimated based on a cost per shipment plus a cost per ton-mile, and is assumed to be the obligation of the Nuclear Waste Fund.

**Centralized Storage of SNF Arriving Uncanistered (Master Code 4.3.1)**

This assessment assumes that SNF arriving uncanistered at the centralized storage facility is placed in metal casks for above-ground storage. The metal casks are assumed to be similar to the NAC ST cask, with capacity for 57 BWR or 27 PWR assemblies. The number of such casks required is based on the cumulative inventory arriving at the central storage facility by legal-weight truck, less the cumulative inventory emplaced (assuming the same emplacement rates for SNF which arrives at the CSF canistered or uncanistered). The cost for metal casks is estimated on a per cask basis, assuming no operation and maintenance cost, and a need to replace only five percent after 20 years.

**Centralized Storage of SNF Arriving Canistered (Master Code 4.3.2)**

This assessment assumes that SNF arriving in dual-purpose rail canisters is placed in concrete bunkers or vaults for centralized above-ground storage. The cost for construction and decommissioning of concrete storage facilities is estimated on a per assembly basis, using factors consistent with those used in estimates of the incremental costs of onsite dry storage.

### Additional Canisters Required for Rail Shipment (Master Code 4.3.3)

Rail shipment sites which have (under onsite storage option one) used storage-only canisters or spent fuel pools for onsite dry storage require dual-purpose canisters for rail shipment. The cost of such canisters (consistent with the cost of those purchased for onsite dry storage) is incurred at pickup and is the obligation of the Nuclear Waste Fund.

## 3.6 COST ANALYSIS PROCEDURES: NEVADA COMPONENTS

Standard engineering analysis procedures were used to estimate the design, construction, equipment and operations costs of Nevada components of the DOE/OCRWM waste management program—intermodal transfer at Caliente, heavy-haul between Caliente and NTS Area 25, rail spur construction and operations between Caliente and Yucca Mountain, centralized storage at NTS Area 25, and geologic disposal. A design concept for each of these components was developed through review of DOE and other sources, then detailed in over 200 cost items, sub-items and elements. Each cost item or element was described or dimensioned, then costed in terms of units purchased at a specified unit cost. Unit costs were developed from standard construction and other industry sources. The allocation of item costs to years in which costs are incurred was based on the overall schedule for transport and emplacement assumed for this assessment and discussed in section 3.4, above.

### Intermodal Transfer Facility (Master Code 3.1)

Thirty-five cost items and elements are considered in estimating the cost of constructing and operating an intermodal transfer facility at Caliente. Major items include the construction of a rail spur to the site and the construction of rail sidings (20 car capacity); the purchase of two switch engines; the installation of a 150-ton crane, the construction of a wastewater treatment plant (1,500 person capacity) for the town of Caliente;* and the construction of a truck service center. Over 40 percent of total systems cost for this component is the cost of staff, utilities and equipment maintenance over a 62-month operations period.

### Heavy-Haul to NTS Area 25 (Master Code 3.2)

Twenty-four cost items and elements are considered in estimating the cost of heavy-haul from Caliente around the north and west sides of the Nellis Air Force Range to a central storage facility at NTS Area 25. Major costs include the construction of slow lanes (up and downgrade); the upgrading of existing road surface and selected road base and bridges; the purchase of major equipment for the heavy-haul operations (transporters, tractors, pusher trucks, escort vehicles, communications); and the consumables (tires, fuel, etc.) for the heavy-haul operation.

### Rail Spur Construction and Operation (Master Code 3.3)

The 365-mile rail spur from Caliente to Yucca Mountain is costed as a government owned and operated "short-line" railroad. Twenty-two cost items are considered, of which by far the largest is the construction of the 365-mile single track rail line. Other significant items include the cost of staff and other operations over a 33-year period; the design costs for the rail line and its ancillary facilities, the

* As specified in Senate Bill 104.

purchase of locomotives, signal systems and other major equipment; and cost of periodic overhaul of major equipment.

#### The Central Storage Facility (Master Code 4.0)

Thirty-eight cost items and elements are considered in estimating the cost of the facility for centralized above-ground storage at NTS Area 25. By far, the largest is the cost of metal and concrete storage for SNF arriving canistered and uncanistered but not yet emplaced (see section 3.5, above). Other major items include the construction of storage pads and access alleys; the construction of a large reinforced concrete transfer facility (used in part as a staging location for the accumulation of uncanistered SNF to be loaded into metal storage casks); and the cost of staff, utilities and equipment maintenance during operation.

#### The Repository (Master Code 5.0)

Ninety cost items and elements are considered in projecting the cost for completing site characterization at Yucca Mountain and for construction and operation of the geologic repository. The major surface facility items are the construction of a waste handling building and a disposal container receiving facility. Major underground construction includes the cost of driving service and emplacement drifts and turnouts. The cost of staff, utilities and equipment maintenance (above-ground and underground) during emplacement, care-taking and closure/decommissioning is a major cost, as is the cost of designing surface and underground facilities (upfront and ongoing during operations). The purchase of about 11,000 containers for emplacement of SNF is also a major cost.

## 3.7 COST PROCEDURES: OTHER PROGRAM COMPONENTS

Several other program components considered in previous DOE estimates of TSLCC do not lend themselves to cost assessment via the site-by-site analysis used for onsite storage and transportation or the engineering cost analysis used for Nevada components.

#### Technical Assistance Training: NWPA Section 180 (c) (Master Code 2.4)

This analysis estimated the cost of technical assistance training required by NWPA Section 180(c) to prepare affected states, counties and Indian tribes to effectively prepare for and respond to emergencies (accidents or incidents) in a shipment campaign involving (under assumptions used in this assessment) 30,400 cask shipments and 65 million cask shipment miles by rail and truck. The state, local and Tribal responsibilities are for "awareness" and "first response", and do not include the full cost of responding to, or cleaning-up after, accidents or incidents.

Costs are estimated in terms of estimated annual payments to 40 states,* 10 particularly affected counties, 4 regional organizations of states, and an unspecified number of Indian Tribes and organizations. The costs also include contracts and agreements (with federal agencies and labs) to prepare and deliver the training.

Costs are assumed to begin two years ahead of the first shipment (2003 in this assessment) and to extend at a relatively high "gear-up"level over ten years, then to continue at a lower "maintenance"

* Two groups of five states are assumed to be affected to a greater degree than the remaining 30.

level throughout the SNF shipment campaign, and at an even lower level during the remaining years of the HLW shipment campaign.

### Repository Site Characterization (Master Code 5.1)

Through FY 1996, DOE expended $4,376 million (FY'96$) on characterization of the nation's first geologic repository for high-level radioactive wastes. Of this, $2,768 million (63.3 percent) was spent at Yucca Mountain, $691 million (15.8 percent) at the Hanford site in Washington, and $741 million (16.9 percent) at the Deaf Smith County site in Texas. An additional $158 million was spent in the mid-1980's in preliminary characterization for the nation's second repository.

In 1991, DOE estimated that characterization at Yucca Mountain would require expenditure of $6,531 million, of which $1,869 million is included in DOE's funding request for FY 1997 or its projected funding requirements for FY 1998-2002. The difference between the 1991 estimate ($6,531 million) and the expenditure through FY 1996 ($4,376 million) is included as the remaining expenditure for site characterization in this assessment. This estimate is assumed to include contingency and project management. The cost of the recently-authorized east-west tunnel in the exploratory studies facility (estimated via engineering costing procedures) is included in addition to the site characterization estimates from 1991. Note that DOE's estimate of funding requirements for site characterization "reflect activities specified in the revised Program Plan through submission of a license application to the Nuclear Regulatory Commission"*—implying that site characterization does not include activities subsequent to submission of the license application, or not reflected in the current Program Plan.

### Other Development and Evaluation Costs (Master Code 6.0)

All DOE expenditure to-date has been "development and evaluation"—a broad category which includes the exploratory studies facility at Yucca Mountain, site characterization at Yucca Mountain and other sites, and various planning activities related to waste acceptance, transportation, and interim or monitored retrievable storage.

In this assessment, projected expenditure for development and evaluation are specified for Yucca Mountain site characterization (master code 5.1) or included in estimates for program management. However, DOE's 9/95 TSLCC included estimates for NRC fees, support of the Nuclear Waste Technical Review Board and the Nuclear Waste Negotiator (whose activities began in 1990 and were terminated in 1995). This assessment uses DOE's estimates (adjusted to FY'96$) for these "other development and evaluation costs"—even though the waste management assumptions for this assessment could require activity by NRC, the NWTRB and other review or regulatory agencies which was not anticipated in 1995.

### Other Program Costs (Master Code 7.0)

This assessment uses DOE's 9/95 estimates (adjusted to FY'96$) for Payments Equal to Taxes and Benefits. However, several program components required by the waste management assumptions of this assessment (intermodal transfer, heavy-haul, rail spur and centralized storage) were not anticipated in previous estimates of TSLCC. For these components, PETT was estimated based on the direct construction and major equipment costs of the facilities that would form an assessment base were the

* Civilian Radioactive Waste Management Program: Funding Requirements (FY 1997-FY 2002), Table 3.

facilities privately-owned and operated. Other factors are the years in which PETT is applicable, the assessment rate (35 percent in Nevada), tax rates (selected FY'96 unit tax rates in Lincoln and Nye Counties), and the portion of the rail spur likely to be located in the two counties.

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# APPENDIX A: ACRONYMS

We have attempted to explain acronyms in the body of the text. The following is a summary list and explanation of the more commonly used acronyms:

CSF: Central Storage Facility
A facility for above-ground dry storage of large volumes of spent fuel previously located in spent fuel pools or dry storage at multiple reactor sites. The facility would include equipment for opening and reloading casks and canisters, but not for consolidation of spent fuel or other operations envisioned for the Monitored Retrievable Storage (MRS) facility specified in the NWPA.

DOE: The US Department of Energy
In this report "DOE" generally refers to the Department's Office of Civilian Radioactive Waste Management (DOE/OCRWM) established by the Nuclear Waste Policy Act to dispose of spent nuclear fuel and other highly radioactive wastes.

ESF: The Exploratory Studies Facility
A five-mile tunnel into and across the emplacement block within Yucca Mountain, in which DOE will conduct tests and experiments critical to determining the suitability of the mountain for permanent geologic disposal.

HLW: High-Level Waste
Highly radioactive material, containing fission products, traces of uranium and plutonium and other transuranic elements, that results from chemical reprocessing of spent fuel.

LWT: Legal-Weight Truck
Legal weight on the nation's highways is generally 80,000 lbs, or 40 tons, including the payload, shipping tackle, truck and trailer.

MTU: Metric Tons Uranium

NRC: The Nuclear Regulatory Commission
Previously part of the Atomic Energy Commission, the NRC is the regulatory body responsible for licensing the repository, nuclear reactors and their pools and dry storage facilities, a centralized dry storage facility, and transportation casks and canisters.

NWF: The Nuclear Waste Fund
Established by the Nuclear Waste Policy Act (Section 302) with revenues from the one mil per kilowatt hour fee on sales of nuclear-generated power to ensure full recovery of the costs of long-term storage and permanent disposal of commercial SNF.

NWPA: The Nuclear Waste Policy Act of 1982
The act is Public Law 97-425, January 7, 1983. It established DOE/OCRWM and its responsibilities to dispose of commercial spent fuel, in return for the payment of fees on sales of nuclear generated power. The act was amended by Title V of Public Law 100-203 in December 1997. Proposed legislation in the Senate (S-104) and House (HR-1270) would replace the NWPA.

PETT: Payments Equal to Taxes
Section 116(c)(3) of the NWPA, requires DOE to grant to the State of Nevada or any affected unit of government amounts equal to the taxes on comparable non-Federal real property and industrial activity.

SNF: Spent Nuclear Fuel
Fuel that has been irradiated in a nuclear reactor to the point that it no longer contributes efficiently to the nuclear chain reaction. Spent fuel is thermally hot and highly radioactive.

TSLCC: Total System Life Cycle Cost
Life cycle costing was created during the 1970's to consider the ownership (operations) as well as the acquisition (design and construction) costs of military systems, and to compare systems over their "life cycle", taking into account the value of money spent at various points in time. See "Life Cycle Costing: Techniques, Models and Applications" by B.S. Dhillon, 1989.

# APPENDIX B: TOTAL SYSTEM COSTS: FY 1983-FY 2071

The table presents annual and cumulative estimates of total systems costs—distinguishing repository and site characterization from other program activity, and comparing estimates of the independent cost assessment with those of DOE published in September 1995. The DOE estimates are those presented in the September 1995 report, adjusted to FY'96$. The independent cost analysis combines two sources:

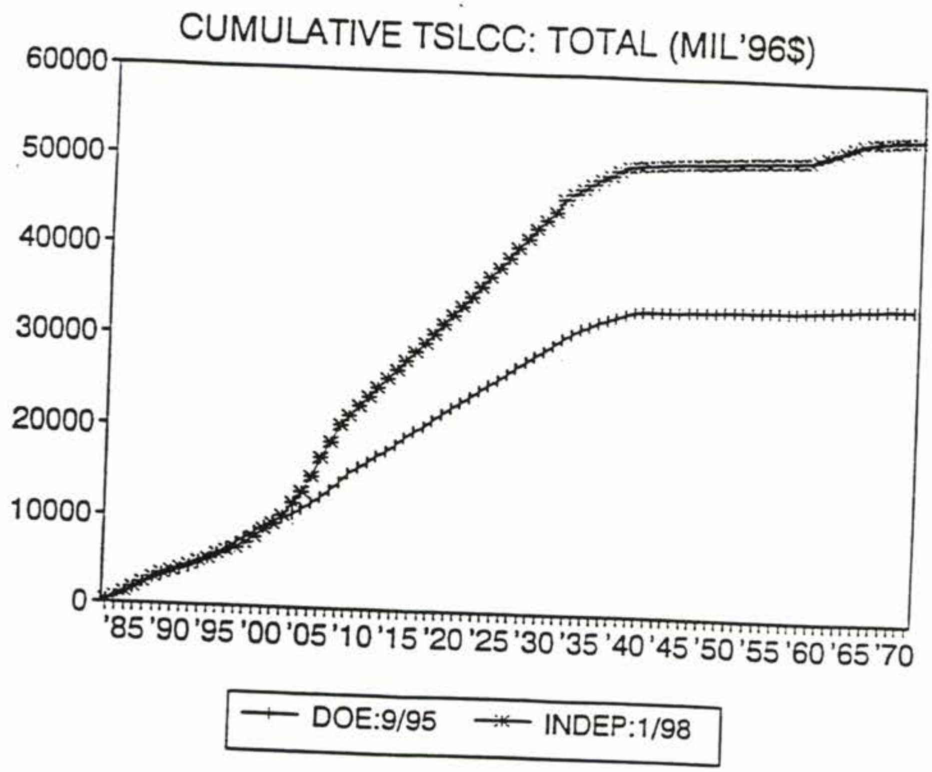
- A tabulation of actual program expenditures (compiled from SOAR #9 reports) from FY 1983 through FY 1996, adjusted to FY'96$.
- Projected expenditures from FY 1997 forward, as discussed in Chapter 3, in FY'96$. The charts compare cumulative total systems costs, distinguishing repository from other program activity.

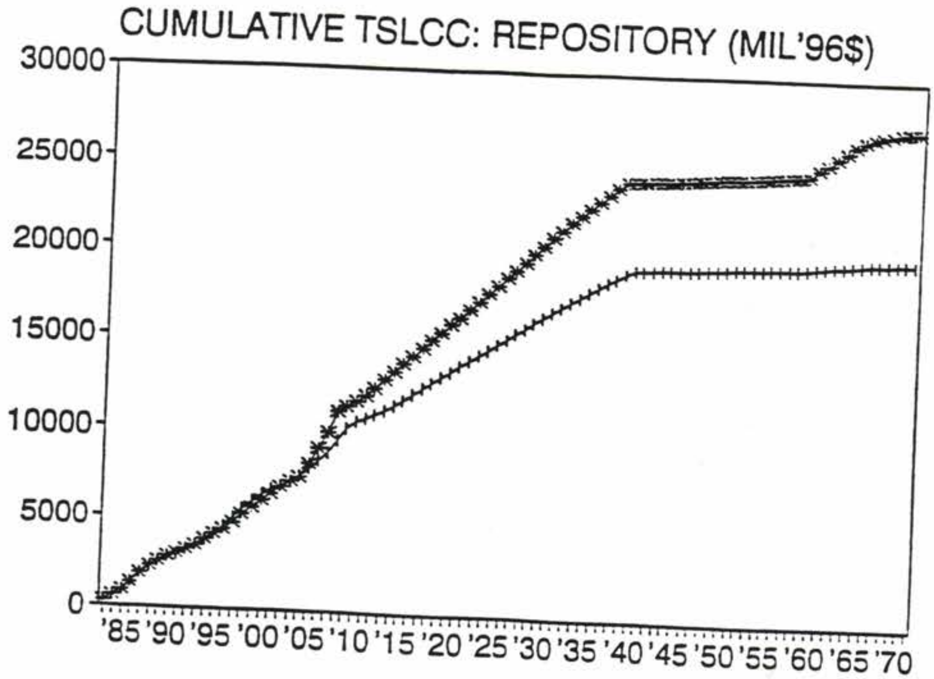
**INDEPENDET COST ASSESSMENT: ACTUAL DOE/OCRWM EXPENSES (FY'83-'96); PROJECTED EXPENSES (FY'97-'71)**
**DOE/OCRWM TSLCC (9/95): MIL CONSTANT (FY'96) $**

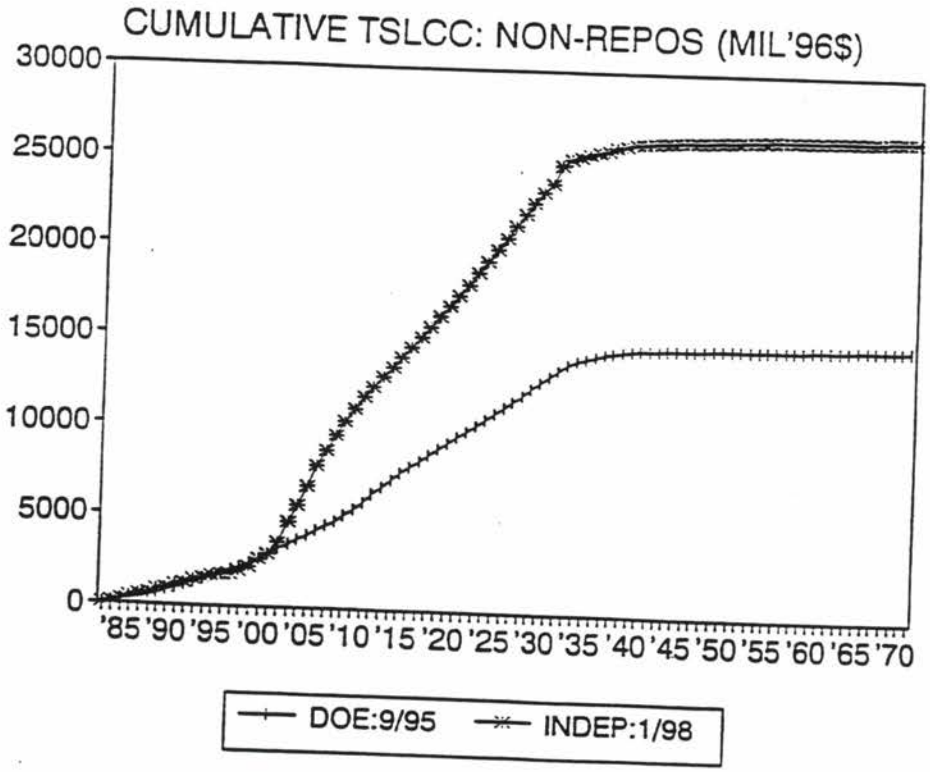
| | Annual Expenses.... INDEP COST ASSESS | | | DOE TSLCC: 9/95 | | | Cumulative Expenses.... INDEP COST ASSESS | | | DOE TSLCC: 9/95 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TOTAL | Reposl SiteC | Other | TOTAL | Repos | Other | TOTAL | Reposl SiteC | Other | TOTAL | Repos | Other |
| 1983 | 280.9 | 248.0 | 32.9 | 250.7 | 233.0 | 17.6 | 281 | 248 | 33 | 251 | 233 | 18 |
| 1984 | 417.6 | 332.6 | 85.0 | 378.5 | 310.7 | 67.8 | 698 | 581 | 118 | 629 | 544 | 85 |
| 1985 | 461.5 | 322.8 | 138.7 | 425.1 | 327.4 | 97.7 | 1160 | 903 | 257 | 1054 | 871 | 183 |
| 1986 | 567.9 | 416.6 | 151.3 | 528.8 | 422.4 | 106.4 | 1728 | 1320 | 408 | 1583 | 1294 | 290 |
| 1987 | 649.7 | 503.8 | 145.9 | 610.9 | 508.8 | 102.0 | 2378 | 1824 | 554 | 2194 | 1802 | 392 |
| 1988 | 508.1 | 394.5 | 113.6 | 478.4 | 381.7 | 96.7 | 2886 | 2218 | 667 | 2672 | 2184 | 488 |
| 1989 | 469.0 | 299.3 | 169.7 | 413.8 | 284.1 | 129.7 | 3355 | 2518 | 837 | 3086 | 2468 | 618 |
| 1990 | 371.9 | 249.6 | 122.4 | 394.9 | 239.0 | 155.9 | 3727 | 2767 | 960 | 3481 | 2707 | 774 |
| 1991 | 348.1 | 211.0 | 137.1 | 366.6 | 214.7 | 151.8 | 4075 | 2978 | 1097 | 3848 | 2922 | 926 |
| 1992 | 364.6 | 225.2 | 139.4 | 392.0 | 225.3 | 166.7 | 4439 | 3203 | 1236 | 4240 | 3147 | 1092 |
| 1993 | 402.6 | 250.0 | 152.6 | 431.0 | 251.2 | 179.8 | 4842 | 3453 | 1389 | 4671 | 3399 | 1272 |
| 1994 | 428.7 | 295.7 | 133.1 | 460.3 | 295.6 | 164.8 | 5271 | 3749 | 1522 | 5131 | 3694 | 1437 |
| 1995 | 523.1 | 388.9 | 134.1 | 558.3 | 382.1 | 176.2 | 5794 | 4138 | 1656 | 5689 | 4076 | 1613 |
| 1996 | 334.3 | 237.7 | 96.5 | 646.0 | 464.8 | 181.2 | 6128 | 4376 | 1752 | 6335 | 4541 | 1794 |
| 1997 | 420.9 | 389.9 | 31.0 | 693.9 | 503.5 | 190.4 | 6549 | 4766 | 1783 | 7029 | 5045 | 1985 |
| 1998 | 573.4 | 417.1 | 156.3 | 684.5 | 481.8 | 202.7 | 7122 | 5183 | 1940 | 7714 | 5526 | 2187 |
| 1999 | 645.6 | 417.8 | 227.8 | 668.4 | 459.7 | 208.7 | 7768 | 5600 | 2167 | 8382 | 5986 | 2396 |
| 2000 | 892.7 | 415.4 | 477.3 | 609.4 | 394.3 | 215.1 | 8661 | 6016 | 2645 | 8991 | 6380 | 2611 |
| 2001 | 669.8 | 415.4 | 254.5 | 606.6 | 291.4 | 315.2 | 9330 | 6431 | 2899 | 9598 | 6672 | 2926 |
| 2002 | 1028.2 | 380.2 | 648.0 | 485.7 | 215.4 | 270.2 | 10359 | 6811 | 3547 | 10084 | 6887 | 3197 |
| 2003 | 1488.4 | 365.6 | 1122.8 | 472.9 | 215.1 | 257.8 | 11847 | 7177 | 4670 | 10557 | 7102 | 3454 |
| 2004 | 1180.5 | 240.8 | 939.7 | 588.4 | 330.0 | 258.4 | 13028 | 7418 | 5610 | 11145 | 7432 | 3713 |
| 2005 | 1792.9 | 755.6 | 1037.3 | 675.0 | 423.2 | 251.8 | 14820 | 8173 | 6647 | 11820 | 7856 | 3965 |
| 2006 | 2031.3 | 853.7 | 1177.6 | 698.8 | 458.3 | 240.5 | 16852 | 9027 | 7825 | 12519 | 8314 | 4205 |
| 2007 | 1721.3 | 876.8 | 844.5 | 770.4 | 481.2 | 289.2 | 18573 | 9904 | 8669 | 13289 | 8795 | 4494 |
| 2008 | 1998.7 | 1120.8 | 877.8 | 931.0 | 667.4 | 253.6 | 20572 | 11025 | 9547 | 14220 | 9462 | 4758 |
| 2009 | 1052.7 | 269.9 | 782.8 | 982.1 | 663.1 | 319.0 | 21624 | 11295 | 10330 | 15202 | 10126 | 5077 |
| 2010 | 996.5 | 301.5 | 695.0 | 733.2 | 373.5 | 359.7 | 22621 | 11596 | 11025 | 15936 | 10499 | 5436 |
| 2011 | 1044.6 | 350.4 | 694.1 | 598.1 | 185.9 | 412.1 | 23666 | 11947 | 11719 | 16534 | 10685 | 5849 |
| 2012 | 1007.1 | 413.6 | 593.4 | 638.4 | 210.2 | 428.2 | 24673 | 12360 | 12312 | 17172 | 10895 | 6277 |
| 2013 | 1012.9 | 451.4 | 561.4 | 641.7 | 235.7 | 406.0 | 25685 | 12812 | 12874 | 17814 | 11131 | 6683 |
| 2014 | 953.4 | 448.7 | 504.7 | 699.0 | 277.7 | 421.2 | 26639 | 13260 | 13378 | 18513 | 11409 | 7104 |
| 2015 | 1030.0 | 448.7 | 581.4 | 734.2 | 326.7 | 407.5 | 27669 | 13709 | 13960 | 19247 | 11735 | 7511 |
| 2016 | 1008.3 | 448.7 | 559.6 | 677.7 | 324.3 | 353.5 | 28677 | 14158 | 14519 | 19925 | 12060 | 7865 |
| 2017 | 1031.7 | 448.7 | 583.0 | 671.8 | 323.6 | 348.1 | 29709 | 14606 | 15102 | 20596 | 12383 | 8213 |
| 2018 | 1032.7 | 450.6 | 582.1 | 669.4 | 318.7 | 350.8 | 30742 | 15057 | 15685 | 21266 | 12702 | 8564 |
| 2019 | 1061.5 | 448.7 | 612.8 | 660.6 | 317.1 | 343.5 | 31803 | 15506 | 16297 | 21926 | 13019 | 8907 |
| 2020 | 1047.0 | 448.7 | 598.3 | 662.5 | 316.0 | 346.5 | 32850 | 15954 | 16896 | 22589 | 13335 | 9254 |
| 2021 | 1034.5 | 448.7 | 585.8 | 663.7 | 316.6 | 347.2 | 33884 | 16403 | 17482 | 23253 | 13652 | 9601 |
| 2022 | 1047.9 | 448.7 | 599.2 | 660.3 | 318.4 | 341.9 | 34932 | 16852 | 18081 | 23913 | 13970 | 9943 |
| 2023 | 1200.9 | 465.7 | 735.2 | 665.9 | 316.1 | 349.8 | 36133 | 17317 | 18816 | 24579 | 14286 | 10293 |
| 2024 | 1066.8 | 448.7 | 618.2 | 663.9 | 317.4 | 346.5 | 37200 | 17766 | 19434 | 25243 | 14604 | 10639 |
| 2025 | 1118.0 | 448.7 | 669.4 | 663.8 | 315.5 | 348.3 | 38318 | 18215 | 20103 | 25906 | 14919 | 10987 |
| 2026 | 1083.4 | 448.7 | 634.7 | 667.5 | 315.5 | 352.0 | 39402 | 18663 | 20738 | 26574 | 15235 | 11339 |
| 2027 | 1139.1 | 448.7 | 690.4 | 667.1 | 318.3 | 348.8 | 40541 | 19112 | 21429 | 27241 | 15553 | 11688 |
| 2028 | 1097.6 | 450.6 | 647.1 | 659.2 | 316.7 | 342.5 | 41638 | 19563 | 22076 | 27900 | 15870 | 12031 |
| 2029 | 1102.2 | 448.7 | 653.5 | 674.7 | 319.4 | 355.3 | 42740 | 20011 | 22729 | 28575 | 16189 | 12386 |
| 2030 | 1080.3 | 448.7 | 631.6 | 656.8 | 302.3 | 354.4 | 43821 | 20460 | 23361 | 29232 | 16491 | 12740 |
| 2031 | 918.9 | 448.7 | 470.2 | 636.6 | 290.1 | 346.5 | 44740 | 20909 | 23831 | 29868 | 16781 | 13087 |
| 2032 | 1464.8 | 448.7 | 1016.2 | 652.9 | 292.5 | 360.5 | 46204 | 21357 | 24847 | 30521 | 17074 | 13447 |
| 2033 | 767.4 | 451.4 | 316.1 | 655.3 | 290.5 | 364.8 | 46972 | 21809 | 25163 | 31177 | 17364 | 13812 |
| 2034 | 554.2 | 401.8 | 152.5 | 502.9 | 293.4 | 209.6 | 47526 | 22210 | 25316 | 31680 | 17658 | 14022 |
| 2035 | 588.3 | 401.8 | 186.6 | 430.2 | 290.8 | 139.3 | 48114 | 22612 | 25502 | 32110 | 17949 | 14161 |
| 2036 | 519.8 | 401.8 | 118.0 | 407.7 | 290.5 | 117.2 | 48634 | 23014 | 25620 | 32517 | 18239 | 14278 |
| 2037 | 520.3 | 401.8 | 118.5 | 411.2 | 284.7 | 126.5 | 49155 | 23416 | 25739 | 32929 | 18524 | 14405 |
| 2038 | 522.1 | 403.6 | 118.5 | 341.4 | 236.5 | 104.9 | 49677 | 23819 | 25857 | 33270 | 18760 | 14510 |
| 2039 | 442.2 | 323.2 | 119.0 | 343.6 | 247.6 | 96.0 | 50119 | 24143 | 25976 | 33614 | 19008 | 14606 |
| 2040 | 163.3 | 51.9 | 111.4 | 305.9 | 241.7 | 64.1 | 50282 | 24194 | 26088 | 33919 | 19250 | 14670 |
| 2041 | 80.6 | 31.7 | 48.9 | 56.3 | 17.4 | 38.9 | 50363 | 24226 | 26137 | 33976 | 19267 | 14709 |
| 2042 | 57.8 | 24.2 | 33.6 | 24.7 | 12.8 | 11.8 | 50420 | 24250 | 26170 | 34000 | 19280 | 14721 |
| 2043 | 75.7 | 24.2 | 51.5 | 24.5 | 12.8 | 11.7 | 50496 | 24274 | 26222 | 34025 | 19293 | 14732 |
| 2044 | 58.1 | 24.2 | 34.0 | 24.4 | 12.8 | 11.6 | 50554 | 24299 | 26256 | 34049 | 19305 | 14744 |
| 2045 | 39.6 | 24.2 | 15.4 | 24.3 | 12.8 | 11.4 | 50594 | 24323 | 26271 | 34074 | 19318 | 14755 |

**INDEPENDET COST ASSESSMENT: ACTUAL DOE/OCRWM EXPENSES (FY'83-'96); PROJECTED EXPENSES (FY'97-'71) DOE/OCRWM TSLCC (9/95): MIL CONSTANT (FY'96) $**

| | Annual Expenses.... INDEP COST ASSESS | | | DOE TSLCC: 9/95 | | | Cumulative Expenses.... INDEP COST ASSESS | | | DOE TSLCC: 9/95 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TOTAL | Reposl SiteC | Other | TOTAL | Repos | Other | TOTAL | Reposl SiteC | Other | TOTAL | Repos | Other |
| 2046 | 38.1 | 24.2 | 13.9 | 24.1 | 12.8 | 11.3 | 50632 | 24347 | 26285 | 34098 | 19331 | 14767 |
| 2047 | 39.3 | 24.2 | 15.1 | 24.0 | 12.8 | 11.2 | 50671 | 24371 | 26300 | 34122 | 19344 | 14778 |
| 2048 | 49.8 | 36.4 | 13.4 | 31.3 | 20.2 | 11.1 | 50721 | 24407 | 26313 | 34153 | 19364 | 14789 |
| 2049 | 46.3 | 36.4 | 9.9 | 31.2 | 20.2 | 10.9 | 50767 | 24444 | 26323 | 34184 | 19384 | 14800 |
| 2050 | 45.0 | 33.3 | 11.6 | 29.2 | 18.4 | 10.8 | 50812 | 24477 | 26335 | 34213 | 19403 | 14811 |
| 2051 | 34.9 | 24.2 | 10.7 | 23.5 | 12.8 | 10.7 | 50847 | 24501 | 26346 | 34237 | 19415 | 14821 |
| 2052 | 76.9 | 24.2 | 52.8 | 23.4 | 12.8 | 10.6 | 50924 | 24526 | 26399 | 34260 | 19428 | 14832 |
| 2053 | 33.6 | 24.2 | 9.4 | 23.3 | 12.8 | 10.5 | 50958 | 24550 | 26408 | 34284 | 19441 | 14842 |
| 2054 | 33.5 | 24.2 | 9.3 | 23.2 | 12.8 | 10.4 | 50991 | 24574 | 26417 | 34307 | 19454 | 14853 |
| 2055 | 38.3 | 24.2 | 14.1 | 23.1 | 12.8 | 10.3 | 51029 | 24598 | 26431 | 34330 | 19467 | 14863 |
| 2056 | 32.8 | 23.7 | 9.1 | 23.0 | 12.8 | 10.2 | 51062 | 24622 | 26440 | 34353 | 19480 | 14873 |
| 2057 | 32.7 | 23.7 | 9.0 | 22.9 | 12.8 | 10.1 | 51095 | 24645 | 26449 | 34376 | 19492 | 14883 |
| 2058 | 44.8 | 36.0 | 8.9 | 30.3 | 20.2 | 10.0 | 51140 | 24681 | 26458 | 34406 | 19513 | 14893 |
| 2059 | 46.4 | 37.6 | 8.8 | 31.2 | 21.2 | 9.9 | 51186 | 24719 | 26467 | 34437 | 19534 | 14903 |
| 2060 | 403.0 | 393.6 | 9.4 | 73.1 | 61.5 | 11.6 | 51589 | 25113 | 26477 | 34510 | 19595 | 14915 |
| 2061 | 339.7 | 330.4 | 9.3 | 63.1 | 51.6 | 11.5 | 51929 | 25443 | 26486 | 34573 | 19647 | 14926 |
| 2062 | 339.6 | 330.4 | 9.2 | 63.0 | 51.6 | 11.4 | 52268 | 25773 | 26495 | 34636 | 19699 | 14938 |
| 2063 | 339.5 | 330.4 | 9.1 | 62.9 | 51.6 | 11.3 | 52608 | 26104 | 26504 | 34699 | 19750 | 14949 |
| 2064 | 339.5 | 330.4 | 9.1 | 62.8 | 51.6 | 11.3 | 52947 | 26434 | 26513 | 34762 | 19802 | 14960 |
| 2065 | 339.4 | 330.4 | 9.0 | 62.7 | 51.6 | 11.2 | 53287 | 26765 | 26522 | 34825 | 19853 | 14972 |
| 2066 | 151.8 | 142.9 | 8.9 | 33.2 | 22.1 | 11.1 | 53439 | 26907 | 26531 | 34858 | 19875 | 14983 |
| 2067 | 136.6 | 127.7 | 8.8 | 30.7 | 19.7 | 11.0 | 53575 | 27035 | 26540 | 34889 | 19895 | 14994 |
| 2068 | 136.5 | 127.7 | 8.8 | 30.7 | 19.7 | 11.0 | 53712 | 27163 | 26549 | 34919 | 19915 | 15005 |
| 2069 | 136.4 | 127.7 | 8.7 | 30.6 | 19.7 | 10.9 | 53848 | 27291 | 26557 | 34950 | 19934 | 15016 |
| 2070 | 32.3 | 23.7 | 8.6 | 14.2 | 3.3 | 10.8 | 53881 | 27314 | 26566 | 34964 | 19938 | 15026 |
| 2071 | 24.9 | 16.4 | 8.5 | 13.0 | 2.2 | 10.8 | 53905 | 27331 | 26575 | 34977 | 19940 | 15037 |
| TOT | 53905 | 27331 | 26575 | 34977 | 19940 | 15037 | | | | | | |
| '97+ | 47777 | 22955 | 24822 | 28642 | 15399 | 13243 | | | | | | |
| %97+ | 88.6% | 84.0% | 93.4% | 81.9% | 77.2% | 88.1% | | | | | | |




CUMULATIVE TSLCC: REPOSITORY (MIL'96$)
30000
25000
20000
15000
10000
5000
0
'85 '90 '95 '00 '05 '10 '15 '20 '25 '30 '35 '40 '45 '50 '55 '60 '65 '70


CUMULATIVE TSLCC: NON-REPOS (MIL'96$)
30000
25000
20000
15000
10000
5000
0
'85 '90 '95 '00 '05 '10 '15 '20 '25 '30 '35 '40 '45 '50 '55 '60 '65 '70
DOE:9/95
INDEP:1/98

# APPENDIX C: PROJECTED TOTAL SYSTEMS COSTS: FY 1997 - FY 2071 (MIL'96$)

The Table presents projected systems costs by "master code" categories. Master code categories were used in the assembly of estimates developed by various costing procedures (discussed in Section 3.4-6). The total in this instance is the total *projected* costs for FY 1997 through FY 2071. These estimates exclude costs which are the responsibility of other offices within DOE (e.g., the vitrification, canistering and interim storage of HLW), or of nuclear utilities (e.g., the cost for onsite storage of SNF that utilities are and will be required to store even if pickup had begun in 1998 and proceeded at S-104 rates). The table also presents the distribution of projected expenses, a calculation of the net present value of the projected costs streams (assuming three percent real interest rate), and the NPV percentage of total projected costs in constant dollar terms.

## THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM: PROJECTED PROGRAM COSTS (FY 1997-FY 2071: MIL'96$)

| MASTER | Description | Total | %total | %categ | NPV | NPV%TOT |
|---|---|---|---|---|---|---|
| 1.0 | ONSITE STORAGE COSTS | 4278.9 | 9.0% | 100.0% | 2215.5 | 51.8% |
| 1.1 | Commercial SNF in Que | 3886.1 | 8.1% | 90.8% | 1970.5 | 50.7% |
| 1.1.1 | Dry Storage | 575.9 | 1.2% | 13.5% | 360.1 | 62.5% |
| 1.1.1.1 | Opt 1/LWT: 26 sites | 133.0 | 0.3% | 3.1% | 85.1 | 64.0% |
| 1.1.1.2 | Opt 1/R125: 17 sites | 100.6 | 0.2% | 2.4% | 64.6 | 64.3% |
| 1.1.1.3 | Opt 2/R125: 11 sites | 202.3 | 0.4% | 4.7% | 125.2 | 61.9% |
| 1.1.1.4 | Opt 1/R75: 14 sites | 32.1 | 0.1% | 0.8% | 21.9 | 68.3% |
| 1.1.1.5 | Opt 2/R75: 5 sites | 108.0 | 0.2% | 2.5% | 63.2 | 58.5% |
| 1.1.2 | Pool Op after Reactor Shutdn | 3273.2 | 6.9% | 76.5% | 1582.5 | 48.3% |
| 1.1.2.1 | Opt 1/LWT: 26 sites | 1350.9 | 2.8% | 31.6% | 674.9 | 50.0% |
| 1.1.2.2 | Opt 1/R125: 17 sites | 799.3 | 1.7% | 18.7% | 349.7 | 43.7% |
| 1.1.2.3 | Opt 2/R125: 11 sites | 236.8 | 0.5% | 5.5% | 130.6 | 55.1% |
| 1.1.2.4 | Opt 1/R75: 14 sites | 757.3 | 1.6% | 17.7% | 353.9 | 46.7% |
| 1.1.2.5 | Opt 2/R75: 5 sites | 129.0 | 0.3% | 3.0% | 73.5 | 57.0% |
| 1.1.3 | Pool Loading Upgrades | 37.0 | 0.1% | 0.9% | 27.9 | 75.4% |
| 1.1.3.1 | Opt 1/LWT: 26 sites | 1.0 | 0.0% | 0.0% | 0.8 | 79.3% |
| 1.1.3.2 | Opt 1/R125: 17 sites | 8.7 | 0.0% | 0.2% | 5.9 | 68.0% |
| 1.1.3.3 | Opt 2/R125: 11 sites | 17.6 | 0.0% | 0.4% | 13.6 | 77.0% |
| 1.1.3.4 | Opt 1/R75: 14 sites | 0.9 | 0.0% | 0.0% | 0.7 | 83.7% |
| 1.1.3.5 | Opt 2/R75: 5 sites | 8.7 | 0.0% | 0.2% | 6.8 | 78.5% |
| 1.2 | DOE SNF & SNF not in Que | 392.8 | 0.8% | 9.2% | 245.1 | 62.4% |
| 1.2.1 | Dry Storage | 5.4 | 0.0% | 0.1% | 4.3 | 80.3% |
| 1.2.2 | Pool Op after Reactor Shutdn | 387.4 | 0.8% | 9.1% | 240.7 | 62.1% |
| 1.2.3 | Pool Loading Upgrades | 0.0 | 0.0% | 0.0% | 0.0 | NA |
| 1.3 | DOE High-Level Waste | NA | 0.0% | 0.0% | 0.0 | NA |
| | | ------ | ------ | ------ | ------ | ------ |
| 2.0 | X-COUNTRY TRANSPORTATION | 5968.2 | 12.5% | 100.0% | 3103.7 | 52.0% |
| 2.1 | Commercial SNF in Que | 4269.3 | 8.9% | 71.5% | 2355.1 | 55.2% |
| 2.1.1 | Cask Shipment Costs | 3060.3 | 6.4% | 51.3% | 1683.1 | 55.0% |
| 2.1.1.1 | Legal-Wt Truck | 1870.6 | 3.9% | 31.3% | 1056.4 | 56.5% |
| 2.1.1.2 | Large Rail | 571.5 | 1.2% | 9.6% | 301.6 | 52.8% |
| 2.1.1.3 | Small Rail | 618.1 | 1.3% | 10.4% | 325.1 | 52.6% |
| 2.1.2 | Shipment Escort Costs | 158.4 | 0.3% | 2.7% | 88.0 | 55.5% |
| 2.1.2.1 | Legal-Wt Truck | 115.7 | 0.2% | 1.9% | 65.5 | 56.6% |
| 2.1.2.2 | Large Rail | 17.6 | 0.0% | 0.3% | 9.3 | 52.9% |
| 2.1.2.3 | Small Rail | 25.1 | 0.1% | 0.4% | 13.2 | 52.5% |
| 2.1.3 | Cask Inspection Costs | 73.4 | 0.2% | 1.2% | 40.2 | 54.8% |
| 2.1.3.1 | Legal-Wt Truck | 44.4 | 0.1% | 0.7% | 25.0 | 56.3% |
| 2.1.3.2 | Large Rail | 12.8 | 0.0% | 0.2% | 6.7 | 52.7% |
| 2.1.3.3 | Small Rail | 16.2 | 0.0% | 0.3% | 8.5 | 52.7% |
| 2.1.4 | Cask & Equip Purchases | 560.8 | 1.2% | 9.4% | 333.3 | 59.4% |
| 2.1.4.1 | Legal-Wt Truck | 290.5 | 0.6% | 4.9% | 177.0 | 60.9% |
| 2.1.4.2 | Large Rail | 125.9 | 0.3% | 2.1% | 72.8 | 57.8% |
| 2.1.4.3 | Small Rail | 144.3 | 0.3% | 2.4% | 83.6 | 57.9% |
| 2.1.5 | Cask & Equip O&M | 327.0 | 0.7% | 5.5% | 178.1 | 54.5% |
| 2.1.5.1 | Legal-Wt Truck | 162.9 | 0.3% | 2.7% | 91.6 | 56.3% |
| 2.1.5.2 | Large Rail | 77.9 | 0.2% | 1.3% | 41.0 | 52.7% |
| 2.1.5.3 | Small Rail | 86.3 | 0.2% | 1.4% | 45.5 | 52.7% |
| 2.1.6 | Cask & Equip Decomm | 78.1 | 0.2% | 1.3% | 25.7 | 32.9% |
| 2.1.6.1 | Legal-Wt Truck | 41.4 | 0.1% | 0.7% | 14.0 | 33.7% |
| 2.1.6.2 | Large Rail | 16.8 | 0.0% | 0.3% | 5.4 | 32.0% |
| 2.1.6.3 | Small Rail | 19.8 | 0.0% | 0.3% | 6.3 | 32.1% |
| 2.1.7 | Hvy Haul to Railhead | 11.4 | 0.0% | 0.2% | 6.6 | 58.5% |
| 2.2 | DOE Spent Nuclear Fuel | 590.1 | 1.2% | 9.9% | 197.4 | 33.5% |
| 2.2.1 | Cask Shipment Costs | 196.3 | 0.4% | 3.3% | 67.4 | 34.3% |
| 2.2.2 | Shipment Escort Costs | 10.0 | 0.0% | 0.2% | 3.4 | 34.3% |
| 2.2.3 | Cask Inspection Costs | 6.5 | 0.0% | 0.1% | 2.2 | 34.3% |
| 2.2.4 | Cask & Equip Purchases | 309.4 | 0.6% | 5.2% | 107.7 | 34.8% |
| 2.2.5 | Cask & Equip O&M | 23.7 | 0.0% | 0.4% | 8.1 | 34.3% |
| 2.2.6 | Cask & Equip Decomm | 44.1 | 0.1% | 0.7% | 8.5 | 19.3% |
| 2.3 | DOE High-Level Wastes | 505.1 | 1.1% | 8.5% | 207.6 | 41.1% |
| 2.3.1 | Cask Shipment Costs | 349.6 | 0.7% | 5.9% | 143.3 | 41.0% |
| 2.3.2 | Shipment Escort Costs | 12.3 | 0.0% | 0.2% | 5.0 | 41.0% |
| 2.3.3 | Cask Inspection Costs | 11.6 | 0.0% | 0.2% | 4.7 | 40.6% |
| 2.3.4 | Cask & Equip Purchases | 74.4 | 0.2% | 1.2% | 33.0 | 44.3% |
| 2.3.5 | Cask & Equip O&M | 47.2 | 0.1% | 0.8% | 19.2 | 40.6% |
| 2.3.6 | Cask & Equip Decomm | 9.9 | 0.0% | 0.2% | 2.4 | 24.5% |
| 2.4 | Technical Assist Trng: 180(c) | 603.7 | 1.3% | 10.1% | 343.6 | 56.9% |
| | | ------ | ------ | ------ | ------- | ------ |

## PROJECTED PROGRAM COSTS (FY 1997-FY 2071: MIL'96$)

| MASTER | Description | Total | %total | %categ | NPV | %NPV |
|---|---|---|---|---|---|---|
| 3.0 | NEVADA TRANSPORTATION | 3244.7 | 6.8% | 100.0% | 2433.5 | 75.0% |
| 3.1 | Intermodal Transfer Facility | 92.3 | 0.2% | 2.8% | 75.9 | 82.2% |
| 3.1.1 | Land and ROW | 0.5 | 0.0% | 0.0% | 0.4 | 94.3% |
| 3.1.2 | Construction | 25.1 | 0.1% | 0.8% | 22.5 | 89.6% |
| 3.1.2.1 | Security Construction | 5.6 | 0.0% | 0.2% | 5.1 | 91.5% |
| 3.1.2.2 | Site Work | 2.7 | 0.0% | 0.1% | 2.4 | 91.5% |
| 3.1.2.3 | Facility Construction | 16.8 | 0.0% | 0.5% | 14.9 | 88.7% |
| 3.1.3 | Major Equipment | 3.2 | 0.0% | 0.1% | 2.8 | 86.3% |
| 3.1.4 | Operations | 63.5 | 0.1% | 2.0% | 50.2 | 79.0% |
| 3.1.4.1 | Staff | 55.9 | 0.1% | 1.7% | 44.2 | 79.0% |
| 3.1.4.2 | Other | 7.6 | 0.0% | 0.2% | 6.0 | 79.0% |
| 3.2 | Heavy Haul to CSF | 437.2 | 0.9% | 13.5% | 381.2 | 87.2% |
| 3.2.1 | Engineering | 15.4 | 0.0% | 0.5% | 14.3 | 92.9% |
| 3.2.2 | Infrastructure Upgrade | 248.0 | 0.5% | 7.6% | 227.0 | 91.5% |
| 3.2.3 | Midway Service Facility | 9.3 | 0.0% | 0.3% | 8.4 | 90.9% |
| 3.2.4 | Equipment | 36.9 | 0.1% | 1.1% | 30.5 | 82.7% |
| 3.2.5 | Operations | 127.6 | 0.3% | 3.9% | 100.8 | 79.0% |
| 3.2.5.1 | Staff | 49.9 | 0.1% | 1.5% | 39.5 | 79.0% |
| 3.2.5.2 | Road Maintenance | 62.8 | 0.1% | 1.9% | 49.6 | 79.0% |
| 3.2.5.3 | Other | 14.9 | 0.0% | 0.5% | 11.8 | 79.0% |
| 3.3 | Rail Spur to CSF/YMP | 2715.1 | 5.7% | 83.7% | 1976.5 | 72.8% |
| 3.3.1 | Misc Upfront Costs | 119.3 | 0.2% | 3.7% | 106.0 | 88.8% |
| 3.3.2 | Construction | 1896.1 | 4.0% | 58.4% | 1497.2 | 79.0% |
| 3.3.2.1 | Rail Spur Const | 1867.3 | 3.9% | 57.5% | 1475.3 | 79.0% |
| 3.3.2.2 | Ancillary Facil Const | 28.8 | 0.1% | 0.9% | 21.9 | 75.9% |
| 3.3.3 | Major Equipment | 20.9 | 0.0% | 0.6% | 15.5 | 74.4% |
| 3.3.4 | Operations | 678.8 | 1.4% | 20.9% | 357.7 | 52.7% |
| 3.3.4.1 | Staff | 556.7 | 1.2% | 17.2% | 293.4 | 52.7% |
| 3.3.4.2 | Other | 122.1 | 0.3% | 3.8% | 64.3 | 52.7% |
| 4.0 | CENTRALIZED STORAGE FACILITY | 9179.3 | 19.2% | 100.0% | 5327.1 | 58.0% |
| 4.1 | Misc Upfront Costs | 65.2 | 0.1% | 0.7% | 60.5 | 92.9% |
| 4.2 | Construction | 429.7 | 0.9% | 4.7% | 372.7 | 86.7% |
| 4.2.1 | Security Construction | 8.4 | 0.0% | 0.1% | 7.4 | 88.0% |
| 4.2.2 | Site Work & Access | 6.6 | 0.0% | 0.1% | 5.8 | 87.9% |
| 4.2.3 | Pads & Alleys | 233.3 | 0.5% | 2.5% | 198.4 | 85.0% |
| 4.2.4 | Facility Construction | 181.3 | 0.4% | 2.0% | 161.1 | 88.8% |
| 4.3 | Major Equipment | 8469.2 | 17.7% | 92.3% | 4728.6 | 55.8% |
| 4.3.1 | Storage Casks, Metal | 3782.1 | 7.9% | 41.2% | 2269.5 | 60.0% |
| 4.3.2 | Storage Casks, Concrete | 628.4 | 1.3% | 6.8% | 395.4 | 62.9% |
| 4.3.3 | Addl Canisters for Rail Ship | 4020.0 | 8.4% | 43.8% | 2029.9 | 50.5% |
| 4.3.4 | Other | 38.6 | 0.1% | 0.4% | 33.8 | 87.5% |
| 4.4 | Operations | 215.2 | 0.5% | 2.3% | 165.2 | 76.8% |
| 4.4.1 | Staff | 204.1 | 0.4% | 2.2% | 156.7 | 76.8% |
| 4.4.2 | Other | 11.1 | 0.0% | 0.1% | 8.5 | 76.8% |
| 5.0 | REPOSITORY | 22955.1 | 48.0% | 100.0% | 11693.3 | 50.9% |
| 5.1 | Site Characterization | 2553.8 | 5.3% | 11.1% | 2282.5 | 89.4% |
| 5.1.1 | As Proposed in 1991 | 2478.6 | 5.2% | 10.8% | 2212.7 | 89.3% |
| 5.1.2 | East-West Tunnel | 75.2 | 0.2% | 0.3% | 69.8 | 92.9% |
| 5.2 | Design & License Application | 1079.2 | 2.3% | 4.7% | 623.2 | 57.7% |
| 5.2.1 | Design: Upfront & Ongoing | 973.6 | 2.0% | 4.2% | 529.3 | 54.4% |
| 5.2.2 | Prepare License | 105.6 | 0.2% | 0.5% | 93.8 | 88.9% |
| 5.3 | Surface Facilities | 6142.5 | 12.9% | 26.8% | 3143.1 | 51.2% |
| 5.3.1 | Construction | 2397.7 | 5.0% | 10.4% | 1737.0 | 72.4% |
| 5.3.1.1 | North | 2265.0 | 4.7% | 9.9% | 1658.9 | 73.2% |
| 5.3.1.2 | South | 132.7 | 0.3% | 0.6% | 78.1 | 58.9% |
| 5.3.2 | Equipment | 78.7 | 0.2% | 0.3% | 48.0 | 61.0% |
| 5.3.3 | Operations | 3666.2 | 7.7% | 16.0% | 1358.1 | 37.0% |
| 5.3.3.1 | Staff | 3530.7 | 7.4% | 15.4% | 1309.9 | 37.1% |
| 5.3.3.2 | Other | 135.5 | 0.3% | 0.6% | 48.2 | 35.6% |
| 5.4 | Underground Facilities | 7158.2 | 15.0% | 31.2% | 3004.6 | 42.0% |
| 5.4.1 | Construction | 5052.4 | 10.6% | 22.0% | 1988.1 | 39.3% |
| 5.4.2 | Equipment | 284.3 | 0.6% | 1.2% | 199.4 | 70.1% |
| 5.4.3 | Operations | 1821.4 | 3.8% | 7.9% | 817.1 | 44.9% |
| 5.4.3.1 | Staff | 703.8 | 1.5% | 3.1% | 234.9 | 33.4% |
| 5.4.3.2 | Other | 1117.6 | 2.3% | 4.9% | 582.2 | 52.1% |
| 5.5 | Waste Containers | 6021.4 | 12.6% | 26.2% | 2639.9 | 43.8% |
| 6.0.0 | OTHER DEVEL & EVAL COSTS | 433.6 | 0.9% | 100.0% | 304.8 | 70.3% |
| 6.1.0 | NRC Fees | 400.0 | 0.8% | 92.3% | 277.7 | 69.4% |
| 6.2.0 | NWTRB | 33.6 | 0.1% | 7.7% | 27.1 | 80.7% |
| 6.3.0 | Nuclear Waste Negotiator | 0.0 | 0.0% | 0.0% | 0.0 | NA |
| 7.0.0 | OTHER PROGRAM COSTS | 1717.8 | 3.6% | 100.0% | 755.5 | 44.0% |
| 7.1.0 | PETT Payments | 1233.0 | 2.6% | 71.8% | 539.4 | 43.7% |
| 7.1.1 | DOE TSLCC 9/95 | 348.0 | 0.7% | 20.3% | 129.2 | 37.1% |
| 7.1.2 | Re Addl NV Components | 885.0 | 1.9% | 51.5% | 410.1 | 46.3% |
| 7.2.0 | Benefits | 484.8 | 1.0% | 28.2% | 216.2 | 44.6% |
| | GRAND TOTAL | 47777.4 | 100.0% | 100.0% | 25833.5 | 54.1% |

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# APPENDIX D: PROJECTED DIRECT AND NON-DIRECT SYSTEMS COSTS: FY 1997 THROUGH FY 2071 (MIL'96$)

Direct costs are estimated via procedures discussed in sections 3.5 through 3.7, above. Other "non-direct" costs (contingency, project and program management) are discussed in section 3.3. The following table presents total projected direct, contingency, project management and program management costs by master code category. (Also included are estimates of the projected obligations of the Nuclear Waste Fund for costs attributable to commercial SNF.) A subsequent table presents these as percentages of total projected costs. A final table presents the factors used to estimate contingency and other non-direct costs in the independent assessment.

The factors are applied at the most detailed master code level, with results summed for higher levels. Contingency factors are applied to direct costs. Project management factors are applied to the sum of direct plus one-third of contingency costs. Program management factors are applied to the sum of direct, contingency and project management costs. Total projected costs are the sum of direct, contingency and project and program management costs. Factors used to estimate the obligation of the Nuclear Waste Fund are applied to total projected costs.

## THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM: DIRECT & NON-DIRECT COSTS (FY 1997-FY 2071: MIL'96$)

| MASTER | Description | DIRECT | CONTNG | PROJCT | PROGRM | TOTAL | NWFOBL |
|---|---|---|---|---|---|---|---|
| 1.0 | ONSITE STORAGE COSTS | 2845.7 | 426.9 | 448.2 | 558.1 | 4278.9 | 3963.7 |
| 1.1 | Commercial SNF in Que | 2584.5 | 387.7 | 407.1 | 506.9 | 3886.1 | 3886.1 |
| 1.1.1 | Dry Storage | 383.0 | 57.5 | 60.3 | 75.1 | 575.9 | 575.9 |
| 1.1.1.1 | Opt 1/LWT: 26 sites | 88.4 | 13.3 | 13.9 | 17.3 | 133.0 | 133.0 |
| 1.1.1.2 | Opt 1/R125: 17 sites | 66.9 | 10.0 | 10.5 | 13.1 | 100.6 | 100.6 |
| 1.1.1.3 | Opt 2/R125: 11 sites | 134.5 | 20.2 | 21.2 | 26.4 | 202.3 | 202.3 |
| 1.1.1.4 | Opt 1/R75: 14 sites | 21.3 | 3.2 | 3.4 | 4.2 | 32.1 | 32.1 |
| 1.1.1.5 | Opt 2/R75: 5 sites | 71.8 | 10.8 | 11.3 | 14.1 | 108.0 | 108.0 |
| 1.1.2 | Pool Op after Reactor Shutdn | 2176.9 | 326.5 | 342.9 | 426.9 | 3273.2 | 3273.2 |
| 1.1.2.1 | Opt 1/LWT: 26 sites | 898.4 | 134.8 | 141.5 | 176.2 | 1350.9 | 1350.9 |
| 1.1.2.2 | Opt 1/R125: 17 sites | 531.6 | 79.7 | 83.7 | 104.3 | 799.3 | 799.3 |
| 1.1.2.3 | Opt 2/R125: 11 sites | 157.5 | 23.6 | 24.8 | 30.9 | 236.8 | 236.8 |
| 1.1.2.4 | Opt 1/R75: 14 sites | 503.6 | 75.5 | 79.3 | 98.8 | 757.3 | 757.3 |
| 1.1.2.5 | Opt 2/R75: 5 sites | 85.8 | 12.9 | 13.5 | 16.8 | 129.0 | 129.0 |
| 1.1.3 | Pool Loading Upgrades | 24.6 | 3.7 | 3.9 | 4.8 | 37.0 | 37.0 |
| 1.1.3.1 | Opt 1/LWT: 26 sites | 0.7 | 0.1 | 0.1 | 0.1 | 1.0 | 1.0 |
| 1.1.3.2 | Opt 1/R125: 17 sites | 5.8 | 0.9 | 0.9 | 1.1 | 8.7 | 8.7 |
| 1.1.3.3 | Opt 2/R125: 11 sites | 11.7 | 1.8 | 1.8 | 2.3 | 17.6 | 17.6 |
| 1.1.3.4 | Opt 1/R75: 14 sites | 0.6 | 0.1 | 0.1 | 0.1 | 0.9 | 0.9 |
| 1.1.3.5 | Opt 2/R75: 5 sites | 5.8 | 0.9 | 0.9 | 1.1 | 8.7 | 8.7 |
| 1.2 | DOE SNF & SNF not in Que | 261.2 | 39.2 | 41.1 | 51.2 | 392.8 | 77.6 |
| 1.2.1 | Dry Storage | 3.6 | 0.5 | 0.6 | 0.7 | 5.4 | 1.1 |
| 1.2.2 | Pool Op after Reactor Shutdn | 257.7 | 38.6 | 40.6 | 50.5 | 387.4 | 76.5 |
| 1.2.3 | Pool Loading Upgrades | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.3 | DOE High-Level Waste | NA | NA | NA | NA | NA | NA |
| 2.0 | X-COUNTRY TRANSPORTATION | 4044.9 | 582.9 | 561.9 | 778.5 | 5968.2 | 4883.9 |
| 2.1 | Commercial SNF in Que | 2839.4 | 425.9 | 447.2 | 556.9 | 4269.3 | 4269.3 |
| 2.1.1 | Cask Shipment Costs | 2035.3 | 305.3 | 320.6 | 399.2 | 3060.3 | 3060.3 |
| 2.1.1.1 | Legal-Wt Truck | 1244.1 | 186.6 | 195.9 | 244.0 | 1870.6 | 1870.6 |
| 2.1.1.2 | Large Rail | 380.1 | 57.0 | 59.9 | 74.5 | 571.5 | 571.5 |
| 2.1.1.3 | Small Rail | 411.1 | 61.7 | 64.7 | 80.6 | 618.1 | 618.1 |
| 2.1.2 | Shipment Escort Costs | 105.4 | 15.8 | 16.6 | 20.7 | 158.4 | 158.4 |
| 2.1.2.1 | Legal-Wt Truck | 77.0 | 11.5 | 12.1 | 15.1 | 115.7 | 115.7 |
| 2.1.2.2 | Large Rail | 11.7 | 1.8 | 1.8 | 2.3 | 17.6 | 17.6 |
| 2.1.2.3 | Small Rail | 16.7 | 2.5 | 2.6 | 3.3 | 25.1 | 25.1 |
| 2.1.3 | Cask Inspection Costs | 48.8 | 7.3 | 7.7 | 9.6 | 73.4 | 73.4 |
| 2.1.3.1 | Legal-Wt Truck | 29.5 | 4.4 | 4.7 | 5.8 | 44.4 | 44.4 |
| 2.1.3.2 | Large Rail | 8.5 | 1.3 | 1.3 | 1.7 | 12.8 | 12.8 |
| 2.1.3.3 | Small Rail | 10.8 | 1.6 | 1.7 | 2.1 | 16.2 | 16.2 |
| 2.1.4 | Cask & Equip Purchases | 373.0 | 55.9 | 58.7 | 73.1 | 560.8 | 560.8 |
| 2.1.4.1 | Legal-Wt Truck | 193.2 | 29.0 | 30.4 | 37.9 | 290.5 | 290.5 |
| 2.1.4.2 | Large Rail | 83.8 | 12.6 | 13.2 | 16.4 | 125.9 | 125.9 |
| 2.1.4.3 | Small Rail | 96.0 | 14.4 | 15.1 | 18.8 | 144.3 | 144.3 |
| 2.1.5 | Cask & Equip O&M | 217.5 | 32.6 | 34.3 | 42.7 | 327.0 | 327.0 |
| 2.1.5.1 | Legal-Wt Truck | 108.3 | 16.2 | 17.1 | 21.2 | 162.9 | 162.9 |
| 2.1.5.2 | Large Rail | 51.8 | 7.8 | 8.2 | 10.2 | 77.9 | 77.9 |
| 2.1.5.3 | Small Rail | 57.4 | 8.6 | 9.0 | 11.3 | 86.3 | 86.3 |
| 2.1.6 | Cask & Equip Decomm | 51.9 | 7.8 | 8.2 | 10.2 | 78.1 | 78.1 |
| 2.1.6.1 | Legal-Wt Truck | 27.6 | 4.1 | 4.3 | 5.4 | 41.4 | 41.4 |
| 2.1.6.2 | Large Rail | 11.2 | 1.7 | 1.8 | 2.2 | 16.8 | 16.8 |
| 2.1.6.3 | Small Rail | 13.2 | 2.0 | 2.1 | 2.6 | 19.8 | 19.8 |
| 2.1.7 | Hvy Haul to Railhead | 7.6 | 1.1 | 1.2 | 1.5 | 11.4 | 11.4 |
| 2.2 | DOE Spent Nuclear Fuel | 392.4 | 58.9 | 61.8 | 77.0 | 590.1 | 123.3 |
| 2.2.1 | Cask Shipment Costs | 130.6 | 19.6 | 20.6 | 25.6 | 196.3 | 45.0 |
| 2.2.2 | Shipment Escort Costs | 6.6 | 1.0 | 1.0 | 1.3 | 10.0 | 2.6 |
| 2.2.3 | Cask Inspection Costs | 4.3 | 0.6 | 0.7 | 0.8 | 6.5 | 1.2 |
| 2.2.4 | Cask & Equip Purchases | 205.8 | 30.9 | 32.4 | 40.4 | 309.4 | 61.1 |
| 2.2.5 | Cask & Equip O&M | 15.8 | 2.4 | 2.5 | 3.1 | 23.7 | 4.7 |
| 2.2.6 | Cask & Equip Decomm | 29.4 | 4.4 | 4.6 | 5.8 | 44.1 | 8.7 |
| 2.3 | DOE High-Level Wastes | 335.9 | 50.4 | 52.9 | 65.9 | 505.1 | 0.0 |
| 2.3.1 | Cask Shipment Costs | 232.5 | 34.9 | 36.6 | 45.6 | 349.6 | 0.0 |
| 2.3.2 | Shipment Escort Costs | 8.2 | 1.2 | 1.3 | 1.6 | 12.3 | 0.0 |
| 2.3.3 | Cask Inspection Costs | 7.7 | 1.2 | 1.2 | 1.5 | 11.6 | 0.0 |
| 2.3.4 | Cask & Equip Purchases | 49.5 | 7.4 | 7.8 | 9.7 | 74.4 | 0.0 |
| 2.3.5 | Cask & Equip O&M | 31.4 | 4.7 | 4.9 | 6.2 | 47.2 | 0.0 |
| 2.3.6 | Cask & Equip Decomm | 6.6 | 1.0 | 1.0 | 1.3 | 9.9 | 0.0 |
| 2.4 | Technical Assist Trng: 180(c) | 477.2 | 47.7 | 0.0 | 78.7 | 603.7 | 491.3 |

## DIRECT & NON-DIRECT COSTS (FY 1997-FY 2071: MIL'96$)

| MASTER | Description | DIRECT | CONTNG | PROJCT | PROGRM | TOTAL | NWFOBL |
|---|---|---|---|---|---|---|---|
| 3.0 | NEVADA TRANSPORTATION | 2077.0 | 412.3 | 332.2 | 423.2 | 3244.7 | 2400.8 |
| 3.1 | Intermodal Transfer Facility | 61.4 | 9.2 | 9.7 | 12.0 | 92.3 | 92.3 |
| 3.1.1 | Land and ROW | 0.3 | 0.0 | 0.0 | 0.1 | 0.5 | 0.5 |
| 3.1.2 | Construction | 16.7 | 2.5 | 2.6 | 3.3 | 25.1 | 25.1 |
| 3.1.2.1 | Security Construction | 3.7 | 0.6 | 0.6 | 0.7 | 5.6 | 5.6 |
| 3.1.2.2 | Site Work | 1.8 | 0.3 | 0.3 | 0.3 | 2.7 | 2.7 |
| 3.1.2.3 | Facility Construction | 11.2 | 1.7 | 1.8 | 2.2 | 16.8 | 16.8 |
| 3.1.3 | Major Equipment | 2.2 | 0.3 | 0.3 | 0.4 | 3.2 | 3.2 |
| 3.1.4 | Operations | 42.3 | 6.3 | 6.7 | 8.3 | 63.5 | 63.5 |
| 3.1.4.1 | Staff | 37.2 | 5.6 | 5.9 | 7.3 | 55.9 | 55.9 |
| 3.1.4.2 | Other | 5.1 | 0.8 | 0.8 | 1.0 | 7.6 | 7.6 |
| 3.2 | Heavy Haul to CSF | 279.6 | 55.9 | 44.7 | 57.0 | 437.2 | 437.2 |
| 3.2.1 | Engineering | 9.9 | 2.0 | 1.6 | 2.0 | 15.4 | 15.4 |
| 3.2.2 | Infrastructure Upgrade | 158.5 | 31.7 | 25.4 | 32.3 | 248.0 | 248.0 |
| 3.2.3 | Midway Service Facility | 5.9 | 1.2 | 1.0 | 1.2 | 9.3 | 9.3 |
| 3.2.4 | Equipment | 23.6 | 4.7 | 3.8 | 4.8 | 36.9 | 36.9 |
| 3.2.5 | Operations | 81.6 | 16.3 | 13.1 | 16.6 | 127.6 | 127.6 |
| 3.2.5.1 | Staff | 31.9 | 6.4 | 5.1 | 6.5 | 49.9 | 49.9 |
| 3.2.5.2 | Road Maintenance | 40.1 | 8.0 | 6.4 | 8.2 | 62.8 | 62.8 |
| 3.2.5.3 | Other | 9.5 | 1.9 | 1.5 | 1.9 | 14.9 | 14.9 |
| 3.3 | Rail Spur to CSF/YMP | 1736.0 | 347.2 | 277.8 | 354.1 | 2715.1 | 1871.3 |
| 3.3.1 | Misc Upfront Costs | 76.3 | 15.3 | 12.2 | 15.6 | 119.3 | 82.2 |
| 3.3.2 | Construction | 1212.4 | 242.5 | 194.0 | 247.3 | 1896.1 | 1306.8 |
| 3.3.2.1 | Rail Spur Const | 1193.9 | 238.8 | 191.0 | 243.6 | 1867.3 | 1286.9 |
| 3.3.2.2 | Ancillary Facil Const | 18.4 | 3.7 | 2.9 | 3.8 | 28.8 | 19.9 |
| 3.3.3 | Major Equipment | 13.4 | 2.7 | 2.1 | 2.7 | 20.9 | 14.4 |
| 3.3.4 | Operations | 434.0 | 86.8 | 69.4 | 88.5 | 678.8 | 467.8 |
| 3.3.4.1 | Staff | 355.9 | 71.2 | 57.0 | 72.6 | 556.7 | 383.7 |
| 3.3.4.2 | Other | 78.1 | 15.6 | 12.5 | 15.9 | 122.1 | 84.1 |
| 4.0 | CENTRALIZED STORAGE FACILITY | 5972.3 | 1060.8 | 948.9 | 1197.3 | 9179.3 | 8686.4 |
| 4.1 | Misc Upfront Costs | 41.7 | 8.3 | 6.7 | 8.5 | 65.2 | 62.5 |
| 4.2 | Construction | 274.7 | 54.9 | 44.0 | 56.0 | 429.7 | 412.1 |
| 4.2.1 | Security Construction | 5.4 | 1.1 | 0.9 | 1.1 | 8.4 | 8.0 |
| 4.2.2 | Site Work & Access | 4.3 | 0.9 | 0.7 | 0.9 | 6.6 | 6.4 |
| 4.2.3 | Pads & Alleys | 149.2 | 29.8 | 23.9 | 30.4 | 233.3 | 223.8 |
| 4.2.4 | Facility Construction | 116.0 | 23.2 | 18.6 | 23.7 | 181.3 | 173.9 |
| 4.3 | Major Equipment | 5518.3 | 970.0 | 876.2 | 1104.7 | 8469.2 | 8005.4 |
| 4.3.1 | Storage Casks, Metal | 2418.2 | 483.6 | 386.9 | 493.3 | 3782.1 | 3319.9 |
| 4.3.2 | Storage Casks, Concrete | 401.8 | 80.4 | 64.3 | 82.0 | 628.4 | 628.4 |
| 4.3.3 | Addl Canisters for Rail Ship | 2673.6 | 401.0 | 421.1 | 524.4 | 4020.0 | 4020.0 |
| 4.3.4 | Other | 24.7 | 4.9 | 4.0 | 5.0 | 38.6 | 37.0 |
| 4.4 | Operations | 137.6 | 27.5 | 22.0 | 28.1 | 215.2 | 206.4 |
| 4.4.1 | Staff | 130.5 | 26.1 | 20.9 | 26.6 | 204.1 | 195.7 |
| 4.4.2 | Other | 7.1 | 1.4 | 1.1 | 1.4 | 11.1 | 10.6 |
| 5.0 | REPOSITORY | 15249.6 | 2616.4 | 2095.0 | 2994.1 | 22955.1 | 17015.5 |
| 5.1 | Site Characterization | 2205.3 | 7.5 | 7.9 | 333.1 | 2553.8 | 1982.0 |
| 5.1.1 | As Proposed in 1991 | 2155.3 | 0.0 | 0.0 | 323.3 | 2478.6 | 1923.6 |
| 5.1.2 | East-West Tunnel | 50.0 | 7.5 | 7.9 | 9.8 | 75.2 | 58.3 |
| 5.2 | Design & License Application | 690.0 | 138.0 | 110.4 | 140.8 | 1079.2 | 837.5 |
| 5.2.1 | Design: Upfront & Ongoing | 622.5 | 124.5 | 99.6 | 127.0 | 973.6 | 755.6 |
| 5.2.2 | Prepare License | 67.5 | 13.5 | 10.8 | 13.8 | 105.6 | 81.9 |
| 5.3 | Surface Facilities | 3927.5 | 785.5 | 628.4 | 801.2 | 6142.5 | 4512.9 |
| 5.3.1 | Construction | 1533.0 | 306.6 | 245.3 | 312.7 | 2397.7 | 1761.6 |
| 5.3.1.1 | North | 1448.2 | 289.6 | 231.7 | 295.4 | 2265.0 | 1664.1 |
| 5.3.1.2 | South | 84.8 | 17.0 | 13.6 | 17.3 | 132.7 | 97.5 |
| 5.3.2 | Equipment | 50.3 | 10.1 | 8.0 | 10.3 | 78.7 | 57.8 |
| 5.3.3 | Operations | 2344.1 | 468.8 | 375.1 | 478.2 | 3666.2 | 2693.6 |
| 5.3.3.1 | Staff | 2257.5 | 451.5 | 361.2 | 460.5 | 3530.7 | 2594.0 |
| 5.3.3.2 | Other | 86.6 | 17.3 | 13.9 | 17.7 | 135.5 | 99.5 |
| 5.4 | Underground Facilities | 4576.9 | 915.4 | 732.3 | 933.7 | 7158.2 | 5259.1 |
| 5.4.1 | Construction | 3230.4 | 646.1 | 516.9 | 659.0 | 5052.4 | 3712.0 |
| 5.4.2 | Equipment | 181.8 | 36.4 | 29.1 | 37.1 | 284.3 | 208.9 |
| 5.4.3 | Operations | 1164.6 | 232.9 | 186.3 | 237.6 | 1821.4 | 1338.2 |
| 5.4.3.1 | Staff | 450.0 | 90.0 | 72.0 | 91.8 | 703.8 | 517.1 |
| 5.4.3.2 | Other | 714.6 | 142.9 | 114.3 | 145.8 | 1117.6 | 821.1 |
| 5.5 | Waste Containers | 3850.0 | 770.0 | 616.0 | 785.4 | 6021.4 | 4423.9 |
| 6.0.0 | OTHER DEVEL & EVAL COSTS | 412.9 | 20.6 | 0.0 | 0.0 | 433.6 | 336.5 |
| 6.1.0 | NRC Fees | 381.0 | 19.0 | 0.0 | 0.0 | 400.0 | 310.5 |
| 6.2.0 | NWTRB | 32.0 | 1.6 | 0.0 | 0.0 | 33.6 | 26.0 |
| 6.3.0 | Nuclear Waste Negotiator | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.0.0 | OTHER PROGRAM COSTS | 1561.6 | 156.2 | 0.0 | 0.0 | 1717.8 | 1260.5 |
| 7.1.0 | PETT Payments | 1120.9 | 112.1 | 0.0 | 0.0 | 1233.0 | 904.8 |
| 7.1.1 | DOE TSLCC 9/95 | 316.4 | 31.6 | 0.0 | 0.0 | 348.0 | 255.4 |
| 7.1.2 | Re Addl NV Components | 804.5 | 80.5 | 0.0 | 0.0 | 885.0 | 649.4 |
| 7.2.0 | Benefits | 440.7 | 44.1 | 0.0 | 0.0 | 484.8 | 355.8 |
| | GRAND TOTAL | 32164.1 | 5276.0 | 4386.1 | 5951.2 | 47777.4 | 38547.3 |

## THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM: DIRECT & NON-DIRECT PROGRAM COSTS (% TOTAL PROJECTED)

| MASTER | Description | DIRECT | CONTNG | PROJCT | PROGRM | TOTAL | NWFOBL |
|---|---|---|---|---|---|---|---|
| 1.0 | ONSITE STORAGE COSTS | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 92.6% |
| 1.1 | Commercial SNF in Que | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.1 | Dry Storage | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.1.1 | Opt 1/LWT: 26 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.1.2 | Opt 1/R125: 17 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.1.3 | Opt 2/R125: 11 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.1.4 | Opt 1/R75: 14 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.1.5 | Opt 2/R75: 5 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.2 | Pool Op after Reactor Shutdn | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.2.1 | Opt 1/LWT: 26 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.2.2 | Opt 1/R125: 17 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.2.3 | Opt 2/R125: 11 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.2.4 | Opt 1/R75: 14 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.2.5 | Opt 2/R75: 5 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.3 | Pool Loading Upgrades | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.3.1 | Opt 1/LWT: 26 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.3.2 | Opt 1/R125: 17 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.3.3 | Opt 2/R125: 11 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.3.4 | Opt 1/R75: 14 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.1.3.5 | Opt 2/R75: 5 sites | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 1.2 | DOE SNF & SNF not in Que | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 19.8% |
| 1.2.1 | Dry Storage | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 19.8% |
| 1.2.2 | Pool Op after Reactor Shutdn | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 19.8% |
| 1.2.3 | Pool Loading Upgrades | NA | NA | NA | NA | NA | NA |
| 1.3 | DOE High-Level Waste | NA | NA | NA | NA | NA | NA |
| 2.0 | X-COUNTRY TRANSPORTATION | 67.8% | 9.8% | 9.4% | 13.0% | 100.0% | 81.8% |
| 2.1 | Commercial SNF in Que | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.1 | Cask Shipment Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.1.1 | Legal-Wt Truck | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.1.2 | Large Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.1.3 | Small Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.2 | Shipment Escort Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.2.1 | Legal-Wt Truck | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.2.2 | Large Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.2.3 | Small Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.3 | Cask Inspection Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.3.1 | Legal-Wt Truck | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.3.2 | Large Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.3.3 | Small Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.4 | Cask & Equip Purchases | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.4.1 | Legal-Wt Truck | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.4.2 | Large Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.4.3 | Small Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.5 | Cask & Equip O&M | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.5.1 | Legal-Wt Truck | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.5.2 | Large Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.5.3 | Small Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.6 | Cask & Equip Decomm | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.6.1 | Legal-Wt Truck | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.6.2 | Large Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.6.3 | Small Rail | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.1.7 | Hvy Haul to Railhead | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 2.2 | DOE Spent Nuclear Fuel | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 20.9% |
| 2.2.1 | Cask Shipment Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 22.9% |
| 2.2.2 | Shipment Escort Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 25.8% |
| 2.2.3 | Cask Inspection Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 19.2% |
| 2.2.4 | Cask & Equip Purchases | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 19.8% |
| 2.2.5 | Cask & Equip O&M | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 19.8% |
| 2.2.6 | Cask & Equip Decomm | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 19.8% |
| 2.3 | DOE High-Level Wastes | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 0.0% |
| 2.3.1 | Cask Shipment Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 0.0% |
| 2.3.2 | Shipment Escort Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 0.0% |
| 2.3.3 | Cask Inspection Costs | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 0.0% |
| 2.3.4 | Cask & Equip Purchases | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 0.0% |
| 2.3.5 | Cask & Equip O&M | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 0.0% |
| 2.3.6 | Cask & Equip Decomm | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 0.0% |
| 2.4 | Technical Assist Trng: 180(c) | 79.1% | 7.9% | 0.0% | 13.0% | 100.0% | 81.4% |

## DIRECT & NON-DIRECT PROGRAM COSTS (% TOTAL PROJECTED)

| MASTER | Description | DIRECT | CONTNG | PROJCT | PROGRM | TOTAL | NWFOBL |
|---|---|---|---|---|---|---|---|
| 3.0 | NEVADA TRANSPORTATION | 64.0% | 12.7% | 10.2% | 13.0% | 100.0% | 74.0% |
| 3.1 | Intermodal Transfer Facility | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.1 | Land and ROW | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.2 | Construction | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.2.1 | Security Construction | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.2.2 | Site Work | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.2.3 | Facility Construction | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.3 | Major Equipment | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.4 | Operations | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.4.1 | Staff | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.1.4.2 | Other | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 3.2 | Heavy Haul to CSF | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.2.1 | Engineering | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.2.2 | Infrastructure Upgrade | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.2.3 | Midway Service Facility | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.2.4 | Equipment | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.2.5 | Operations | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.2.5.1 | Staff | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.2.5.2 | Road Maintenance | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.2.5.3 | Other | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 3.3 | Rail Spur to CSF/YMP | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 3.3.1 | Misc Upfront Costs | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 3.3.2 | Construction | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 3.3.2.1 | Rail Spur Const | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 3.3.2.2 | Ancillary Facil Const | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 3.3.3 | Major Equipment | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 3.3.4 | Operations | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 3.3.4.1 | Staff | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 3.3.4.2 | Other | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 68.9% |
| 4.0 | CENTRALIZED STORAGE FACILITY | 65.1% | 11.6% | 10.3% | 13.0% | 100.0% | 94.6% |
| 4.1 | Misc Upfront Costs | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.2 | Construction | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.2.1 | Security Construction | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.2.2 | Site Work & Access | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.2.3 | Pads & Alleys | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.2.4 | Facility Construction | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.3 | Major Equipment | 65.2% | 11.5% | 10.3% | 13.0% | 100.0% | 94.5% |
| 4.3.1 | Storage Casks, Metal | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 87.8% |
| 4.3.2 | Storage Casks, Concrete | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 100.0% |
| 4.3.3 | Addl Canisters for Rail Ship | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 100.0% |
| 4.3.4 | Other | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.4 | Operations | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.4.1 | Staff | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 4.4.2 | Other | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 95.9% |
| 5.0 | REPOSITORY | 66.4% | 11.4% | 9.1% | 13.0% | 100.0% | 74.1% |
| 5.1 | Site Characterization | 86.4% | 0.3% | 0.3% | 13.0% | 100.0% | 77.6% |
| 5.1.1 | As Proposed in 1991 | 87.0% | 0.0% | 0.0% | 13.0% | 100.0% | 77.6% |
| 5.1.2 | East-West Tunnel | 66.5% | 10.0% | 10.5% | 13.0% | 100.0% | 77.6% |
| 5.2 | Design & License Application | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 77.6% |
| 5.2.1 | Design: Upfront & Ongoing | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 77.6% |
| 5.2.2 | Prepare License | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 77.6% |
| 5.3 | Surface Facilities | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.3.1 | Construction | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.3.1.1 | North | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.3.1.2 | South | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.3.2 | Equipment | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.3.3 | Operations | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.3.3.1 | Staff | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.3.3.2 | Other | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.4 | Underground Facilities | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.4.1 | Construction | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.4.2 | Equipment | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.4.3 | Operations | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.4.3.1 | Staff | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.4.3.2 | Other | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 5.5 | Waste Containers | 63.9% | 12.8% | 10.2% | 13.0% | 100.0% | 73.5% |
| 6.0.0 | OTHER DEVEL & EVAL COSTS | 95.2% | 4.8% | 0.0% | 0.0% | 100.0% | 77.6% |
| 6.1.0 | NRC Fees | 95.2% | 4.8% | 0.0% | 0.0% | 100.0% | 77.6% |
| 6.2.0 | NWTRB | 95.2% | 4.8% | 0.0% | 0.0% | 100.0% | 77.6% |
| 6.3.0 | Nuclear Waste Negotiator | NA | NA | NA | NA | NA | NA |
| 7.0.0 | OTHER PROGRAM COSTS | 90.9% | 9.1% | 0.0% | 0.0% | 100.0% | 73.4% |
| 7.1.0 | PETT Payments | 90.9% | 9.1% | 0.0% | 0.0% | 100.0% | 73.4% |
| 7.1.1 | DOE TSLCC 9/95 | 90.9% | 9.1% | 0.0% | 0.0% | 100.0% | 73.4% |
| 7.1.2 | Re Addl NV Components | 90.9% | 9.1% | 0.0% | 0.0% | 100.0% | 73.4% |
| 7.2.0 | Benefits | 90.9% | 9.1% | 0.0% | 0.0% | 100.0% | 73.4% |
| | GRAND TOTAL | 67.3% | 11.0% | 9.2% | 12.5% | 100.0% | 80.7% |

## THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM: NON-DIRECT COST FACTORS

| MASTER | Description | CONTNG | PROJCT | PROGRM | NWFND |
|---|---|---|---|---|---|
| 1.0 | ONSITE STORAGE COSTS | | | | |
| 1.1 | Commercial SNF in Que | | | | |
| 1.1.1 | Dry Storage | | | | |
| 1.1.1.1 | Opt 1/LWT: 26 sites | 15% | 15% | 15% | 100% |
| 1.1.1.2 | Opt 1/R125: 17 sites | 15% | 15% | 15% | 100% |
| 1.1.1.3 | Opt 2/R125: 11 sites | 15% | 15% | 15% | 100% |
| 1.1.1.4 | Opt 1/R75: 14 sites | 15% | 15% | 15% | 100% |
| 1.1.1.5 | Opt 2/R75: 5 sites | 15% | 15% | 15% | 100% |
| 1.1.2 | Pool Op after Reactor Shutdn | | | | |
| 1.1.2.1 | Opt 1/LWT: 26 sites | 15% | 15% | 15% | 100% |
| 1.1.2.2 | Opt 1/R125: 17 sites | 15% | 15% | 15% | 100% |
| 1.1.2.3 | Opt 2/R125: 11 sites | 15% | 15% | 15% | 100% |
| 1.1.2.4 | Opt 1/R75: 14 sites | 15% | 15% | 15% | 100% |
| 1.1.2.5 | Opt 2/R75: 5 sites | 15% | 15% | 15% | 100% |
| 1.1.3 | Pool Loading Upgrades | | | | |
| 1.1.3.1 | Opt 1/LWT: 26 sites | 15% | 15% | 15% | 100% |
| 1.1.3.2 | Opt 1/R125: 17 sites | 15% | 15% | 15% | 100% |
| 1.1.3.3 | Opt 2/R125: 11 sites | 15% | 15% | 15% | 100% |
| 1.1.3.4 | Opt 1/R75: 14 sites | 15% | 15% | 15% | 100% |
| 1.1.3.5 | Opt 2/R75: 5 sites | 15% | 15% | 15% | 100% |
| 1.2 | DOE SNF & SNF not in Que | | | | |
| 1.2.1 | Dry Storage | 15% | 15% | 15% | 20% |
| 1.2.2 | Pool Op after Reactor Shutdn | 15% | 15% | 15% | 20% |
| 1.2.3 | Pool Loading Upgrades | 15% | 15% | 15% | 20% |
| 1.3 | DOE High-Level Waste | | | | |
| 2.0 | X-COUNTRY TRANSPORTATION | | | | |
| 2.1 | Commercial SNF in Que | | | | |
| 2.1.1 | Cask Shipment Costs | | | | |
| 2.1.1.1 | Legal-Wt Truck | 15% | 15% | 15% | 100% |
| 2.1.1.2 | Large Rail | 15% | 15% | 15% | 100% |
| 2.1.1.3 | Small Rail | 15% | 15% | 15% | 100% |
| 2.1.2 | Shipment Escort Costs | | | | |
| 2.1.2.1 | Legal-Wt Truck | 15% | 15% | 15% | 100% |
| 2.1.2.2 | Large Rail | 15% | 15% | 15% | 100% |
| 2.1.2.3 | Small Rail | 15% | 15% | 15% | 100% |
| 2.1.3 | Cask Inspection Costs | | | | |
| 2.1.3.1 | Legal-Wt Truck | 15% | 15% | 15% | 100% |
| 2.1.3.2 | Large Rail | 15% | 15% | 15% | 100% |
| 2.1.3.3 | Small Rail | 15% | 15% | 15% | 100% |
| 2.1.4 | Cask & Equip Purchases | | | | |
| 2.1.4.1 | Legal-Wt Truck | 15% | 15% | 15% | 100% |
| 2.1.4.2 | Large Rail | 15% | 15% | 15% | 100% |
| 2.1.4.3 | Small Rail | 15% | 15% | 15% | 100% |
| 2.1.5 | Cask & Equip O&M | | | | |
| 2.1.5.1 | Legal-Wt Truck | 15% | 15% | 15% | 100% |
| 2.1.5.2 | Large Rail | 15% | 15% | 15% | 100% |
| 2.1.5.3 | Small Rail | 15% | 15% | 15% | 100% |
| 2.1.6 | Cask & Equip Decomm | | | | |
| 2.1.6.1 | Legal-Wt Truck | 15% | 15% | 15% | 100% |
| 2.1.6.2 | Large Rail | 15% | 15% | 15% | 100% |
| 2.1.6.3 | Small Rail | 15% | 15% | 15% | 100% |
| 2.1.7 | Hvy Haul to Railhead | | | | |
| 2.2 | DOE Spent Nuclear Fuel | | | | |
| 2.2.1 | Cask Shipment Costs | 15% | 15% | 15% | 23% |
| 2.2.2 | Shipment Escort Costs | 15% | 15% | 15% | 26% |
| 2.2.3 | Cask Inspection Costs | 15% | 15% | 15% | 19% |
| 2.2.4 | Cask & Equip Purchases | 15% | 15% | 15% | 20% |
| 2.2.5 | Cask & Equip O&M | 15% | 15% | 15% | 20% |
| 2.2.6 | Cask & Equip Decomm | 15% | 15% | 15% | 20% |
| 2.3 | DOE High-Level Wastes | | | | |
| 2.3.1 | Cask Shipment Costs | 15% | 15% | 15% | 0% |
| 2.3.2 | Shipment Escort Costs | 15% | 15% | 15% | 0% |
| 2.3.3 | Cask Inspection Costs | 15% | 15% | 15% | 0% |
| 2.3.4 | Cask & Equip Purchases | 15% | 15% | 15% | 0% |
| 2.3.5 | Cask & Equip O&M | 15% | 15% | 15% | 0% |
| 2.3.6 | Cask & Equip Decomm | 15% | 15% | 15% | 0% |
| 2.4 | Technical Assist Trng: 180(c) | 10% | 0% | 15% | 81% |

## NON-DIRECT COST FACTORS

| MASTER | Description | CONTNG | PROJCT | PROGRM | NWFND |
|---|---|---|---|---|---|
| 3.0 | NEVADA TRANSPORTATION | | | | |
| 3.1 | Intermodal Transfer Facility | | | | |
| 3.1.1 | Land and ROW | 15% | 15% | 15% | 100% |
| 3.1.2 | Construction | | | | |
| 3.1.2.1 | Security Construction | 15% | 15% | 15% | 100% |
| 3.1.2.2 | Site Work | 15% | 15% | 15% | 100% |
| 3.1.2.3 | Facility Construction | 15% | 15% | 15% | 100% |
| 3.1.3 | Major Equipment | 15% | 15% | 15% | 100% |
| 3.1.4 | Operations | | | | |
| 3.1.4.1 | Staff | 15% | 15% | 15% | 100% |
| 3.1.4.2 | Other | 15% | 15% | 15% | 100% |
| 3.2 | Heavy Haul to CSF | | | | |
| 3.2.1 | Engineering | 20% | 15% | 15% | 100% |
| 3.2.2 | Infrastructure Upgrade | 20% | 15% | 15% | 100% |
| 3.2.3 | Midway Service Facility | 20% | 15% | 15% | 100% |
| 3.2.4 | Equipment | 20% | 15% | 15% | 100% |
| 3.2.5 | Operations | | | | |
| 3.2.5.1 | Staff | 20% | 15% | 15% | 100% |
| 3.2.5.2 | Road Maintenance | 20% | 15% | 15% | 100% |
| 3.2.5.3 | Other | 20% | 15% | 15% | 100% |
| 3.3 | Rail Spur to CSF/YMP | | | | |
| 3.3.1 | Misc Upfront Costs | 20% | 15% | 15% | 69% |
| 3.3.2 | Construction | | | | |
| 3.3.2.1 | Rail Spur Const | 20% | 15% | 15% | 69% |
| 3.3.2.2 | Ancillary Facil Const | 20% | 15% | 15% | 69% |
| 3.3.3 | Major Equipment | 20% | 15% | 15% | 69% |
| 3.3.4 | Operations | | | | |
| 3.3.4.1 | Staff | 20% | 15% | 15% | 69% |
| 3.3.4.2 | Other | 20% | 15% | 15% | 69% |
| 4.0 | CENTRALIZED STORAGE FACILITY | | | | |
| 4.1 | Misc Upfront Costs | 20% | 15% | 15% | 96% |
| 4.2 | Construction | | | | |
| 4.2.1 | Security Construction | 20% | 15% | 15% | 96% |
| 4.2.2 | Site Work & Access | 20% | 15% | 15% | 96% |
| 4.2.3 | Pads & Alleys | 20% | 15% | 15% | 96% |
| 4.2.4 | Facility Construction | 20% | 15% | 15% | 96% |
| 4.3 | Major Equipment | | | | |
| 4.3.1 | Storage Casks, Metal | 20% | 15% | 15% | 88% |
| 4.3.2 | Storage Casks, Concrete | 20% | 15% | 15% | 100% |
| 4.3.3 | Addl Canisters for Rail Ship | 15% | 15% | 15% | 100% |
| 4.3.4 | Other | 20% | 15% | 15% | 96% |
| 4.4 | Operations | | | | |
| 4.4.1 | Staff | 20% | 15% | 15% | 96% |
| 4.4.2 | Other | 20% | 15% | 15% | 96% |
| 5.0 | REPOSITORY | | | | |
| 5.1 | Site Characterization | | | | |
| 5.1.1 | As Proposed in 1991 | 0% | 0% | 15% | 78% |
| 5.1.2 | East-West Tunnel | 15% | 15% | 15% | 78% |
| 5.2 | Design & License Application | | | | |
| 5.2.1 | Design: Upfront & Ongoing | 20% | 15% | 15% | 78% |
| 5.2.2 | Prepare License | 20% | 15% | 15% | 78% |
| 5.3 | Surface Facilities | | | | |
| 5.3.1 | Construction | | | | |
| 5.3.1.1 | North | 20% | 15% | 15% | 73% |
| 5.3.1.2 | South | 20% | 15% | 15% | 73% |
| 5.3.2 | Equipment | 20% | 15% | 15% | 73% |
| 5.3.3 | Operations | | | | |
| 5.3.3.1 | Staff | 20% | 15% | 15% | 73% |
| 5.3.3.2 | Other | 20% | 15% | 15% | 73% |
| 5.4 | Underground Facilities | | | | |
| 5.4.1 | Construction | 20% | 15% | 15% | 73% |
| 5.4.2 | Equipment | 20% | 15% | 15% | 73% |
| 5.4.3 | Operations | | | | |
| 5.4.3.1 | Staff | 20% | 15% | 15% | 73% |
| 5.4.3.2 | Other | 20% | 15% | 15% | 73% |
| 5.5 | Waste Containers | 20% | 15% | 15% | 73% |
| 6.0.0 | OTHER DEVEL & EVAL COSTS | | | | |
| 6.1.0 | NRC Fees | 5% | 0% | 0% | 78% |
| 6.2.0 | NWTRB | 5% | 0% | 0% | 78% |
| 6.3.0 | Nuclear Waste Negotiator | 5% | 0% | 0% | 78% |
| 7.0.0 | OTHER PROGRAM COSTS | | | | |
| 7.1.0 | PETT Payments | | | | |
| 7.1.1 | DOE TSLCC 9/95 | 10% | 0% | 0% | 73% |
| 7.1.2 | Re Addl NV Components | 10% | 0% | 0% | 73% |
| 7.2.0 | Benefits | 10% | 0% | 0% | 73% |
| | GRAND TOTAL | | | | |

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# APPENDIX E: ANNUAL PROJECTED TOTAL SYSTEMS COSTS (MIL'96$)

The following tables present projected costs on an annual basis. All figures include direct, contingency and project and program management costs, as estimated for the independent assessment.

## THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM: PROJECTED PROGRAM COSTS (FY 1997-FY 2011; MIL'96$)

| MASTER | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 0.4 | 8.9 | 28.1 | 31.5 | 46.1 | 66.9 | 62.9 | 45.6 | 56.7 | 69.4 | 73.5 | 74.6 | 65.2 | 65.2 | 89.9 |
| 1.1 | 0.0 | 8.6 | 14.3 | 17.7 | 32.3 | 53.1 | 49.1 | 31.8 | 42.9 | 55.9 | 60.1 | 61.2 | 51.8 | 51.7 | 76.3 |
| 1.1.1 | 0.0 | 1.8 | 7.4 | 6.6 | 13.7 | 20.1 | 18.2 | 10.6 | 20.0 | 36.8 | 35.9 | 24.6 | 23.3 | 15.9 | 27.5 |
| 1.1.1.1 | 0.0 | 0.0 | 1.4 | 0.2 | 0.2 | 0.2 | 4.5 | 0.3 | 11.9 | 12.8 | 20.9 | 13.2 | 3.1 | 6.3 | 3.2 |
| 1.1.1.2 | 0.0 | 0.0 | 1.4 | 0.3 | 0.1 | 5.7 | 6.7 | 2.4 | 4.7 | 13.6 | 4.1 | 4.6 | 7.4 | 1.2 | 4.6 |
| 1.1.1.3 | 0.0 | 1.3 | 4.2 | 3.3 | 11.9 | 12.0 | 6.5 | 5.7 | 1.7 | 4.6 | 1.6 | 4.3 | 8.3 | 5.5 | 6.2 |
| 1.1.1.4 | 0.0 | 0.0 | 0.0 | 2.3 | 1.0 | 1.7 | 0.2 | 2.0 | 1.3 | 0.3 | 5.7 | 1.7 | 1.5 | 1.1 | 1.3 |
| 1.1.1.5 | 0.0 | 0.4 | 0.3 | 0.4 | 0.6 | 0.5 | 0.2 | 0.3 | 0.3 | 5.5 | 3.5 | 0.8 | 2.9 | 1.7 | 12.1 |
| 1.1.2 | 0.0 | 6.8 | 6.9 | 11.1 | 18.6 | 21.3 | 23.1 | 20.9 | 22.9 | 17.7 | 21.8 | 30.6 | 28.5 | 35.9 | 44.8 |
| 1.1.2.1 | 0.0 | 2.5 | 2.6 | 4.2 | 7.9 | 9.1 | 9.9 | 8.5 | 7.8 | 7.0 | 7.3 | 14.5 | 13.1 | 22.2 | 25.0 |
| 1.1.2.2 | 0.0 | 1.4 | 1.4 | 2.3 | 3.5 | 4.1 | 4.4 | 4.8 | 5.9 | 5.3 | 5.5 | 6.1 | 3.2 | 3.6 | 3.5 |
| 1.1.2.3 | 0.0 | 0.8 | 0.8 | 1.2 | 1.9 | 2.2 | 2.4 | 2.6 | 3.2 | 0.0 | 0.0 | 0.0 | 3.2 | 3.6 | 3.6 |
| 1.1.2.4 | 0.0 | 1.5 | 1.5 | 2.4 | 3.7 | 4.2 | 4.6 | 5.0 | 6.1 | 5.5 | 5.7 | 6.3 | 5.7 | 6.4 | 6.3 |
| 1.1.2.5 | 0.0 | 0.6 | 0.6 | 1.0 | 1.5 | 1.8 | 1.9 | 0.0 | 0.0 | 0.0 | 3.3 | 3.7 | 3.3 | 0.0 | 6.4 |
| 1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 11.6 | 7.7 | 0.3 | 0.0 | 1.4 | 2.4 | 6.0 | 0.0 | 0.0 | 4.0 |
| 1.1.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.3 | 0.0 | 0.3 | 0.0 | 0.0 | C.0 | 0.0 | 0.0 |
| 1.1.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 2.4 | 2.7 | 0.0 | 0.0 | 0.0 |
| 1.1.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.1 | 7.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.0 |
| 1.1.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.3 | 0.0 | 0.0 | 0.0 |
| 1.2 | 0.4 | 0.4 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.6 |
| 1.2.1 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.2 |
| 1.2.2 | 0.0 | 0.0 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.1 | 13.1 | 13.1 | 13.1 | 13.1 | 13.4 |
| 1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.3 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 21.5 | 21.5 | 234.3 | 96.2 | 161.0 | 159.6 | 199.4 | 189.4 | 166.8 | 163.9 | 169.9 |
| 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 212.8 | 74.7 | 139.5 | 138.1 | 177.9 | 167.9 | 145.3 | 142.4 | 144.3 |
| 2.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 71.5 | 58.9 | 87.1 | 95.5 | 120.6 | 121.0 | 122.8 | 108.3 | 118.0 |
| 2.1.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 58.1 | 44.7 | 59.9 | 73.7 | 89.7 | 80.3 | 83.2 | 62.5 | 73.9 |
| 2.1.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.5 | 6.0 | 10.8 | 10.6 | 16.3 | 23.3 | 21.0 | 22.1 | 20.0 |
| 2.1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.9 | 8.3 | 16.4 | 11.2 | 14.6 | 17.3 | 18.6 | 23.7 | 24.0 |
| 2.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.2 | 3.4 | 4.8 | 5.4 | 6.7 | 6.5 | 6.6 | 5.5 | 6.2 |
| 2.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.7 | 2.8 | 3.8 | 4.6 | 5.7 | 5.1 | 5.2 | 3.8 | 4.6 |
| 2.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.3 | 0.3 | 0.5 | 0.7 | 0.6 | 0.7 | 0.6 |
| 2.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.3 | 0.7 | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 | 1.0 |
| 2.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 1.4 | 2.0 | 2.2 | 2.8 | 2.8 | 2.9 | 2.6 | 2.8 |
| 2.1.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 1.0 | 1.4 | 1.7 | 2.0 | 1.8 | 1.9 | 1.5 | 1.8 |
| 2.1.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 | 0.3 | 0.5 | 0.5 | 0.5 | 0.5 |
| 2.1.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.4 | 0.3 | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 |
| 2.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 128.7 | 5.0 | 36.3 | 25.3 | 35.3 | 24.7 | 0.0 | 13.5 | 4.5 |
| 2.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 91.6 | 0.0 | 3.2 | 25.3 | 25.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.1 | 5.0 | 15.1 | 0.0 | 10.1 | 20.1 | 0.0 | 0.0 | 0.0 |
| 2.1.4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 27.1 | 0.0 | 18.0 | 0.0 | 0.0 | 4.5 | 0.0 | 13.5 | 4.5 |
| 2.1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.6 | 5.6 | 8.7 | 9.2 | 11.7 | 12.2 | 12.6 | 11.9 | 12.6 |
| 2.1.5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.8 | 3.7 | 5.0 | 6.2 | 7.5 | 6.7 | 7.1 | 5.5 | 6.4 |
| 2.1.5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.8 | 1.4 | 1.4 | 2.1 | 3.0 | 2.9 | 3.1 | 2.7 |
| 2.1.5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 1.2 | 2.4 | 1.6 | 2.1 | 2.4 | 2.6 | 3.3 | 3.4 |
| 2.1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.4 | 0.6 | 0.5 | 0.6 | 0.8 | 0.5 | 0.5 | 0.3 |
| 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.1 |
| 2.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 |
| 2.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 |
| 2.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| 2.2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 21.5 | 21.5 | 21.5 | 21.5 | 21.5 | 21.5 | 21.5 | 21.5 | 21.5 | 21.5 | 21.5 |

**PROJECTED PROGRAM COSTS (FY 1997-FY 2011; MIL'96$)**

| MASTER | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|---|---|
| 3.0 | 3.9 | 88.3 | 139.6 | 141.7 | 66.4 | 412.1 | 432.7 | 451.6 |
| 3.1 | 0.0 | 0.5 | 9.8 | 12.6 | 5.9 | 12.7 | 12.7 | 12.7 |
| 3.1.1 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2 | 0.0 | 0.0 | 9.8 | 12.6 | 2.7 | 0.0 | 0.0 | 0.0 |
| 3.1.2.1 | 0.0 | 0.0 | 5.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.2 | 0.0 | 0.0 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.3 | 0.0 | 0.0 | 1.5 | 12.6 | 2.7 | 0.0 | 0.0 | 0.0 |
| 3.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 0.0 | 0.0 | 0.0 |
| 3.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 12.7 | 12.7 | 12.7 |
| 3.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 11.2 | 11.2 | 11.2 |
| 3.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 1.5 | 1.5 |
| 3.2 | 3.9 | 87.8 | 91.0 | 90.0 | 19.1 | 25.5 | 25.5 | 43.4 |
| 3.2.1 | 3.9 | 3.9 | 3.9 | 3.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.2 | 0.0 | 82.7 | 82.7 | 82.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.3 | 0.0 | 1.3 | 4.5 | 3.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 19.1 | 0.0 | 0.0 | 17.8 |
| 3.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 25.5 | 25.5 | 25.5 |
| 3.2.5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 | 10.0 | 10.0 |
| 3.2.5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 12.6 | 12.6 | 12.6 |
| 3.2.5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0 | 3.0 | 3.0 |
| 3.3 | 0.0 | 0.0 | 38.8 | 39.1 | 41.4 | 373.9 | 394.4 | 395.5 |
| 3.3.1 | 0.0 | 0.0 | 38.8 | 39.1 | 41.4 | 0.0 | 0.0 | 0.0 |
| 3.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 373.9 | 373.9 | 375.0 |
| 3.3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 373.5 | 373.5 | 373.5 |
| 3.3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 1.5 |
| 3.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.6 | 20.6 |
| 3.3.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 16.9 | 16.9 |
| 3.3.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.7 | 3.7 |
| 4.0 | 0.0 | 32.3 | 32.9 | 274.2 | 70.7 | 95.1 | 339.7 | 295.0 |
| 4.1 | 0.0 | 32.3 | 32.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2 | 0.0 | 0.0 | 0.0 | 248.4 | 64.7 | 58.3 | 58.3 | 0.0 |
| 4.2.1 | 0.0 | 0.0 | 0.0 | 5.7 | 2.7 | 0.0 | 0.0 | 0.0 |
| 4.2.2 | 0.0 | 0.0 | 0.0 | 4.3 | 2.3 | 0.0 | 0.0 | 0.0 |
| 4.2.3 | 0.0 | 0.0 | 0.0 | 58.3 | 58.3 | 58.3 | 58.3 | 0.0 |
| 4.2.4 | 0.0 | 0.0 | 0.0 | 180.0 | 1.3 | 0.0 | 0.0 | 0.0 |
| 4.3 | 0.0 | 0.0 | 0.0 | 25.9 | 6.0 | 6.0 | 250.6 | 264.3 |
| 4.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 220.2 | 217.7 |
| 4.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 22.1 | 23.8 |
| 4.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.5 | 22.8 |
| 4.3.4 | 0.0 | 0.0 | 0.0 | 25.9 | 6.0 | 6.0 | 0.8 | 0.0 |
| 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 30.7 | 30.7 | 30.7 |
| 4.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 29.2 | 29.2 | 29.2 |
| 4.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 1.6 | 1.6 |
| 5.0 | 389.9 | 417.1 | 417.8 | 415.4 | 415.4 | 380.2 | 365.6 | 240.8 |
| 5.1 | 389.9 | 417.1 | 382.6 | 345.0 | 345.0 | 345.0 | 329.2 | 0.0 |
| 5.1.1 | 389.9 | 379.5 | 345.0 | 345.0 | 345.0 | 345.0 | 329.2 | 0.0 |
| 5.1.2 | 0.0 | 37.6 | 37.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2 | 0.0 | 0.0 | 35.2 | 70.4 | 70.4 | 35.2 | 35.2 | 35.2 |
| 5.2.1 | 0.0 | 0.0 | 0.0 | 35.2 | 35.2 | 35.2 | 35.2 | 35.2 |
| 5.2.2 | 0.0 | 0.0 | 35.2 | 35.2 | 35.2 | 0.0 | 0.0 | 0.0 |
| 5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 44.7 |
| 5.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 7.4 |
| 5.3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 |
| 5.3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 6.1 |
| 5.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 37.3 |
| 5.3.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 35.2 |
| 5.3.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.1 |
| 5.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 160.9 |
| 5.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 113.1 |
| 5.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 47.8 |
| 5.4.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 11.7 |
| 5.4.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 36.1 |
| 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6.0.0 | 26.8 | 26.8 | 26.8 | 26.8 | 31.2 | 31.2 | 29.0 | 24.6 |
| 6.1.0 | 24.4 | 24.4 | 24.4 | 24.4 | 28.9 | 28.9 | 26.6 | 22.2 |
| 6.2.0 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| 6.3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.0.0 | 0.0 | 0.0 | 0.4 | 3.0 | 18.6 | 21.2 | 24.2 | 26.7 |
| 7.1.0 | 0.0 | 0.0 | 0.4 | 3.0 | 9.2 | 12.2 | 15.4 | 18.1 |
| 7.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 5.3 | 5.3 | 5.3 | 5.3 |
| 7.1.2 | 0.0 | 0.0 | 0.4 | 3.0 | 3.9 | 6.9 | 10.1 | 12.8 |
| 7.2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.3 | 9.1 | 8.8 | 8.6 |
| | 420.9 | 573.4 | 645.6 | 892.7 | 669.8 | 1028.2 | 1488.4 | 1180.5 |

| MASTER | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|
| 3.0 | 445.3 | 466.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 |
| 3.1 | 12.7 | 12.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4 | 12.7 | 12.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.1 | 11.2 | 11.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.2 | 1.5 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2 | 25.5 | 25.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5 | 25.5 | 25.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.1 | 10.0 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.2 | 12.6 | 12.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.3 | 3.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3 | 407.1 | 428.3 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 |
| 3.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2 | 386.5 | 386.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.1 | 373.5 | 373.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.2 | 13.1 | 13.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.3 | 0.0 | 20.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 |
| 3.3.4.1 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 |
| 3.3.4.2 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 |
| 4.0 | 325.9 | 436.5 | 505.2 | 547.0 | 484.1 | 392.2 | 371.6 |
| 4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3 | 295.2 | 405.8 | 474.5 | 516.3 | 484.1 | 392.2 | 371.6 |
| 4.3.1 | 215.2 | 332.8 | 355.3 | 350.3 | 285.3 | 177.7 | 157.7 |
| 4.3.2 | 42.6 | 35.0 | 51.4 | 65.3 | 63.2 | 68.5 | 54.8 |
| 4.3.3 | 37.4 | 38.0 | 67.7 | 100.7 | 135.7 | 146.1 | 159.1 |
| 4.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4 | 30.7 | 30.7 | 30.7 | 30.7 | 0.0 | 0.0 | 0.0 |
| 4.4.1 | 29.2 | 29.2 | 29.2 | 29.2 | 0.0 | 0.0 | 0.0 |
| 4.4.2 | 1.6 | 1.6 | 1.6 | 1.6 | 0.0 | 0.0 | 0.0 |
| 5.0 | 755.6 | 853.7 | 876.8 | 1120.8 | 269.9 | 301.5 | 350.4 |
| 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 |
| 5.2.1 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 |
| 5.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3 | 572.1 | 664.5 | 680.0 | 635.8 | 72.5 | 72.5 | 72.5 |
| 5.3.1 | 534.8 | 627.3 | 642.7 | 547.9 | 0.0 | 0.0 | 0.0 |
| 5.3.1.1 | 480.9 | 593.0 | 641.7 | 547.9 | 0.0 | 0.0 | 0.0 |
| 5.3.1.2 | 53.9 | 34.2 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.2 | 0.0 | 0.0 | 0.0 | 50.6 | 0.0 | 0.0 | 0.0 |
| 5.3.3 | 37.3 | 37.3 | 37.3 | 37.3 | 72.5 | 72.5 | 72.5 |
| 5.3.3.1 | 35.2 | 35.2 | 35.2 | 35.2 | 70.4 | 70.4 | 70.4 |
| 5.3.3.2 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| 5.4 | 161.4 | 167.0 | 174.7 | 452.4 | 143.7 | 143.7 | 143.7 |
| 5.4.1 | 113.5 | 119.2 | 126.9 | 120.2 | 95.8 | 95.8 | 95.8 |
| 5.4.2 | 0.0 | 0.0 | 0.0 | 284.3 | 0.0 | 0.0 | 0.0 |
| 5.4.3 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 |
| 5.4.3.1 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 |
| 5.4.3.2 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 |
| 5.5 | 0.0 | 0.0 | 0.0 | 10.5 | 31.6 | 63.2 | 112.2 |
| 6.0.0 | 19.0 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 3.3 |
| 6.1.0 | 16.6 | 11.1 | 11.1 | 11.1 | 11.1 | 11.1 | 3.3 |
| 6.2.0 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 0.0 |
| 6.3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.0.0 | 29.3 | 32.0 | 32.3 | 32.7 | 32.6 | 39.6 | 38.8 |
| 7.1.0 | 21.0 | 23.9 | 24.5 | 25.0 | 25.2 | 25.5 | 25.3 |
| 7.1.1 | 5.3 | 5.3 | 5.3 | 5.3 | 5.3 | 5.3 | 4.8 |
| 7.1.2 | 15.7 | 18.6 | 19.2 | 19.7 | 19.9 | 20.2 | 20.5 |
| 7.2.0 | 8.3 | 8.1 | 7.9 | 7.6 | 7.4 | 14.1 | 13.5 |
| | 1792.9 | 2031.3 | 1721.3 | 1998.7 | 1052.7 | 996.5 | 1044.6 |

## THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM: PROJECTED PROGRAM COSTS (FY 2012-FY 2026; MIL'96$)

| MASTER | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 76.2 | 82.5 | 126.7 | 149.9 | 157.9 | 181.9 | 180.5 | 187.3 | 180.4 | 196.8 | 190.4 | 187.5 | 198.7 | 232.8 | 228.6 |
| 1.1 | 62.8 | 69.1 | 113.3 | 136.4 | 144.5 | 168.5 | 167.1 | 173.9 | 167.0 | 183.4 | 177.0 | 174.1 | 185.3 | 219.4 | 215.2 |
| 1.1.1 | 22.1 | 24.9 | 29.2 | 32.9 | 38.0 | 26.1 | 19.3 | 20.2 | 14.1 | 8.0 | 8.3 | 7.5 | 9.1 | 19.6 | 10.5 |
| 1.1.1.1 | 1.7 | 7.3 | 4.8 | 7.1 | 3.9 | 1.7 | 1.1 | 2.8 | 0.7 | 1.7 | 0.8 | 3.3 | 3.2 | 11.5 | 1.2 |
| 1.1.1.2 | 2.0 | 4.2 | 3.4 | 0.6 | 8.8 | 2.6 | 1.9 | 3.0 | 2.1 | 0.3 | 2.3 | 0.3 | 0.3 | 2.5 | 0.3 |
| 1.1.1.3 | 2.5 | 7.2 | 12.7 | 16.6 | 12.0 | 12.6 | 9.7 | 10.7 | 7.7 | 4.6 | 4.1 | 2.7 | 4.0 | 2.9 | 6.6 |
| 1.1.1.4 | 1.1 | 0.1 | 0.5 | 5.6 | 1.3 | 0.4 | 1.3 | 0.5 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.5 | 14.8 | 6.0 | 7.8 | 3.1 | 12.1 | 8.8 | 5.4 | 3.2 | 2.5 | 1.5 | 1.0 | 1.1 | 1.6 | 2.7 | 2.4 |
| 1.1.2 | 40.7 | 43.2 | 81.6 | 103.5 | 106.5 | 142.4 | 147.7 | 153.7 | 152.9 | 175.4 | 168.7 | 166.7 | 176.1 | 199.9 | 204.7 |
| 1.1.2.1 | 21.0 | 21.8 | 36.8 | 46.0 | 48.8 | 69.9 | 77.5 | 78.3 | 88.1 | 100.7 | 90.7 | 87.1 | 83.9 | 69.8 | 60.7 |
| 1.1.2.2 | 3.0 | 2.6 | 6.8 | 6.6 | 7.0 | 7.8 | 8.3 | 14.9 | 11.7 | 13.4 | 24.8 | 32.5 | 39.6 | 73.0 | 83.3 |
| 1.1.2.3 | 3.0 | 2.7 | 15.9 | 26.9 | 21.8 | 25.1 | 30.4 | 25.3 | 23.8 | 21.5 | 9.6 | 5.3 | 0.0 | 0.0 | 0.0 |
| 1.1.2.4 | 5.3 | 8.6 | 12.8 | 15.5 | 16.5 | 22.4 | 24.1 | 26.9 | 24.9 | 34.7 | 38.8 | 41.8 | 52.6 | 57.1 | 55.1 |
| 1.1.2.5 | 8.4 | 7.5 | 9.3 | 8.6 | 12.4 | 17.1 | 7.5 | 8.3 | 4.4 | 5.0 | 4.8 | 0.0 | 0.0 | 0.0 | 5.5 |
| 1.1.3 | 0.0 | 1.0 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.2 | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.3 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 |
| 1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.2 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 |
| 1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.3 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 2.0 | 152.8 | 149.4 | 144.2 | 215.5 | 166.3 | 160.0 | 168.3 | 173.1 | 161.3 | 162.5 | 178.8 | 311.7 | 178.7 | 196.6 | 168.9 |
| 2.1 | 131.3 | 134.2 | 129.0 | 142.4 | 132.1 | 126.7 | 135.6 | 141.0 | 129.8 | 131.2 | 147.8 | 280.8 | 148.0 | 166.0 | 138.8 |
| 2.1.1 | 110.6 | 113.0 | 108.6 | 120.0 | 111.4 | 106.5 | 110.0 | 111.0 | 109.2 | 110.4 | 124.9 | 112.8 | 120.0 | 104.9 | 92.1 |
| 2.1.1.1 | 68.8 | 71.0 | 63.8 | 76.7 | 68.0 | 61.3 | 66.7 | 63.1 | 67.4 | 65.3 | 81.1 | 73.0 | 74.5 | 58.2 | 46.9 |
| 2.1.1.2 | 21.3 | 20.9 | 22.6 | 21.6 | 19.7 | 20.7 | 24.7 | 19.7 | 21.3 | 20.7 | 21.4 | 19.2 | 21.4 | 20.2 | 24.9 |
| 2.1.1.3 | 20.6 | 21.2 | 22.2 | 21.7 | 23.8 | 24.5 | 18.6 | 28.2 | 20.5 | 24.4 | 22.4 | 20.6 | 24.1 | 26.5 | 20.2 |
| 2.1.2 | 5.7 | 5.9 | 5.6 | 6.2 | 5.8 | 5.3 | 5.6 | 5.6 | 5.6 | 5.5 | 6.6 | 5.8 | 6.2 | 5.3 | 4.5 |
| 2.1.2.1 | 4.2 | 4.4 | 4.0 | 4.6 | 4.2 | 3.7 | 4.1 | 3.8 | 4.1 | 4.0 | 5.0 | 4.4 | 4.6 | 3.6 | 2.9 |
| 2.1.2.2 | 0.7 | 0.6 | 0.7 | 0.7 | 0.6 | 0.6 | 0.8 | 0.6 | 0.7 | 0.6 | 0.7 | 0.6 | 0.7 | 0.6 | 0.8 |
| 2.1.2.3 | 0.8 | 0.9 | 0.9 | 0.9 | 1.0 | 1.0 | 0.8 | 1.1 | 0.8 | 1.0 | 0.9 | 0.8 | 1.0 | 1.1 | 0.8 |
| 2.1.3 | 2.7 | 2.7 | 2.6 | 2.9 | 2.7 | 2.6 | 2.6 | 2.7 | 2.6 | 2.7 | 2.9 | 2.8 | 2.9 | 2.5 | 2.2 |
| 2.1.3.1 | 1.7 | 1.7 | 1.5 | 1.9 | 1.6 | 1.5 | 1.6 | 1.5 | 1.6 | 1.6 | 1.9 | 1.8 | 1.8 | 1.4 | 1.1 |
| 2.1.3.2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 | 0.5 | 0.5 | 0.6 |
| 2.1.3.3 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.7 | 0.5 | 0.7 | 0.6 | 0.5 | 0.6 | 0.7 | 0.6 |
| 2.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 9.0 | 0.0 | 0.0 | 0.0 | 128.7 | 5.0 | 36.3 | 25.3 |
| 2.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 91.6 | 0.0 | 3.2 | 25.3 |
| 2.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.1 | 5.0 | 15.1 | 0.0 |
| 2.1.4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.0 | 0.0 | 0.0 | 0.0 | 27.1 | 0.0 | 18.0 | 0.0 |
| 2.1.5 | 11.9 | 12.2 | 11.7 | 12.9 | 12.0 | 11.9 | 11.8 | 12.3 | 11.7 | 12.2 | 12.8 | 12.3 | 12.7 | 11.6 | 10.5 |
| 2.1.5.1 | 6.1 | 6.3 | 5.5 | 7.0 | 5.9 | 5.5 | 5.9 | 5.7 | 6.0 | 5.8 | 7.0 | 6.8 | 6.6 | 5.0 | 4.0 |
| 2.1.5.2 | 2.9 | 2.9 | 3.0 | 2.9 | 2.7 | 2.9 | 3.3 | 2.8 | 2.8 | 2.9 | 2.9 | 2.6 | 2.9 | 2.8 | 3.5 |
| 2.1.5.3 | 2.8 | 3.0 | 3.1 | 3.0 | 3.3 | 3.4 | 2.6 | 3.9 | 2.9 | 3.5 | 3.0 | 2.9 | 3.2 | 3.8 | 3.0 |
| 2.1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 18.1 | 0.7 | 4.9 | 3.6 |
| 2.1.6.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 13.1 | 0.0 | 0.5 | 3.6 |
| 2.1.6.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.7 | 2.0 | 0.0 |
| 2.1.6.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.7 | 0.0 | 2.5 | 0.0 |
| 2.1.7 | 0.5 | 0.4 | 0.5 | 0.4 | 0.3 | 0.4 | 0.5 | 0.3 | 0.6 | 0.3 | 0.4 | 0.3 | 0.5 | 0.5 | 0.7 |
| 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3 | 0.0 | 0.0 | 0.0 | 57.9 | 19.0 | 18.1 | 17.5 | 17.0 | 16.4 | 16.1 | 15.9 | 15.7 | 15.5 | 15.4 | 14.9 |
| 2.3.1 | 0.0 | 0.0 | 0.0 | 17.8 | 16.2 | 15.3 | 14.6 | 14.2 | 13.6 | 13.3 | 13.1 | 12.9 | 12.8 | 12.7 | 12.1 |
| 2.3.2 | 0.0 | 0.0 | 0.0 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 | 0.4 |
| 2.3.3 | 0.0 | 0.0 | 0.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 2.3.4 | 0.0 | 0.0 | 0.0 | 37.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.5 | 0.0 | 0.0 | 0.0 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| 2.3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.4 | 21.5 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |

## PROJECTED PROGRAM COSTS (FY 2012-FY 2026; MIL'96$)

| MASTER | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.0 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 |
| 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 |
| 3.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 |
| 3.3.4.1 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 |
| 3.3.4.2 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 |
| 4.0 | 301.8 | 267.2 | 171.8 | 154.3 | 174.0 | 180.0 | 172.6 | 191.9 | 196.3 | 166.5 | 170.3 | 176.5 | 181.4 | 180.9 | 178.5 |
| 4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3 | 301.8 | 267.2 | 171.8 | 154.3 | 174.0 | 180.0 | 172.6 | 191.9 | 196.3 | 166.5 | 170.3 | 176.5 | 181.4 | 180.9 | 178.5 |
| 4.3.1 | 115.1 | 95.1 | 10.5 | 16.1 | 22.8 | 24.1 | 22.3 | 22.4 | 47.9 | 22.5 | 28.7 | 32.7 | 37.9 | 8.9 | 5.1 |
| 4.3.2 | 42.7 | 24.5 | 6.0 | 4.3 | 2.8 | 2.4 | 6.9 | 4.6 | 3.3 | 1.7 | 3.8 | 0.7 | 5.4 | 4.0 | 7.4 |
| 4.3.3 | 144.0 | 147.6 | 155.3 | 133.9 | 148.5 | 153.5 | 143.5 | 164.9 | 145.0 | 142.3 | 137.9 | 143.1 | 138.1 | 167.9 | 165.9 |
| 4.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.0 | 413.6 | 451.4 | 448.7 | 448.7 | 448.7 | 448.7 | 450.6 | 448.7 | 448.7 | 448.7 | 448.7 | 465.7 | 448.7 | 448.7 | 448.7 |
| 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 |
| 5.2.1 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 |
| 5.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3 | 72.5 | 75.2 | 72.5 | 72.5 | 72.5 | 72.5 | 74.4 | 72.5 | 72.5 | 72.5 | 72.5 | 89.5 | 72.5 | 72.5 | 72.5 |
| 5.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.2 | 0.0 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 17.1 | 0.0 | 0.0 | 0.0 |
| 5.3.3 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 |
| 5.3.3.1 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 |
| 5.3.3.2 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| 5.4 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 |
| 5.4.1 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 |
| 5.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.4.3 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 |
| 5.4.3.1 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 |
| 5.4.3.2 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 |
| 5.5 | 175.3 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 |
| 6.0.0 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| 6.1.0 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| 6.2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6.3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.0.0 | 38.7 | 38.4 | 38.1 | 37.8 | 37.5 | 37.2 | 36.9 | 36.6 | 36.3 | 36.1 | 35.8 | 35.6 | 35.4 | 35.1 | 34.9 |
| 7.1.0 | 25.5 | 25.7 | 25.7 | 25.7 | 25.7 | 25.8 | 25.8 | 25.9 | 25.9 | 26.0 | 26.0 | 26.0 | 26.1 | 26.1 | 26.1 |
| 7.1.1 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 |
| 7.1.2 | 20.7 | 20.8 | 20.9 | 20.9 | 20.9 | 20.9 | 21.0 | 21.0 | 21.1 | 21.1 | 21.2 | 21.2 | 21.3 | 21.3 | 21.3 |
| 7.2.0 | 13.2 | 12.8 | 12.4 | 12.0 | 11.7 | 11.4 | 11.0 | 10.7 | 10.4 | 10.1 | 9.8 | 9.5 | 9.3 | 9.0 | 8.8 |
| | 1007.1 | 1012.9 | 953.4 | 1030.0 | 1008.3 | 1031.7 | 1032.7 | 1061.5 | 1047.0 | 1034.5 | 1047.9 | 1200.9 | 1066.8 | 1118.0 | 1083.4 |

# THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM: PROJECTED PROGRAM COSTS (FY 2027-FY 2041; MIL'96$)

| MASTER | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 249.8 | 241.5 | 217.4 | 153.0 | 49.1 | 13.4 | 0.0 | 11.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1 | 249.8 | 241.5 | 217.4 | 153.0 | 49.1 | 0.0 | 0.0 | 11.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1 | 12.0 | 7.0 | 3.5 | 0.3 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.1 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.2 | 5.7 | 0.3 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.3 | 3.8 | 4.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.5 | 0.7 | 2.1 | 0.3 | 0.3 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2 | 237.8 | 234.4 | 213.9 | 152.8 | 48.1 | 0.0 | 0.0 | 11.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.1 | 81.9 | 65.9 | 40.6 | 32.2 | 7.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.2 | 92.6 | 104.3 | 110.2 | 68.2 | 22.2 | 0.0 | 0.0 | 11.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.4 | 57.1 | 64.2 | 63.1 | 52.4 | 18.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.5 | 6.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 13.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 13.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.3 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 2.0 | 202.8 | 179.1 | 132.0 | 157.0 | 142.0 | 512.6 | 93.3 | 21.5 | 65.1 | 21.7 | 21.7 | 22.3 | 22.9 | 15.8 | 0.0 |
| 2.1 | 173.7 | 148.9 | 100.6 | 125.6 | 107.1 | 14.3 | 0.0 | 0.0 | 1.4 | 0.0 | 0.0 | 0.7 | 1.2 | 0.0 | 0.0 |
| 2.1.1 | 112.5 | 102.2 | 84.6 | 92.8 | 85.9 | 12.0 | 0.0 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.1 | 65.2 | 57.6 | 32.1 | 42.3 | 41.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.2 | 20.2 | 22.7 | 22.9 | 22.7 | 23.6 | 3.6 | 0.0 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.3 | 27.1 | 21.9 | 29.6 | 27.9 | 20.6 | 8.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2 | 5.7 | 5.2 | 3.9 | 4.4 | 4.2 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.1 | 4.0 | 3.6 | 2.0 | 2.6 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.2 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.3 | 1.1 | 0.9 | 1.2 | 1.1 | 0.8 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3 | 2.7 | 2.4 | 2.0 | 2.3 | 2.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.1 | 1.6 | 1.3 | 0.8 | 1.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.2 | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.3 | 0.7 | 0.6 | 0.8 | 0.7 | 0.6 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4 | 35.3 | 24.7 | 0.0 | 13.5 | 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.1 | 25.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.2 | 10.1 | 20.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.3 | 0.0 | 4.5 | 0.0 | 13.5 | 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5 | 12.1 | 10.9 | 10.0 | 10.8 | 9.8 | 1.6 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.1 | 5.9 | 4.9 | 2.8 | 3.8 | 3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.2 | 2.6 | 3.1 | 3.1 | 3.1 | 3.3 | 0.5 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.3 | 3.6 | 3.0 | 4.1 | 3.8 | 3.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6 | 5.0 | 3.3 | 0.0 | 1.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 1.2 | 0.0 | 0.0 |
| 2.1.6.1 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.2 | 1.3 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 |
| 2.1.6.3 | 0.0 | 0.6 | 0.0 | 1.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 0.0 | 0.0 |
| 2.1.7 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 3.6 | 466.9 | 71.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 136.4 | 59.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.1 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.3 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 303.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 15.9 | 7.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3 | 14.0 | 15.0 | 16.2 | 16.2 | 16.2 | 16.1 | 16.2 | 16.2 | 58.4 | 16.4 | 16.4 | 16.4 | 16.4 | 10.6 | 0.0 |
| 2.3.1 | 11.3 | 12.3 | 13.5 | 13.4 | 13.4 | 13.4 | 13.5 | 13.5 | 13.4 | 13.6 | 13.6 | 13.6 | 13.6 | 8.8 | 0.0 |
| 2.3.2 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.3 | 0.0 |
| 2.3.3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.3 | 0.0 |
| 2.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 37.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.5 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.2 | 0.0 |
| 2.3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.4 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 0.0 |

## PROJECTED PROGRAM COSTS (FY 2027-FY 2041; MIL'96$)

| MASTER | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.0 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.5 | 20.6 | 20.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4.1 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 16.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4.2 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.0 | 179.2 | 168.2 | 246.0 | 263.7 | 221.4 | 432.2 | 164.8 | 61.5 | 63.8 | 59.3 | 59.9 | 59.3 | 59.3 | 58.9 | 15.1 |
| 4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3 | 179.2 | 168.2 | 246.0 | 263.7 | 221.4 | 432.2 | 164.8 | 61.5 | 63.8 | 59.3 | 59.9 | 59.3 | 59.3 | 58.9 | 15.1 |
| 4.3.1 | 20.8 | 6.1 | 6.1 | 7.9 | 2.6 | 380.4 | 159.0 | 53.7 | 50.7 | 51.4 | 52.0 | 51.4 | 51.4 | 51.0 | 13.1 |
| 4.3.2 | 3.5 | 0.4 | 5.1 | 4.4 | 3.1 | 2.0 | 5.8 | 7.9 | 7.6 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 2.0 |
| 4.3.3 | 154.9 | 161.6 | 234.8 | 251.4 | 215.6 | 49.8 | 0.0 | 0.0 | 5.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.0 | 448.7 | 450.6 | 448.7 | 448.7 | 448.7 | 448.7 | 451.4 | 401.8 | 401.8 | 401.8 | 401.8 | 403.6 | 323.2 | 51.9 | 31.7 |
| 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0:0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 0.0 |
| 5.2.1 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 22.2 | 0.0 |
| 5.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3 | 72.5 | 74.4 | 72.5 | 72.5 | 72.5 | 72.5 | 75.2 | 72.5 | 72.5 | 72.5 | 72.5 | 74.3 | 72.5 | 2.1 | 30.8 |
| 5.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.2 | 0.0 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 |
| 5.3.3 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 2.1 | 30.8 |
| 5.3.3.1 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 70.4 | 0.0 | 28.7 |
| 5.3.3.2 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| 5.4 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 143.7 | 96.7 | 96.7 | 96.7 | 96.7 | 96.7 | 96.7 | 0.9 | 0.9 |
| 5.4.1 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 95.8 | 0.0 | 0.0 |
| 5.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.4.3 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 47.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| 5.4.3.1 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 11.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.4.3.2 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 36.1 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| 5.5 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 210.4 | 131.9 | 26.7 | 0.0 |
| 6.0.0 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 0.6 |
| 6.1.0 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 0.6 |
| 6.2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6.3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.0.0 | 34.7 | 34.4 | 34.2 | 34.0 | 33.8 | 34.1 | 34.1 | 34.0 | 33.8 | 33.7 | 33.6 | 33.5 | 33.4 | 33.3 | 33.2 |
| 7.1.0 | 26.2 | 26.2 | 26.2 | 26.2 | 26.2 | 26.7 | 26.9 | 27.0 | 27.1 | 27.2 | 27.3 | 27.3 | 27.4 | 27.5 | 27.5 |
| 7.1.1 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 |
| 7.1.2 | 21.3 | 21.3 | 21.4 | 21.4 | 21.4 | 21.9 | 22.1 | 22.2 | 22.3 | 22.3 | 22.4 | 22.5 | 22.6 | 22.7 | 22.7 |
| 7.2.0 | 8.5 | 8.3 | 8.0 | 7.8 | 7.6 | 7.4 | 7.1 | 6.9 | 6.7 | 6.6 | 6.4 | 6.2 | 6.0 | 5.8 | 5.7 |
| | 1139.1 | 1097.6 | 1102.2 | 1080.3 | 918.9 | 1464.8 | 767.4 | 554.2 | 588.3 | 519.8 | 520.3 | 522.1 | 442.2 | 163.3 | 80.6 |

**THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM:
PROJECTED PROGRAM COSTS (FY 2042-FY 2056; MIL'96$)**

| MASTER | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.3 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 2.0 | 0.0 | 18.1 | 0.7 | 4.9 | 3.6 | 5.0 | 3.3 | 0.0 | 1.9 | 1.1 | 43.2 | 0.0 | 0.0 | 4.9 | 0.0 |
| 2.1 | 0.0 | 18.1 | 0.7 | 4.9 | 3.6 | 5.0 | 3.3 | 0.0 | 1.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6 | 0.0 | 18.1 | 0.7 | 4.9 | 3.6 | 5.0 | 3.3 | 0.0 | 1.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.1 | 0.0 | 13.1 | 0.0 | 0.5 | 3.6 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.2 | 0.0 | 1.3 | 0.7 | 2.0 | 0.0 | 1.3 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.3 | 0.0 | 3.7 | 0.0 | 2.5 | 0.0 | 0.0 | 0.6 | 0.0 | 1.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 43.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 43.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.9 | 0.0 |
| 2.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.9 | 0.0 |
| 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

## PROJECTED PROGRAM COSTS (FY 2042-FY 2056; MIL'96$)

| MASTER | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.0 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 36.4 | 36.4 | 33.3 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 23.7 |
| 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3 | 23.2 | 23.2 | 23.2 | 23.2 | 23.2 | 23.2 | 35.5 | 35.5 | 32.4 | 23.2 | 23.2 | 23.2 | 23.2 | 23.2 | 22.8 |
| 5.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.3 | 23.2 | 23.2 | 23.2 | 23.2 | 23.2 | 23.2 | 35.5 | 35.5 | 32.4 | 23.2 | 23.2 | 23.2 | 23.2 | 23.2 | 22.8 |
| 5.3.3.1 | 21.2 | 21.2 | 21.2 | 21.2 | 21.2 | 21.2 | 33.4 | 33.4 | 30.3 | 21.2 | 21.2 | 21.2 | 21.2 | 21.2 | 21.2 |
| 5.3.3.2 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.7 |
| 5.4 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| 5.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.4.3 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| 5.4.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.4.3.2 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6.0.0 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| 6.1.0 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| 6.2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6.3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.0.0 | 33.0 | 32.9 | 32.7 | 9.9 | 9.8 | 9.6 | 9.5 | 9.4 | 9.2 | 9.1 | 9.0 | 8.9 | 8.8 | 8.6 | 8.5 |
| 7.1.0 | 27.5 | 27.5 | 27.5 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 |
| 7.1.1 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 |
| 7.1.2 | 22.7 | 22.7 | 22.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.2.0 | 5.5 | 5.4 | 5.2 | 5.1 | 4.9 | 4.8 | 4.6 | 4.5 | 4.4 | 4.3 | 4.1 | 4.0 | 3.9 | 3.8 | 3.7 |
| | 57.8 | 75.7 | 58.1 | 39.6 | 38.1 | 39.3 | 49.8 | 46.3 | 45.0 | 34.9 | 76.9 | 33.6 | 33.5 | 38.3 | 32.8 |

**THE CURRENTLY-PROPOSED HI-LEVEL NW MGT PROGRAM: PROJECTED PROGRAM COSTS (FY 2057-FY 2071; MIL'96$)**

| MASTER | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 207 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.1.3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.3 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.6.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

## PROJECTED PROGRAM COSTS (FY 2057-FY 2071; MIL'96$)

| MASTER | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.1.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.2.5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.3.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.0 | 23.7 | 36.0 | 37.6 | 393.6 | 330.4 | 330.4 | 330.4 | 330.4 | 330.4 | 142.9 | 127.7 | 127.7 | 127.7 | 23.7 | 16.4 |
| 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3 | 22.8 | 35.0 | 36.7 | 113.8 | 95.7 | 95.7 | 95.7 | 95.7 | 95.7 | 41.9 | 37.6 | 37.6 | 37.6 | 7.7 | 5.6 |
| 5.3.1 | 0.0 | 0.0 | 0.0 | 5.5 | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 | 2.0 | 1.8 | 1.8 | 1.8 | 0.3 | 0.2 |
| 5.3.1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.1.2 | 0.0 | 0.0 | 0.0 | 5.5 | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 | 2.0 | 1.8 | 1.8 | 1.8 | 0.3 | 0.2 |
| 5.3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.3.3 | 22.8 | 35.0 | 36.7 | 108.3 | 91.0 | 91.0 | 91.0 | 91.0 | 91.0 | 39.9 | 35.8 | 35.8 | 35.8 | 7.4 | 5.4 |
| 5.3.3.1 | 21.2 | 33.4 | 35.0 | 106.6 | 89.4 | 89.4 | 89.4 | 89.4 | 89.4 | 38.3 | 34.1 | 34.1 | 34.1 | 5.8 | 3.8 |
| 5.3.3.2 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 |
| 5.4 | 0.9 | 0.9 | 0.9 | 279.8 | 234.7 | 234.7 | 234.7 | 234.7 | 234.7 | 101.0 | 90.2 | 90.2 | 90.2 | 16.0 | 10.8 |
| 5.4.1 | 0.0 | 0.0 | 0.0 | 225.6 | 189.1 | 189.1 | 189.1 | 189.1 | 189.1 | 81.0 | 72.2 | 72.2 | 72.2 | 12.2 | 8.0 |
| 5.4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.4.3 | 0.9 | 0.9 | 0.9 | 54.2 | 45.6 | 45.6 | 45.6 | 45.6 | 45.6 | 20.0 | 18.0 | 18.0 | 18.0 | 3.8 | 2.8 |
| 5.4.3.1 | 0.0 | 0.0 | 0.0 | 53.3 | 44.7 | 44.7 | 44.7 | 44.7 | 44.7 | 19.1 | 17.1 | 17.1 | 17.1 | 2.9 | 1.9 |
| 5.4.3.2 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6.0.0 | 0.6 | 0.6 | 0.6 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| 6.1.0 | 0.6 | 0.6 | 0.6 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| 6.2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6.3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.0.0 | 8.4 | 8.3 | 8.2 | 8.3 | 8.2 | 8.1 | 8.0 | 8.0 | 7.9 | 7.8 | 7.7 | 7.6 | 7.6 | 7.5 | 7.4 |
| 7.1.0 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 |
| 7.1.1 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 |
| 7.1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7.2.0 | 3.6 | 3.5 | 3.4 | 3.5 | 3.4 | 3.3 | 3.2 | 3.1 | 3.0 | 3.0 | 2.9 | 2.8 | 2.7 | 2.7 | 2.6 |
| | 32.7 | 44.8 | 46.4 | 403.0 | 339.7 | 339.6 | 339.5 | 339.5 | 339.4 | 151.8 | 136.6 | 136.5 | 136.4 | 32.3 | 24.9 |

**ATTACHMENT U**

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## *COMMENTS ON THE DEIS FOR YUCCA MOUNTAIN - AUGUST 1999*

January 5, 2000

Introduction

The Draft Environmental Impact Statement (DEIS) for the Yucca Mountain high-level waste project was issued in August 1999 and includes an evaluation of environmental consequences (in terms of dose) of alternative repository design concepts and alternatives. The conclusion drawn from the results of these evaluations is that compliance is achieved.

There is however, strong evidence which casts doubt on the validity of the conclusions and these compliance assessments in light of NWPA and NEPA requirements. This evidence is related to the choice of groundwater pathways selected for the analyses.

At Yucca Mountain, the primary human exposure pathway is through ingestion of ground water. In conducting a performance assessment for Yucca Mountain, an accurate view of the groundwater flow field is essential. This is because the velocity of the groundwater is one of the most sensitive parameters in the transport equation, and therefore strongly influences dose calculations. The direction of the groundwater pathway is important as it dictates the hydrologic and geochemical character of the rock encountered along the pathway. Direction along with velocity strongly influence sorption and other important variables such as dilution and effective porosity in the saturated zone.

There has been considerable debate over the actual flow paths which would be followed by the radionuclides released from the repository. Modeling results performed by the State of Nevada (Lehman and Brown, 1994, Lehman and Brown, 1995) indicate major differences may exist in flow path direction, velocity, and sorptive capability compared to that used in the latest assessments by the DOE, including the DEIS, when all data sets are utilized.

By failing to evaluate credible alternative models of, or opposing views of the saturated zone, the DOE is not in compliance with NEPA. Being out of compliance with NEPA means automatic noncompliance with the NWPA. They are specifically out of compliance with NEPA 1502 for: not summarizing, discussing or using important data sets; They have failed to evaluate credible opposing viewpoints; and the DOE does not propose testing to reduce uncertainty in the choice between alternative conceptual flowpaths.

In addition to these NEPA/NWPA compliance issues, several technical concerns are discussed which involve ranges of parameters utilized and parameters which could have been used but weren't. These points will be discussed separately below.

NEPA/NWPA Related Issues

1. Non-compliance with NEPA (1502.22)

The Nuclear Waste Policy Act requires that an EIS, consistent with the National Environmental Policy Act (NEPA) be prepared and accompany a recommendation for site approval. The amended NWPA (1987) still requires consistency with NEPA, but does not require the DOE to consider:

1. The need for the repository
2. Alternative sites to Yucca Mountain, or
3. Non-geological alternatives

NWPA Section 114(f) specifically states that all other provisions of NEPA apply. NEPA Section 1502.22 relates to incomplete or unavailable information. This section was developed as a result of dropping the "Worst case analysis" from previous NEPA provisions. NEPA regulations amended in 1986 now require that if information is available that would aid in evaluating uncertain effects, it must be obtained and analyzed unless it is too expensive to do so. If costs are prohibitive, then it must be disclosed as incomplete or unavailable information. Specifically, regulations require that if information cannot be obtained, the EIS must include :

1. A statement that such information is incomplete or unavailable.

2. A statement of the relevance of the incomplete or unavailable information to evaluating reasonably foreseeable significant adverse impacts on the human environment.

3. A summary of existing credible scientific evidence which is relevant to evaluating reasonably foreseeable significant adverse impacts on the human environment.

4. The agency's evaluation of such impacts based upon theoretical approaches or research methods generally accepted in the scientific community.

The Yucca Mountain DEIS is not in compliance with numbers 2, 3 or 4 above. While the DOE has stated that information used in determining the groundwater flow model is incomplete or unavailable, the existing credible scientific evidence which is relevant to evaluating reasonably foreseeable significant adverse impacts has not been summarized nor has it all been utilized in developing flowpaths.

Also, the impacts evaluation assumed the same groundwater flow paths and characteristics which were used in the DOE Viability Assessment and Total System Performance Assessment documents; i.e. a matrix type flow evaluation utilizing only 2D flow and 1D transport calculations. While these are generally accepted methods, they may not be representative of the saturated zone flow field that exists at Yucca Mountain today.

The DOE has not utilized all available and relevant data in their pathway identification or characterization. Because of this, the impacts in terms of dose to the Critical Group(s) or receptors may be misrepresented. While recognizing differing viewpoints regarding groundwater flow, the DEIS fails to analyze flowpaths from a full data set that considers this information. Because all data that have been generated are not considered in the impacts evaluation, there may be significant differences in the groundwater impacts projected in the DEIS. Unless these analyses are considered, impacts projected in the DEIS are inadequate for NEPA compliance and their credibility questionable.

In addition, the requirement to disclose all credible scientific evidence extends to responsible opposing views provided these are supported by theoretical approaches or research methods generally accepted in the scientific community.

The Yucca Mountain DEIS recognizes differing viewpoints regarding groundwater flow (Section 3.1.4.2. and Section 5.2.3.4.) and references the State of Nevada study of Lehman and Brown, but it fails to evaluate the impacts and actually gives little credibility to this alternative flowpath model. The DEIS admits that the alternative flowpath could produce different results, however, it states the extent to which the different viewpoint would affect the impacts is unknown but speculates the effects would be minimal (due to long canister lifetimes). This may not be the case, and in terms of doses to populations of the State of Nevada, any credible alternative must be evaluated.

2. NEPA Compliance - Required Evaluations

While NEPA regulations amended in May, 1986, eliminated the worst case analysis requirement, it did not eliminate the requirement that agencies evaluate the reasonably foreseeable significant adverse impacts of an action, even if information is unavailable or incomplete. Rather, it specified that the evaluation must be carefully conducted and based on credible scientific evidence. Furthermore, NEPA regulation (40 CFR 1502) requires disclosure of all credible scientific evidence, including responsible opposing views which are supported by theoretical approaches or research methods generally accepted in the scientific community.

We suggest that to be in compliance with NEPA that the DOE is required to consider effects of credible alternative models in the DEIS. While the DEIS recognizes differing viewpoints regarding groundwater flow (Section 3.1.4.2. and Section 5.2.3.4) and references the State of Nevada funded studies of Lehman and Brown, 1995, there has been no evaluation of the impacts.

3. Inadequate use of existing data in analyses to reduce uncertainty.

In order to evaluate the conclusions of either the Viability Assessment (TSPA/VA) or the Draft

Environmental Impact Statement (DEIS), the basic underlying assumptions of the latest Performance Assessments (TSPA) must be examined. The TSPA documents form the technical basis and justifications of DEIS or TSPA/VA conclusions. The relative importance of these assumptions to the outcomes of the TSPA also should be understood.

It has been known for some time that the Yucca Mountain ground water system has a range of temperatures associated with it, spatially It also has been hypothesized that certain features in the water table surface (embayments) are coincident with major faults. These facts lead to the hypothesis that faults and fractures dominate the flow of groundwater through the volcanic tuffs underlying Yucca Mountain. Measurements and interpretations by the USGS and our own analysis of water table fluctuations and groundwater temperature seem to collaborate this hypothesis.

In the hydrogeologic assessments of ground water pathways in complex systems such as exist at Yucca Mountain, heat may be used as a flowpath tracer. Using heat along with hydraulic head and chemistry measurements serves to constrain the results of analyses which tend to have non-unique solutions. The use of heat and chemical tracers can give a much more reliable answer to ground water flow directions in a complex system than the use of hydraulic head data alone. Unfortunately, the latest Total System Performance Assessment (TSPA) of Yucca Mountain (November 1998) which forms the technical basis for the TSPA/VA and DEIS did not include geologic structure, temperature, or chemistry data in their determination of saturated zone ground water flowpath velocities or directions. It is our contention that DOE must utilize all relevant data available to them in determining ground water flowpaths to potential receptors, not just selective or partial data sets.

The use of partial data sets is also addressed in NEPA 1502.22 item 3 above. The NEPA would require all data be summarized which are significant to impacts assessments. The DOE has utilized flow modeling in the DEIS which is based on one dimensional or two dimensional hydrologic or transport models which are only calibrated to hydraulic head measurements. Other data sets have been available, some since the late 1980's which could help the DOE better constrain and define the actual pathways taken by radionuclides from the repository to the receptors. These data sets include temperature (Sass, 1988), geochemistry developed by the USGS and Nye County, well hydraulics data obtained from Nye county pump tests and geologic structure information developed by the CNWRA.

The State of Nevada-funded studies utilized hydraulic head, temperature and structure explicitly in their 3-D modeling efforts. These studies have shown significant differences in flowpaths and are additionally supported by more recent geochemistry data sets and developing structural data. The flowpath evaluated by the DOE utilizing hydraulic head data only, one obtains a flowpath which is initially moving eastward and then southeastward. This flow path allows the radionuclides to move quickly from the fractured tuffs of Yucca Mountain into the Valley Fill sediments of Forty Mile Wash. This flow path allows the radionuclides to be in contact with "alluvium" (modeled as fine grained sediments) which naturally are expected to have high sorptive capability for radionuclides, for very long distances. Thus, traveling on the DOE pathway, sorption and dispersion would act to retard and disperse the radionuclides of concern, and yield minimal doses to affected populations.

On the other hand, if the preferred radionuclide pathway is as modeled by Lehman and Brown, 1994 and 1995, then it is likely that significant increases in calculated dose could occur. Comparing this flowpath to the DOE flowpath, a radionuclide would travel first south through the mountain block and then southeast or even possibly south west for some time in the fractured tuff rock before emerging into the Valley Fill sediments south or southeast of the mountain block. These differences are important as the fractured tuff rock yields smaller values of sorptive capability. Further, velocities in the fractured tuff are expected to be orders of magnitude faster than those of the Valley Fill sediments. The pathway through the Valley Fill would also be much shorter via this route, minimizing sorption of radionuclides. It may also be expected to limit dispersion of radionuclides and volumetric flux rates used in the dispersion calculations. Nye County pump test data indicates compartmentalization of the flow field, possibly into small blocks. This small compartments will not have as large a volume of water as is assumed in the DEIS. These effects all combine to yield higher doses.

Technical Concerns Choice of Pathway and Receptor

1. Addressing Uncertainties

The Yucca Mountain DEIS acknowledges uncertainty in data in a number of technical areas, and identifies a number of on going and additional studies that it intends to conduct to address these uncertainties (DEIS Section 5.2.4). However, the DEIS does not discuss uncertainties in the groundwater flowpath, nor are there planned additional studies to address the potential for a different flowpath than that used in the impacts evaluation.

2. Location of Receptor and Receptor Type

As we commented on the VA, there are serious concerns about the selection of groundwater pathway and its associated hydrologic and geochemical parameters used for compliance assessments. As stated earlier there has been considerable debate over the actual flow paths which would be followed by the radionuclides released from the repository. We most likely have several different groundwater pathways for radionuclide travel and several differing populations to consider in the compliance determination, i.e., Lathrop Wells and Amargosa Valley. These flow path directions range from approximately 90° east To 180° south, roughly. The flow pathways are complicated to model accurately, because they are diverse, chemically and hydrologically and could be significantly different in terms of calculating radionuclide transport via the groundwater and concentrations at a given point. Further, EPA has not defined the Critical Group or receptor as yet.

3. Dilution Calculations

Appendix I. Section 1.4.5.4 discusses how the dilution factors were calculated. These numbers will need to be compared to annual yields of the basins to determine if they are representative. If compartmentalization of the flow field is envisioned, then dilution volumes may only be fractions of the assumed yields.

A specific example can be cited on page 5-34 in Section 5.4.3, Table 5-13. This table shows population consequences from groundwater releases of radionuclides during 10,000 years after repository closure for the low thermal load scenario. Here the scaling factor for changing the dose rate for the maximally exposed individual into a dose rate for a member of the population was computed by diluting 46 acre-feet of water infiltrating through the repository by the annual water use in the Amargosa Valley of about 14,000 acre-feet. If exposures are to be calculated at Lathrop Wells, or anywhere along Highway 95 of north of Highway 95, then these dilution volumes are probably too high and not accurate, especially given a compartmentalized system.

4. Infiltration through the unsaturated zone.

The distribution of infiltration across the Yucca Mountain block is questioned. The distribution of infiltration used in the DEIS is highest at the crest. There are indicators which would suggest that peak infiltration is on the western flank of the mountain block. Infiltration in this western block region may be underestimated and its effect unknown.

5. Long Canister Lifetimes

The very long canister lifetimes assumed in these analyses force almost total dependance upon the proper working of the canister. There is no precedence for this lengthy canister performance, so total reliance on this engineered aspect of the system is not justified, nor is it what was envisioned in the NWPA or previous EPA standards. Defense in depth is not fully realized if this approach is taken. Further, corrosion models are highly dependent upon the system modeled, i.e., high temperature, low temperature, wet or dry repository. The environment under which corrosion is calculated has not been definitely specified. Rather DOE is keeping their options open making review of options and their effects complicated.

<u>Summary</u>

In summary, the DEIS for Yucca Mountain is not in compliance with the NWPA or NEPA. Additionally there are numerous instances where important parameters to the outcome of the assessments are not considered realistic or valid. DOE is in the process of reconsidering its saturated zone flow models. Until these models are finalized, and used in the analyses of consequences, no credance can be given to conclusions drawn in the DEIS.

# ATTACHMENT V

# THE TRANSPORTATION OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE:

## A Systematic Basis for Planning and Management at National, Regional, and Community Levels

**September 10, 1996**

**Prepared for**
**Nevada Nuclear Waste Project Office**

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# ABBREVIATIONS

| | |
|---|---|
| BN | Burlington Northern Railroad |
| BWR | Boiling Water Reactor |
| CCP | "Current Capabilities" Scenario |
| CNW | Chicago and North Western Railroad |
| DOE | U.S. Department of Energy |
| DOT | U.S. Department of Transportation |
| EIS | Environmental Impact Statement |
| EM | Environmental Management |
| FICA | Facility Interface Capabilities Assessment |
| FRA | Federal Railroad Administration |
| GA | General Atomics |
| GE | General Electric |
| GTW | Grand Trunk Western Railroad |
| HANF | Hanford |
| HLW | High-Level Radioactive Waste |
| HM164 | Hazardous Materials Regulation 164 |
| HTG | High Temperature Gas |
| INEL | Idaho National Engineering Laboratory |
| LWT | Legal-Weight Truck |
| MPC | Multi Purpose Canister |
| MSC | Miscellaneous Spent Nuclear Fuel |
| MTU | Metric Tons of Uranium |
| MXR | "Maximum Rail" Scenario |
| NAC | Nuclear Assurance Corporation |
| NRC | Nuclear Regulatory Commission |
| NSP | Northern States Power |
| NSTI | Near-Site Transport Infrastructure |
| OCRWM | Office of Civilian Radioactive Waste Management |
| O-D | Origin-Destination |
| PSG&E | Public Service Gas & Electric |
| PWR | Pressurized Water Reactor |
| RSA | Regional Servicing Agent |
| RSC | Research Reactor Fuel |
| SF | Santa Fe Railroad |
| SNF | Spent Nuclear Fuel |
| SP | Southern Pacific Transportation Company |
| SRS | Savannah River Site |
| TMI | Three Mile Island |
| UP | Union Pacific Railroad |
| TVA | Tennessee Valley Authority |
| WVDP | West Valley Demonstration Project |

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# SUMMARY

To describe a national shipment campaign in a fashion which provides the inputs needed for risk and impact analysis as well as the information needed for coordinated planning and management requires an integrated assessment process for systematic consideration of at least the following factors:

- Waste origins, storage locations, and shipment sites
- Waste inventory: current and projected
- Waste acceptance startup and rate
- Priorities for waste acceptance and pickup
- Waste shipment groups
- Transportation cask options
- Transportation mode and cask choices by shipment site
- Routing criteria and routing options

Consideration of these factors enables one to provide useful information in response to basic questions regarding the shipment campaign in prospect under legislation proposed in the 104th Congress: e.g., How many cask shipments are expected? In which acceptance/pickup years? On which rail and highway routes? Through which states and communities? Sections 1 through 15 of this report discuss the factors in an integrated assessment process for a national shipment campaign, the assumptions used in this analysis, and the sources and bases for these assumptions. Sections 16 through 20 discuss the results of alternative scenarios involving three sets of transportation mode and cask choices, and two regional routing options. Section 21 illustrates a process for assembly of additional information on route features needed in risk analysis and management of transportation operations.

Three alternative sets of transportation cask choices at 80 shipment sites are considered:

- An assessment of *current capabilities* for cask loading and near-site transportation suggests that 32 commercial plant sites could choose to ship by legal-weight truck—either in currently-available casks for highway transport of uncanistered fuel or in a high-capacity cask such as the GA-4/9, if and when available.

- An *MPC base case* scenario of transportation choices could reduce to 17 the number of commercial sites shipping by legal-weight truck, and encourage 14 sites to use large-capacity rather than smaller capacity rail casks. However, implementation of the MPC base case requires investments to improve loading capabilities and/or near-site transportation at many sites, plus provision of as-yet-uncertified high-capacity transportation casks and canisters.

- A *maximum rail* scenario of transportation choices could reduce to three the number of commercial sites shipping by legal-weight truck. The maximum rail scenario is almost identical to the scenario assumed by DOE in its recent strategy study for transport to a potential repository at Yucca Mountain.

The *current capabilities* scenario results in 79,300 legal-weight truck casks shipped 62.3 million miles on 13,700 miles of the nation's public highways, *plus* 12,600 rail casks shipped 14.0 million miles

on 18,800 miles of the nation's railroads. The high-capacity legal-weight truck cask, if available and used consistently, could reduce highway transport to 31,400 casks shipped 14.7 million miles. Implementation of the *MPC base case* scenario with high-capacity truck casks could further reduce highway transport to 6,300 casks shipped 5.7 million miles over 10,200 miles of the nation's public highways. These reductions, however, would require investments to improve loading and/or near-site transportation capabilities at 29 sites, and would also involve increases in rail cask shipments (10 percent), rail cask shipment miles (9 percent), and rail route miles affected (13 percent). Implementation of the *maximum rail* scenario would further reduce highway transport to 1,150 high-capacity casks shipped 1.0 million miles over 4,200 miles of the nation's public highways. These reductions would require further investment in loading and/or near-site transportation capabilities at 14 sites, and it would also involve further increases in rail cask shipments (9 percent), rail cask shipment miles (10 percent) and rail route miles affected (11 percent).

Different phases of the 30-year shipment campaign affect different portions of the nation's rail and highway networks to different extents. For example, truck shipment comprises 35 percent of the 86,600 metric tons shipped under the *current capabilities* scenario of transportation choices, but 66 percent of the 4,400 metric tons shipped in the first three years of the 30-year shipment campaign. Truck shipment comprises 11 percent of the MTU shipped under the *MPC base case* scenario, but 27 percent in the first three years. These differences reflect the loading and near-site transportation capabilities of sites storing fuel with high-priority for acceptance and pickup.

Perspectives on a national shipment campaign tend to correlate with one's position as an origin, corridor or destination community for shipments of highly-toxic and long-lived radioactive materials. Under the *MPC base case* scenario (default routing), seven states comprising two percent of the nation's population are neither origins, corridors nor the destination for shipments of SNF or HLW. Another seven states comprising 18 percent of the nation's population are origins for such shipments but not corridors for shipments from other states. Still another seven states plus the District of Columbia are corridors but not origins for such shipments; these comprise seven percent of the nation's population. Twenty-eight states comprising 71 percent of the nation's population are both origins for SNF or HLW shipments and corridors for shipments originating elsewhere. The major corridor states under the MPC base case scenario (default routing) are Utah (65 sites), Nebraska (60 sites), Wyoming (58 sites), Illinois (47 sites), Iowa (32 sites), Kansas (28 sites), Missouri (27 sites) and Indiana (25 sites).

All shipments converge in Nevada, the destination state and intended permanent storage location for the nation's SNF and HLW. Nevada has about 0.5 percent of the nation's population. Under default routing, truck shipments enter the state on I-15, either from California moving north alongside the Las Vegas Strip, or from Arizona moving southwest through the Moapa Indian Reservation. Accessing US-95 at the interchange locally known as the "Spaghetti Bowl," truck shipments move northwest through rapidly developing Las Vegas suburbs, entering the Nevada Test Site at the Lathrop Wells, in the Nye County community of Amargosa Valley. Rail shipments enter the state on the Union Pacific railroad, either from California moving north alongside the Strip and through Las Vegas and the Moapa Indian Reservation, or from Utah south to the Lincoln County community of Caliente. At Caliente, rail casks would be transferred to heavy-haul trucks for shipment along U.S. highways and state roads, accessing the Nevada Test Site via a newly constructed road across the Nellis Air Force Range (a 162-mile journey), or continuing on public highways along a circuitous route north and west of the Nellis Air Force Range.

Many departures from default routing could occur as states consider designated alternative routes for "highway route-controlled quantities" of SNF and HLW, and as utilities consider alternative railheads for rail shipments and carriers consider implications for rail freight traffic. These departures have implications, some major, others minor, for the national routing system for SNF and HLW shipments—which route segments are affected, when and to what degree. One major option is a "consolidated southern" routing in which truck shipments from the East and Midwest are oriented to I-40 through St. Louis, Oklahoma City, and Albuquerque rather than to I-80 and I-70, and rail shipments are oriented to the Santa Fe lines through Kansas City, Amarillo and Barstow rather than to the Union Pacific through Nebraska and Wyoming or the Southern Pacific through Kansas and Colorado.

The assessment compares cask shipments under default and consolidated southern routing for five rail and five highway route segments in four states (Wyoming, Colorado, New Mexico, and Nevada). Consolidated southern routing could eliminate or substantially reduce rail and highway cask shipments on the selected Wyoming and Colorado route segments and on the Nevada route segments for shipments from the north. At the same time, however, consolidated southern routing would increase rail and highway shipments on route segments through New Mexico, Arizona and California (east of Barstow), and on the Nevada route segments for shipments from the south and alongside the Las Vegas Strip.

The national shipment campaign in prospect under legislation proposed in the 104th Congress involves 80 sites shipping on different schedules, by different modes, using large portions of the nation's major rail and highway systems, over a 30+ year period, through many states and communities which may have widely varying perspectives on the potential risks and impacts, and widely varying resources for planning and coordination with other affected states and with the relevant federal agencies. Policy considerations to limit, divert or manage impacts need to be combined with an integrated assessment process which provides all parties with systematically-developed information on the implications of the shipment campaign at national, regional, and community levels.

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# INTRODUCTION

The 1982 Nuclear Waste Policy Act (NWPA) formalized the goal that spent nuclear fuel (SNF) and high-level radioactive waste (HLW) from roughly 80 temporary storage locations in 36 states should be transported to one or perhaps two permanent geologic repositories for permanent disposal. 1987 amendments to the NWPA specified that Yucca Mountain (NV) was to be the site for the nation's single prospective geologic repository and the ultimate destination for these highly-toxic and long-lived materials.

Less clear since 1987 has been the strategy for managing waste until the time that the permanent repository is available. Should it continue to be stored at its current "temporary" locations, and shipped to the permanent repository when it is available? If so, federal government acceptance could be delayed 10, 20 or even more years beyond the 1998 acceptance date promised in 1982. Should it be transported to a centralized above-ground storage facility (which under current law cannot be in the same state as the permanent repository) to await a second shipment to the geologic disposal site? If so, the federal government would have to find a suitable site outside Nevada, and persuade its stakeholders that centralized storage would not become de facto a permanent above-ground repository.

Legislation proposed in the 104th Congress* would deal with these questions by shipping waste early and to Nevada. The legislation directs DOE to accept spent nuclear fuel at specified annual rates beginning not later than November 1999 for transport to a specified destination—a centralized above-ground storage facility on the Nevada Test Site, adjacent to Yucca Mountain. A viability assessment completed in 1998 is intended to provide some assurance that the wastes shipped to Nevada for above-ground storage could ultimately be disposed at a Yucca Mountain geologic repository, and that a second shipment to another interim or permanent site will not be necessary.

Neither Congress nor DOE has developed a plan for implementing the transportation and storage provisions of the proposed legislation. It is uncertain, for example, when shipments would begin, how rapidly they would proceed, what shipment priorities might be, what transportation/storage casks might be available, how utilities would choose among available casks, what routes would prove most acceptable, etc. How would these questions be resolved, and who would be involved in their resolution, at what stage and with what authority, responsibility and capability? How will the risks, "real" and "perceived," be addressed, assessed, and effectively managed? Even the role and accountability of DOE is uncertain, given its recent initiative to privatize the entire civilian spent fuel transportation system, leaving decisions about shipping containers, modes and routes largely up to private contractors.

Though occasional shipments of spent fuel and other highly-radioactive materials (e.g., cesium, naval reactor fuel) have been safely conducted and effectively managed, no land-based shipment campaign of the scale implied by proposed legislation has been conducted in the U.S. or elsewhere. How best to plan for and effectively manage such a campaign in our participatory federal system of governance of the 1990's has not been decided. It is generally assumed that such a campaign would require the coordinated participation of several federal and many state, local, and private agencies—each responsive to its own constituencies. It is acknowledged that these agencies would need to participate in an extensive array of

* Senate bill 1936 (S. 1936), a substitute for the earlier Senate bill 1271. A companion bill (H.R. 1020) is under consideration in the House of Representatives.

activities over many months, years, even decades. It is generally acknowledged that a detailed description of the national shipment campaign, including an inventory of key local conditions potentially affected, is required as the basis for coordinated planning and management. But, though proposed legislation would make an unprecedented national shipment campaign a near-term prospect, such a detailed description is not available as a resource for the many parties which would expect to participate in its coordinated planning and management.

One way to reduce uncertainty is to develop scenarios which reflect specific assumptions regarding relevant factors, and which then provide detailed information (e.g., shipments by cask type, origin, route segment, and year) needed as the basis for planning and management. One purpose of this report is to describe several possible scenarios for the shipment campaign in prospect under S. 1936, and the direct consequences of these scenarios—prospective cask shipments of particular types on particular rail and highway routes in particular years. In the process, the report identifies the several factors and assumptions that underlie any scenario for a national campaign for shipment of SNF and HLW. These factors, combined in an integrated assessment process, suggest the type of information base needed in the planning and management of national shipment campaign—the inputs needed for analysis of risks and impacts, and for identification and resolution of issues ranging from overall campaign efficiency, to regional routing options, to issues specific to particular communities or route segments.

This study applied an integrated assessment system to develop scenarios considering three sets of potential utility transportation choices, two alternative routing strategies and two alternative truck cask options. It will be apparent in review of the factors and assumptions that many other scenarios for the prospective shipment campaign are possible. The integrated assessment process supports the consistent development of alternative scenarios with comparable outputs at the national, regional, and route-segment level.

As introduction to the scenarios, this section discusses the *activities* involved in planning and managing a national shipment campaign, the *agencies* which must coordinate to conduct these activities, the *information* needed as a basis for coordinated planning and management, and the *factors* that must be considered in generating this information.

### Activities

To identify the range of activities involved in planning and managing a national shipment campaign, one might consider DOE's May 10, 1996 notice of proposed policies and procedures for implementing section 180(c) of the Nuclear Waste Policy Act regarding training for safe routine transportation and emergency response training.[1] A review of this notice, which summarizes and responds to previous stakeholder comments on the subject, provides a useful list of the activities which will be involved in the transportation of SNF and HLW from about 80 origin sites across the country, along numerous highway and rail routes, across many jurisdictions and communities, over a 30-year period to an interim or permanent storage site in Nevada. The list of activities, only a few of which DOE proposes to support with 180(c) funds, includes:

- route selection
- alternative route analysis
- route risk analysis
- route inspection (highway and rail)
- contingency routing plans
- transportation infrastructure improvements

- shipment notification
- shipment tracking
- shipment escorting
- provision of public information on routing and shipments
- preparation and enforcement of transportation operations protocols
- carrier and shipper compliance reviews
- assessment of state and local capabilities regarding safe routine transport and emergency response
- enhancement and maintenance of state and local emergency preparedness
- enhancement and maintenance of emergency response and recovery capabilities
- awareness training for first-on-scene and first responder personnel
- specialized training for emergency management and recovery personnel
- public information training for route community liaison personnel
- training for hospital personnel, if and as necessary
- waste acceptance scheduling (start date and annual rate)
- waste acceptance prioritization
- transportation cask design, certification, production, and delivery
- cask loading (wet or dry)
- accident notification
- safe parking designation and procedures
- provision of equipment for emergency response, inspection, first response personnel

**Agencies**

If the activities involved in nuclear waste transportation are numerous and varied, the actors are numerous and varied as well—adding to the need for federal agencies as well as potentially affected states and local governments to have a sound description of and an effective role in planning the shipment campaign in prospect. The actors, whose respective roles and responsibilities have been much discussed but not decided, include federal, state, local agencies as well as utility shippers, contract carriers, and others.

- Federal agencies include:

  — DOE/OCRWM (Office of Civilian Radioactive Waste Management) . . . manager of the Nuclear Waste Fund and responsible for high-level waste management strategy.

  — DOE/EM (Environmental Management) . . . responsible for HLW in the DOE complex, and for the Nevada Test Site Area 25, designated as the site for centralized above-ground storage in proposed legislation.

  — DOT/RSPA (Research and Special Programs Administration) . . . responsible for implementation guidelines for HMTUSA (the Hazardous Materials Transportation Uniform Safety Act).

  — DOT/FHWA (Federal Highway Administration) . . . responsible for implementation of HM164, and for inspection of highway shipments.

  — DOT/FRA (Federal Railroad Administration) . . . responsible for rail inspections and regulation, and for special studies regarding rail shipments.

- NRC (Nuclear Regulatory Commission) . . . responsible for certification of storage and transportation canisters and casks.

- FEMA (Federal Emergency Management Agency) . . . responsible for emergency management and response in transport of radiological materials.

- Coast Guard/Corps of Engineers . . . responsible for regulation of barge shipments and intermodal transfer at barge terminals.

- State agencies include state police and highway patrols, emergency management agencies, utility regulatory commissions, agencies responsible for route designation, radiological health agencies, environmental regulation agencies, etc.

- State agencies need to coordinate with their counterparts in adjacent states and with Indian tribes, perhaps via regional groups.

- State agencies also need to coordinate with local jurisdictions (especially police, fire, and transportation departments) and with utility (and DOE) shippers and their selected carriers.

- Operating under federal and state guidelines, various private organizations are likely to be directly responsible for cask fabrication, truck transport, and/or rail transport. Furthermore, DOE could convey to private industry contractors broad responsibility for planning and managing campaigns for transporting high-level nuclear waste from various sections of the country. A May 28, 1996 notice in the Federal Register[2] indicates that DOE/OCRWM anticipates contracting with private industry for:

  - virtually all aspects of spent fuel acceptance
  - supplying transportation (and storage) casks
  - transportation to a designated storage facility
  - any required intermodal transport or heavy-haul
  - handling uncanistered spent fuel, as necessary.

  Under such contracts—DOE anticipates two or more contractors serving four regions—the private companies would be permitted to:

  - alter the order of spent fuel acceptance (presumably in consultation with utilities) and/or
  - recommend preferred transportation routes (presumably in consultation with states).

### Assessment and Management Information Needs

However roles and responsibilities are decided, any federal, state, local agency or contractor will need certain information as a basis for planning, coordination, and management:

- how many cask shipments are expected?
- containing what types of SNF or HLW?
- in what types of casks?
- in which acceptance year?
- from which storage locations?
- by what mode? (rail, highway, barge)
- on which rail or highway route segments?

In sum, though they may focus on topics or geographic areas of particular relevance to their own responsibilities or contributions, any participating agency will need to plan and manage with reference to a detailed description of the shipment campaign, consistently developed at national, regional, and community levels.

### Assessment System Factors

To generate such information for a transportation scenario, however, requires an assessment system in which explicit assumptions are made and information systematically generated regarding at least the following factors:

- Waste origins and storage locations (section 1)
- Current and projected inventory (section 2)
- Waste acceptance startup and rate (section 3)
- Priorities for waste acceptance and pickup (section 4)
- Waste shipment groups (section 5)
- Cask options (section 6)
- Transportation choices and choice factors (sections 7 through 11)
- Annual cask shipments (section 12)
- Routing criteria, mapping, and segmentation (sections 13 and 14)
- Routing options: origin-destination pairs (section 15)

Combined in an integrated assessment system, these factors generate information regarding:

- Routes and cask shipments over the 30-year (life of operations) national campaign (section 16).
- Routes and cask shipments at the Nevada destination—the end of the funnel (section 17).
- Regional routing alternatives and consequences for particular routes in various states (section 18).
- Annual cask shipments and the routes involved in various phases of the campaign (section 19).
- Transportation operations requirements—cask shipment miles, cask shipment miles per MTU shipped, cask shipments per route mile affected (section 20).

Assessment of risks, impacts, and policy options requires systematically-assembled information on key features along affected routes, as illustrated in section 21.

### Scenarios Considered in this Study

Using an integrated assessment system, this study describes the national shipment campaign for scenarios which differ in utility transportation choices (three alternative sets), routing strategy (a base case and a consolidated southern routing strategy across central and western states) and cask options (two rail casks, plus one of two legal-weight truck casks). Figure 1 summarizes the factors varied and held constant in these scenarios, providing references to relevant sections of the report.

The integrated assessment system can be used to describe in similar dimensions and detail any national shipment campaign which could emerge—e.g., scenarios reflecting a different current or projected inventory, different acceptance rates or priorities for pickup, alternative cask options, different utility transportation choices and/or alternative routing criteria.

## Figure I-1. The Transportation of SNF and HLW: Key Assess System Factors and Variables

| | SPENT NUCLEAR FUEL | HIGH-LEVEL WASTE |
|---|---|---|
| 1.WASTE ORIGINS | 124 commercial reactors in 34 states<br><br>Spent fuel from research reactors:<br>General Atomics.... priority ranking<br>DOE: 8 sites<br>Domestic non-DOE: 8 sites<br>Foreign: 3 temp storage sites in US | 4 major DOE sites:<br>Hanford (WA)<br>Idaho Nat Eng Lab (ID)<br>Savannah River (SC)<br>West Valley Demo Proj (NY) |
| STORAGE LOCATIONS | 82 pools assoc with individual reactors<br>20 pools joined by transfer canals<br>11 pools shared by two reactors<br>7 pools at offsite locations (3 DOE)<br>14 onsite dry strg facil (ex & planned) | Same 4 major DOE sites |
| SHIPMENT SITES | 83 sites (4 DOE) in 36 states | Same 4 major DOE sites |
| 2.INVENTORY | Nov'94: 10809 MTU in 59418 BWR assemblies<br>19149 MTU in 44602 PWR assemblies<br>86 MTU in HTG, RSC, MSC SNF<br>30044 MTU total<br><br>Cumul: 30,682 MTU in 169,675 BWR assemblies<br>55,931 MTU in 129,517 PWR assemblies<br>86 MTU in HTG, RSC, MSC, SNF<br>86,699 MTU total | 13789-28372 canisters of vitrified HLW<br>Hanford: 7067-15000 canisters<br>INEL: 704-8500 canisters<br>SRS: 5717-4572 canisters<br>WVDP: 300 canisters |
| 3.ACCEPTANCE START | Annual estimates, w/o specified start yr | Year 15: ie 2015 if 2000 start yr |
| ACCEPTANCE RATE | Years 1- 5: 9100 MTU<br>Years 6-10: 15000 MTU<br>Years 11-15: 15000 MTU | Years 15-20: 4000 canisters<br>Years 21-25: 4500 canisters<br>Years 26-30: 5000 canisters |
| 4.ACCEPTANCE PRIORITY | Oldest fuel (current & projected) first<br>No within utility reallocations<br>No among utility trades | Generally: 1. WVDP<br>2. SRS<br>3. HANF<br>4. INEL |
| 5.SHIPMENT GROUPS | Among acceptance years? No<br>Among assembly types? Yes<br>Among reactor types? No<br>Among waste origins? No | Not applicable (canistered waste) |
| 6.CASK OPTIONS | R125: similar to DOE's 125-ton MPC<br>R75: similar to DOE's 75-ton MPC<br>LWT: legal-weight truck cask<br>T4/9: the GA-4/9 cask, used if available<br>T1/2: similar to the NAC LWT | R100: an adaption of DOE's 125-ton MPC |
| 7.CASK LOADING FACTORS | Design crane capacity (tons)<br>Operating crane capacity (tons)<br>Cask set-down area (max cask option)<br>Cask length requirement (max cask option) | Assume adequate to load R100 |
| 8.NEAR-SITE INFRASRUC | Onsite rail ?<br>Operating onsite rail ?<br>Onsite rail upgrade cost<br>Distance to offsite railhead | Assume adequate to ship R100 |
| 9.OTHER TRANSPORTATION CHOICE FACTORS | Federal policies<br>Utility choice criteria<br>Changes at or near utility sites | DOE policy<br>Changes at or near DOE sites |
| 10.TRANSP CHOICE DECISION | Four case examples:<br>Monticello<br>Big Rock Point<br>Point Beach<br>Salem/Hope Creek<br>Enrico Fermi | Factors 6-8 determine |

**Figure I-1 (Cont).**

| | SPENT NUCLEAR FUEL | HIGH-LEVEL WASTE |
|---|---|---|
| 11.TRANSP CHOICE SCENARIOS | Current capabilities<br>MPC base case<br>Maximum rail | All rail shipment, using R100 |
| 12.CASK SHIPMENTS | BWR/PWR assemblies in shipment group/ cask capacity (partially-filled cask=1)<br><br>Non-BWR/PWR MTU in shipment group/ MTU per cask (BWR/PWR) | Canisters in shipment group/ 5 canisters per cask (partially-filled cask=1) |
| 13.ROUTING CRITERIA | | |
| Default route/ highway: | HM 164; max use of interstate hwys;<br>Min transit time; two drivers;<br>Pop centers not avoided. | NA |
| Default route/ rail: | Nearest railhead or designated barge:<br>Min carrier transfer; min transit time;<br>Pop centers not avoided | Same as SNF |
| Consolidated southern route/ Highway | Uses Interstate 40 west of Okla City,<br>Interstate 15 north to Las V & Yucca Mtn | NA |
| Consolidated southern route/ rail: | Uses Sante Fe lines west of Kansas City,<br>Union Pacific north to intermodal transfer | Same as SNF |
| 14.ROUTE IDENTIFICATION & MAPPING | Locate designated route segments<br>Identify on base highway/rail maps<br>Route segmentation | Same as SNF |
| 15.ROUTING CASE EXAMPLES | Oyster Creek (NJ) to Yucca Mtn (NV)<br>Fermi (MI) to Yucca Mtn (NV)<br>Browns Ferry (AL) to Yucca Mtn (NV)<br>Cooper Station (NE) to Yucca Mtn (NV)<br>Grand Gulf (MS) to Yucca Mtn (NV)<br>Diablo Canyon (CA) to Yucca Mtn (NV) | NA |
| 16. NATIONAL SHIPMENT CAMPAIGN | Life of Operations Cask Shipments<br>Default routing<br>3 transportation choice scenarios | Year 15-30 cask shipments<br>Sames as SNF |
| 17. NEVADA IMPLICATIONS | Life of operations cask shipments<br>Default routing<br>Nevada route segments<br>3 transportation choice scenarios | Year 15-30 cask shipments<br>Same as SNF<br>Same as SNF |
| 18. REGIONAL ROUTING OPTIONS | Life of operations cask shipments<br>Default and So consol routing<br>Selected route segments in:<br>Wyoming (UP and I-80)<br>Colorado (SP and I-70)<br>New Mexico (SF and I-40)<br>Nevada (UP and I-15)<br>3 transportation choice scenarios | Year 15-30 cask shipments<br>Same as SNF |
| 19.NATL SHIPMENT CAMPAIGN: ANNUAL SHIPMENTS | Current capabil choices/default routing<br>Year 1 cask shipments by origin:<br>Year 2 cask shipments by origin:<br>Year 3 cask shipments by origin:<br>Year 20 cask shipments by origin:<br>Maximum rail choices/default routing<br>Year 20 cask shipments by origin: | All rail shipment/default routing:<br>Year 1 cask shipments by origin:<br>Year 2 cask shipments by origin:<br>Year 3 cask shipments by origin:<br>Year 20 cask shipments by origin: |

**Figure I-1 (Cont).**

| | | |
|---|---|---|
| 20. TRANSP OPER REQUIREMENTS | Life of operations and years 1-3<br>Cask shipment miles (total and per MTU)<br>Cask shipments per route mile<br>2 transportation choice scenarios | Year 15-30 cask shipments<br>Cask shipments miles (total)<br>Same as SNF<br>Same as SNF |
| 21.ROUTE FEATURES | Illustrative:<br>Key route characteristics<br>Route conditions<br>Key facilities alongside<br>Administrative boundaries<br>Segment-specific management policies | Same as SNF |

# 1. WASTE ORIGINS, STORAGE LOCATIONS AND SHIPMENT SITES

In common practice, a reactor name may be used to refer to any of several facilities at a site, or to the site itself. Thus, the term "Calvert Cliffs" may be used to refer to either or both of Baltimore Gas and Electric's two nuclear powerplants, to the joined spent fuel pools at those reactors, to the site's concrete module dry storage facility, or the site itself on the Patuxent River near Lusby in Calvert County. In assessment, however, it is useful to maintain a distinction between the facilities which generate spent fuel, the facilities where this waste is temporarily stored, and the sites from which such waste may be shipped to a centralized or permanent storage facility. The same applies to high-level waste at DOE's defense sites and to other nuclear waste requiring geologic disposal.

## Spent Fuel Origins and Storage Locations

In its Acceptance Priority Ranking reports,[3] DOE identifies SNF by the reactor from which it was discharged and by its current storage location. For example:

- The 136 BWR assemblies discharged from the Oyster Creek reactor in Ocean County, New Jersey on May 1, 1972 are now stored at Oyster Creek—meaning the spent fuel pool associated with the Oyster Creek reactor.

- The 85 BWR assemblies discharged from the Quad Cities 2 reactor in Rock Island County, Illinois on December 22, 1974 are now stored at Quad Cities 1—meaning the joined spent fuel storage pools for Quad Cities reactors 1 and 2.

- The 509 BWR assemblies discharged from the Dresden 2 reactor near Morris, Illinois on February 19, 1972 are now stored at Morris—meaning that they have been moved to the nearby General Electric spent fuel storage facility.

- The 102 PWR assemblies discharged from the Robinson 2 reactor in Hartsville, South Carolina on May 4, 1974 are now stored at the Brunswick 1 PWR pool—meaning that they have been transported to Southport, North Carolina for storage in the portion of the Brunswick 1 spent fuel pool designed for BWR assemblies.

Thus, there is a distinction between spent fuel origins and storage locations. Origins are nuclear reactors. Storage locations are spent fuel pools which are sometimes shared among two reactors, or joined by a transfer canal, or, increasingly, on-site dry storage facilities such as those at Surry or Calvert Cliffs, or off-site pools such as those are Morris, or the Idaho National Engineering Lab (INEL). Tables 1-1 and 1-2 present the list of spent fuel origins and storage locations used in this assessment.

In aggregate, DOE's listing of spent fuel discharges describes where spent fuel from particular reactors is now stored, and where spent fuel at particular storage locations came from. For example:

- The 2,200 BWR assemblies discharged through November 1994 from the Peachbottom 3 reactor near York, Pennsylvania are all stored at the Peachbottom 3 spent fuel pool, which has capacity to store 3,814 BWR assemblies.

- Of the 808 PWR assemblies discharged through November 1994 from the Oconee 3 reactor in the western corner of South Carolina, 444 (55 percent) are now stored at the Oconee 3 spent fuel pool, 244 (30.2 percent) are in dry storage facilities at the Oconee site, 58 (7.2 percent) are stored at the Oconee 1 spent fuel pool shared by the Oconee 1 and Oconee 2 reactors, and 62 (7.7 percent) are stored at the McGuire 2 spent fuel pool in North Carolina.

- Of the 3,217 spent fuel assemblies stored at GE's Morris facility in Gundy County, Illinois in November 1994, 1,054 (32.8 percent) are BWR assemblies discharged from the Copper Station reactor in Nebraska, 1,058 (32.9 percent) are BWR assemblies discharged from the Monticello reactor in Minnesota, 753 (23.4 percent) are BWR assemblies from the nearby Dresden 2 reactor, 270 (8.4 percent) are PWR assemblies from the San Onofre 1 reactor in California, and 82 (2.5 percent) are PWR assemblies from the Haddam Neck reactor in Connecticut.

- Of the 1,018 spent fuel assemblies stored at INEL in November 1994, 744 (73.1 percent) are HTG assemblies from Fort St. Vrain in Colorado, 177 are PWR assemblies from the damaged Three Mile Island 2 reactor in Pennsylvania, 69 (6.8 percent) are PWR assemblies from the Surry 1 and 2 reactors in Virginia, 18 (1.8 percent) are PWR assemblies from the Turkey Point 3 reactor in Florida, 6 (0.6 percent) are PWR assemblies from the Point Beach 1 reactor in Wisconsin, and 4 are BWR assemblies from Dresden 1 in Illinois and Peachbottom 2 in Pennsylvania.

### Waste Origin and Storage Location Assumptions

- **The Current Inventory of Spent Nuclear Fuel**

  As mentioned, spent fuel discharges through November 1994 are identified in DOE Acceptance Priority Ranking reports by the reactor from which the fuel was discharged and by the current storage location. In this assessment, the 30,044 MTU discharged through November 1994 are assumed to remain at their November 1994 storage location until accepted by DOE for transport to an interim or permanent storage facility. We have not attempted to project future transfers of spent fuel among storage locations.

- **Projected Inventory of Spent Nuclear Fuel**

  For the no-new-reactor-orders case in which nuclear reactors are assumed to operate at an assumed percentage of capacity through their NRC license term, DOE forecasts annual discharges through 2042 by the reactor from which the fuel is discharged.[4] In this assessment, we have identified the pool location to which the fuel would be discharged. For example, projected discharges from the Point Beach 2 reactor near Two Creeks, Wisconsin would go to the Point Beach 1 pool shared by Point Beach reactors 1 and 2, while projected discharges from the Comanche Peak 2 reactor near Glen Rose, Texas would go to the Comanche Peak 1 and 2 pools which are connected by a transfer canal. However, we have not attempted to project future transfers of this fuel either to onsite dry storage facilities or to pools at other sites owned by the same utility, or to pools at sites such as Morris or INEL.

- **High-Level Waste Origins and Storage Locations**

  For HLW generated at defense sites, DOE forecasts the projected number of canisters (containing vitrified HLW) which will require disposal in a geologic repository.[5] In this assessment, we assume that the HLW is vitrified, canistered, and stored until pick up at the site at which it was generated.

### Shipment Sites

Route analysis requires the identification of a point of origin for each shipment—the place from which the legal-weight truck, heavy-haul truck, rail or barge shipment begins. This assessment associates each storage location with a shipment origin (Table 1-3). For example, spent fuel stored at the separate pools at Arkansas Nuclear's reactors 1 and 2 or at the Arkansas Nuclear dry storage facility all have the same shipment origin. Similarly, spent fuel stored at the connected pools at Calvert Cliffs reactors 1 and 2 or at the Calvert Cliffs dry storage facility all have the same shipment origin.

As will be discussed in Sections 7 and 8, transportation choices are keyed both to the facilities at the storage location (e.g., the characteristics of the separate, shared or joined spent fuel pools, or of the dry storage facility) *and* to the characteristics of near-site infrastructure (e.g., the availability of onsite rail, the distance to an offsite railhead, and the characteristics of the community along the heavy-haul route).

## Table 1-1. Originators of Spent Nuclear Fuel or High-Level Waste

| # | WASTE ORIGINS: | COMPANY: | STATE | WASTE TYPE | WASTE TYPE | DESIGN CAPAC (MWE) | UTIL STRTUP YEAR | UTIL SHUTD YEAR |
|---|---|---|---|---|---|---|---|---|
| 1 | ARKANSAS NUCLEAR 1 | ARKANSAS POWER & LIGHT | AK | PWR | COMM | 850 | 1974 | 2014 |
| 2 | ARKANSAS NUCLEAR 2 | ARKANSAS POWER & LIGHT | AK | PWR | COMM | 912 | 1978 | 2018 |
| 3 | BEAVER VALLEY 1 | DUQUESNE LIGHT COMPANY | PA | PWR | COMM | 835 | 1975 | 2016 |
| 4 | BEAVER VALLEY 2 | DUQUESNE LIGHT COMPANY | PA | PWR | COMM | 857 | 1987 | 2027 |
| 5 | BELLEFONTE 1 | TENNESSEE VALLEY AUTHORITY | AL | PWR | COMM | 1235 | ???? | ???? |
| 6 | BELLEFONTE 2 | TENNESSEE VALLEY AUTHORITY | AL | PWR | COMM | 1235 | ???? | ???? |
| 7 | BIG ROCK 1 | CONSUMERS POWER COMPANY | MI | BWR | COMM | 72 | 1962 | 2000 |
| 8 | BRAIDWOOD 1 | COMMONWEALTH EDISON CO. | IL | PWR | COMM | 1175 | 1987 | 2025 |
| 9 | BRAIDWOOD 2 | COMMONWEALTH EDISON CO. | IL | PWR | COMM | 1175 | 1988 | 2027 |
| 10 | BROWNS FERRY 1 | TENNESSEE VALLEY AUTHORITY | AL | BWR | COMM | 1065 | 1973 | 2013 |
| 11 | BROWNS FERRY 2 | TENNESSEE VALLEY AUTHORITY | AL | BWR | COMM | 1065 | 1974 | 2014 |
| 12 | BROWNS FERRY 3 | TENNESSEE VALLEY AUTHORITY | AL | BWR | COMM | 1065 | 1977 | 2016 |
| 13 | BRUNSWICK 1 | CAROLINA POWER & LIGHT | NC | BWR | COMM | 821 | 1976 | 2016 |
| 14 | BRUNSWICK 2 | CAROLINA POWER & LIGHT | NC | BWR | COMM | 821 | 1974 | 2014 |
| 15 | BYRON 1 | COMMONWEALTH EDISON CO. | IL | PWR | COMM | 1120 | 1985 | 2024 |
| 16 | BYRON 2 | COMMONWEALTH EDISON CO. | IL | PWR | COMM | 1120 | 1987 | 2026 |
| 17 | CALLAWAY 1 | UNION ELECTRIC CO. | MO | PWR | COMM | 1171 | 1984 | 2024 |
| 18 | CALVERT CLIFFS 1 | BALTIMORE GAS & ELECTRIC CO. | MD | PWR | COMM | 845 | 1975 | 2014 |
| 19 | CALVERT CLIFFS 2 | BALTIMORE GAS & ELECTRIC CO. | MD | PWR | COMM | 845 | 1976 | 2016 |
| 20 | CATAWBA 1 | DUKE POWER COMPANY | SC | PWR | COMM | 1145 | 1985 | 2024 |
| 21 | CATAWBA 2 | DUKE POWER COMPANY | SC | PWR | COMM | 1145 | 1986 | 2026 |
| 22 | CLINTON 1 | ILLINOIS POWER CO. | IL | BWR | COMM | 933 | 1987 | 2026 |
| 23 | COMANCHE PEAK 1 | TEXAS UTILITIES ELECTRIC CO. | TX | PWR | COMM | 1150 | 1990 | 2030 |
| 24 | COMANCHE PEAK 2 | TEXAS UTILITIES ELECTRIC CO. | TX | PWR | COMM | 1150 | 1993 | 2033 |
| 25 | COOK 1 | INDIANA MICHIGAN POWER CO. | MI | PWR | COMM | 1030 | 1975 | 2014 |
| 26 | COOK 2 | INDIANA MICHIGAN POWER CO. | MI | PWR | COMM | 1100 | 1978 | 2017 |
| 27 | COOPER STATION | NEBRASKA PUBLIC POWER DISTRICT | NB | BWR | COMM | 778 | 1974 | 2014 |
| 28 | CRYSTAL RIVER 3 | FLORIDA POWER CORPORATION | FL | PWR | COMM | 825 | 1977 | 2016 |
| 29 | DAVIS-BESSE 1 | TOLEDO EDISON CO. | OH | PWR | COMM | 906 | 1977 | 2017 |
| 30 | DIABLO CANYON 1 | PACIFIC GAS & ELECTRIC CO. | CA | PWR | COMM | 1086 | 1984 | 2008 |
| 31 | DIABLO CANYON 2 | PACIFIC GAS & ELECTRIC CO. | CA | PWR | COMM | 1119 | 1985 | 2010 |
| 32 | DRESDEN 1 | COMMONWEALTH EDISON CO. | IL | BWR | COMM | 200 | 1960 | 1978 |
| 33 | DRESDEN 2 | COMMONWEALTH EDISON CO. | IL | BWR | COMM | 794 | 1970 | 2006 |
| 34 | DRESDEN 3 | COMMONWEALTH EDISON CO. | IL | BWR | COMM | 794 | 1971 | 2011 |
| 35 | DUANE ARNOLD | IOWA ELEC LGT & PWR (IES UTIL) | IO | BWR | COMM | 538 | 1974 | 2014 |
| 36 | ENRICO FERMI 2 | DETROIT EDISON CO. | MI | BWR | COMM | 1093 | 1985 | 2025 |
| 37 | FARLEY 1 | ALABAMA POWER & LIGHT | AL | PWR | COMM | 829 | 1977 | 2017 |
| 38 | FARLEY 2 | ALABAMA POWER & LIGHT | AL | PWR | COMM | 829 | 1981 | 2021 |
| 39 | FITZPATRICK | POWER AUTHORITY OF NEW YORK STATE | NY | BWR | COMM | 821 | 1975 | 2014 |
| 40 | FORT CALHOUN | OMAHA PUBLIC POWER DISTRICT | NB | PWR | COMM | 486 | 1973 | 2008 |
| 41 | FORT ST VRAIN | PUBLIC SERVICE CO. OF COLORADO | CO | HTG | COMM | 330 | 1979 | 1989 |
| 42 | GINNA | ROCHESTER GAS & ELECTRIC | NY | PWR | COMM | 490 | 1969 | 2009 |
| 43 | GRAND GULF 1 | SYSTEM ENERGY RESOURCES | MS | BWR | COMM | 1250 | 1984 | 2022 |
| 44 | HADDAM NECK | CONNECTICUTT YANKEE ATOMIC POWER | CT | PWR | COMM | 582 | 1967 | 2007 |
| 45 | HARRIS 1 | CAROLINA POWER & LIGHT | NC | PWR | COMM | 940 | 1987 | 2026 |
| 46 | HATCH 1 | GEORGIA POWER COMPANY | GA | BWR | COMM | 777 | 1974 | 2014 |
| 47 | HATCH 2 | GEORGIA POWER COMPANY | GA | BWR | COMM | 784 | 1978 | 2018 |
| 48 | HOPE CREEK | PUBLIC SERVICE ELECTRIC & GAS CO | NJ | BWR | COMM | 1118 | 1986 | 2025 |
| 49 | HUMBOLDT BAY | PACIFIC GAS & ELECTRIC CO. | CA | BWR | COMM | 65 | 1963 | 1976 |
| 50 | INDIAN POINT 1 | CONSOLIDATED EDISON OF NY | NY | PWR | COMM | 265 | 1962 | 1980 |
| 51 | INDIAN POINT 2 | CONSOLIDATED EDISON OF NY | NY | PWR | COMM | 873 | 1973 | 2013 |
| 52 | INDIAN POINT 3 | PORT AUTHORITY OF NEW YORK | NY | PWR | COMM | 965 | 1976 | 2015 |
| 53 | KEWAUNEE | WISCONSIN PUBLIC SERVICE CO. | WI | PWR | COMM | 535 | 1974 | 2013 |
| 54 | LACROSSE | DAIRYLAND POWER COOP. | WI | BWR | COMM | 50 | 1968 | 1987 |
| 55 | LASALLE 1 | COMMONWEALTH EDISON CO. | IL | BWR | COMM | 1122 | 1982 | 2022 |
| 56 | LASALLE 2 | COMMONWEALTH EDISON CO. | IL | BWR | COMM | 1122 | 1984 | 2023 |
| 57 | LIMERICK 1 | PHILADELPHIA ELECTRIC CO. | PA | BWR | COMM | 1055 | 1985 | 2024 |
| 58 | LIMERICK 2 | PHILADELPHIA ELECTRIC CO. | PA | BWR | COMM | 1055 | 1989 | 2029 |
| 59 | MAINE YANKEE | MAINE YANKEE ATOMIC | ME | PWR | COMM | 825 | 1972 | 2008 |
| 60 | MCGUIRE 1 | DUKE POWER COMPANY | NC | PWR | COMM | 1180 | 1981 | 2021 |
| 61 | MCGUIRE 2 | DUKE POWER COMPANY | NC | PWR | COMM | 1180 | 1983 | 2023 |
| 62 | MILLSTONE 1 | NORTHEAST UTILITY SVC CO. | CT | BWR | COMM | 660 | 1970 | 2010 |
| 63 | MILLSTONE 2 | NORTHEAST UTILITY SVC CO. | CT | PWR | COMM | 870 | 1975 | 2015 |
| 64 | MILLSTONE 3 | NORTHEAST UTILITY SVC CO. | CT | PWR | COMM | 1150 | 1986 | 2025 |
| 65 | MONTICELLO | NORTHERN STATES POWER CO. | MN | BWR | COMM | 545 | 1971 | 2010 |
| 66 | NINE MILE POINT 1 | NIAGRA MOHAWK POWER CO. | NY | BWR | COMM | 620 | 1969 | 2009 |
| 67 | NINE MILE POINT 2 | NIAGRA MOHAWK POWER CO. | NY | BWR | COMM | 1080 | 1987 | 2025 |
| 68 | NORTH ANNA 1 | VIRGINIA POWER | VA | PWR | COMM | 907 | 1978 | 2018 |
| 69 | NORTH ANNA 2 | VIRGINIA POWER | VA | PWR | COMM | 907 | 1980 | 2020 |
| 70 | OCONEE 1 | DUKE POWER COMPANY | SC | PWR | COMM | 887 | 1973 | 2013 |
| 71 | OCONEE 2 | DUKE POWER COMPANY | SC | PWR | COMM | 887 | 1973 | 2013 |
| 72 | OCONEE 3 | DUKE POWER COMPANY | SC | PWR | COMM | 886 | 1974 | 2014 |

Source: Spent Fuel Storage Requirements: 1994-2042 (DOE/RW-0431-Rev.1: June 1995)

**Table 1-1 (Cont).**

| # | WASTE ORIGINS: | COMPANY: | STATE | WASTE TYPE | WASTE TYPE | DESIGN CAPAC (MWE) | UTIL STRTUP YEAR | UTIL SHUTD YEAR |
|---|---|---|---|---|---|---|---|---|
| 73 | OYSTER CREEK 1 | GPU NUCLEAR CORP | NJ | BWR | COMM | 650 | 1969 | 2009 |
| 74 | PALISADES | CONSUMERS POWER CO. | MI | PWR | COMM | 805 | 1971 | 2007 |
| 75 | PALO VERDE 1 | ARIZONA PUBLIC SERVICE CO. | AZ | PWR | COMM | 1270 | 1985 | 2024 |
| 76 | PALO VERDE 2 | ARIZONA PUBLIC SERVICE CO. | AZ | PWR | COMM | 1270 | 1986 | 2025 |
| 77 | PALO VERDE 3 | ARIZONA PUBLIC SERVICE CO. | AZ | PWR | COMM | 1270 | 1987 | 2027 |
| 78 | PEACHBOTTOM 2 | PHILADELPHIA ELECTRIC CO. | PA | BWR | COMM | 1065 | 1974 | 2008 |
| 79 | PEACHBOTTOM 3 | PHILADELPHIA ELECTRIC CO. | PA | BWR | COMM | 1065 | 1974 | 2008 |
| 80 | PERRY 1 | CLEVELAND ELEC ILLUMINATING CO. | OH | BWR | COMM | 1265 | 1986 | 2026 |
| 81 | PILGRIM 1 | BOSTON EDISON CO. | MA | BWR | COMM | 655 | 1972 | 2012 |
| 82 | POINT BEACH 1 | WISCONSIN ELECTRIC POWER CO. | WI | PWR | COMM | 497 | 1970 | 2010 |
| 83 | POINT BEACH 2 | WISCONSIN ELECTRIC POWER CO. | WI | PWR | COMM | 497 | 1972 | 2013 |
| 84 | PRAIRIE ISLAND 1 | NORTHERN STATES POWER CO. | MN | PWR | COMM | 530 | 1973 | 2013 |
| 85 | PRAIRIE ISLAND 2 | NORTHERN STATES POWER CO. | MN | PWR | COMM | 530 | 1974 | 2014 |
| 86 | QUAD CITIES 1 | COMMONWEALTH EDISON CO. | IL | BWR | COMM | 789 | 1972 | 2012 |
| 87 | QUAD CITIES 2 | COMMONWEALTH EDISON CO. | IL | BWR | COMM | 789 | 1972 | 2012 |
| 88 | RANCHO SECO 1 | SACRAMENTO MUNICIPAL UTILITY DIST. | CA | PWR | COMM | 918 | 1974 | 1989 |
| 89 | RIVER BEND 1 | GULF STATES UTILITIES CO. | LA | BWR | COMM | 936 | 1985 | 2025 |
| 90 | ROBINSON 2 | CAROLINA POWER & LIGHT | SC | PWR | COMM | 700 | 1970 | 2010 |
| 91 | SALEM 1 | PUBLIC SERVICE ELECTRIC & GAS CO | NJ | PWR | COMM | 1115 | 1976 | 2016 |
| 92 | SALEM 2 | PUBLIC SERVICE ELECTRIC & GAS CO | NJ | PWR | COMM | 1115 | 1981 | 2020 |
| 93 | SAN ONOFRE 1 | SOUTHERN CALIF EDISON | CA | PWR | COMM | 436 | 1967 | 1992 |
| 94 | SAN ONOFRE 2 | SOUTHERN CALIF EDISON | CA | PWR | COMM | 1070 | 1982 | 2013 |
| 95 | SAN ONOFRE 3 | SOUTHERN CALIF EDISON | CA | PWR | COMM | 1080 | 1983 | 2013 |
| 96 | SEABROOK 1 | NORTH ATLANTIC ENERGY SERVICE | NH | PWR | COMM | 1150 | 1990 | 2026 |
| 97 | SEQUOYAH 1 | TENNESSEE VALLEY AUTHORITY | TN | PWR | COMM | 1148 | 1980 | 2020 |
| 98 | SEQUOYAH 2 | TENNESSEE VALLEY AUTHORITY | TN | PWR | COMM | 1148 | 1981 | 2021 |
| 99 | SHOREHAM | LONG ISLAND LIGHTING CO. | NY | BWR | COMM | 849 | 1986 | 1987 |
| 100 | SOUTH TEXAS 1 | HOUSTON LIGHTING & POWER CO. | TX | PWR | COMM | 1250 | 1988 | 2027 |
| 101 | SOUTH TEXAS 2 | HOUSTON LIGHTING & POWER CO. | TX | PWR | COMM | 1250 | 1989 | 2028 |
| 102 | ST LUCIE 1 | FLORIDA POWER & LIGHTING CO. | FL | PWR | COMM | 830 | 1976 | 2016 |
| 103 | ST LUCIE 2 | FLORIDA POWER & LIGHTING CO. | FL | PWR | COMM | 804 | 1983 | 2023 |
| 104 | SUMMER 1 | SOUTH CAROLINA ELECTRIC & GAS | SC | PWR | COMM | 900 | 1982 | 2022 |
| 105 | SURRY 1 | VIRGINIA POWER | VA | PWR | COMM | 788 | 1972 | 2012 |
| 106 | SURRY 2 | VIRGINIA POWER | VA | PWR | COMM | 788 | 1973 | 2013 |
| 107 | SUSQUEHANNA 1 | PENNSYLVANIA POWER & LIGHT | PA | BWR | COMM | 1065 | 1982 | 2022 |
| 108 | SUSQUEHANNA 2 | PENNSYLVANIA POWER & LIGHT | PA | BWR | COMM | 1065 | 1984 | 2024 |
| 109 | THREE MILE ISLAND 1 | GPU NUCLEAR CORP | PA | PWR | COMM | 819 | 1974 | 2014 |
| 110 | TROJAN | PORTLAND GENERAL ELECTRIC CO. | OR | PWR | COMM | 1130 | 1975 | 1992 |
| 111 | TURKEY POINT 3 | FLORIDA POWER & LIGHTING CO. | FL | PWR | COMM | 693 | 1972 | 2007 |
| 112 | TURKEY POINT 4 | FLORIDA POWER & LIGHTING CO. | FL | PWR | COMM | 693 | 1973 | 2007 |
| 113 | VERMONT YANKEE 1 | VERMONT YANKEE NUCLEAR POWER | VT | BWR | COMM | 514 | 1972 | 2012 |
| 114 | VOGTLE 1 | GEORGIA POWER CO. | GA | PWR | COMM | 1069 | 1987 | 2027 |
| 115 | VOGTLE 2 | GEORGIA POWER CO. | GA | PWR | COMM | 1069 | 1989 | 2029 |
| 116 | WASHINGTON NUCLEAR 2 | WASH PUBLIC POWER SUPPLY SYSTEM | WA | BWR | COMM | 1100 | 1984 | 2023 |
| 117 | WASHINGTON NUCLEAR 3 | WASH PUBLIC POWER SUPPLY SYSTEM | WA | BWR | COMM | 1250 | ???? | ???? |
| 118 | WATERFORD 3 | LOUISIANNA POWER & LIGHT | LA | PWR | COMM | 1104 | 1985 | 2024 |
| 119 | WATTS BAR 1 | TENNESSEE VALLEY AUTHORITY | TN | PWR | COMM | 1165 | ???? | ???? |
| 120 | WATTS BAR 2 | TENNESSEE VALLEY AUTHORITY | TN | PWR | COMM | 1165 | ???? | ???? |
| 121 | WOLF CREEK 1 | WOLF CREEK NUCLEAR OPERATING CORP. | KS | PWR | COMM | 1150 | 1985 | 2025 |
| 122 | YANKEE-ROWE 1 | YANKEE ATOMIC ELECTRIC CO. | MA | PWR | COMM | 175 | 1960 | 1991 |
| 123 | ZION 1 | COMMONWEALTH EDISON CO. | IL | PWR | COMM | 1085 | 1973 | 2013 |
| 124 | ZION 2 | COMMONWEALTH EDISON CO. | IL | PWR | COMM | 1085 | 1973 | 2013 |
| 125 | GENERAL ATOMICS | GENERAL ATOMICS | CA | RSH | DFNS | NA | ???? | ???? |
| 126 | HANFORD | DOE/HANFORD | WA | HLW | DFNS | NA | ???? | ???? |
| 127 | INEL | DOE/INEL | ID | HLW | DFNS | NA | ???? | ???? |
| 128 | SAVANNAH RIVER | DOE/SAVANNAH RIVER | SC | HLW | DFNS | NA | ???? | ???? |
| 129 | WEST VALLEY | DOE/WEST VALLEY | NY | HLW | DFNS | NA | ???? | ???? |

Source: Spent Fuel Storage Requirements: 1994-2042 (DOE/RW-0431-Rev.1: June 1995)

## Table 1-2. Storage Locations for Spent Nuclear Fuel and High-Level Waste

| | STORAGE LOCATIONS: | WASTE TYPE | UTIL STRTUP YEAR | UTIL SHUTD YEAR | STRG CAPAC (ASSEMBLIES) LICEN | STRG CAPAC (ASSEMBLIES) MAX | FULL CORE ASMB | NOTES: |
|---|---|---|---|---|---|---|---|---|
| 1 | ARKANSAS NUCLEAR 1 | PWR | 1974 | 2014 | 968 | 948 | 177 | |
| 2 | ARKANSAS NUCLEAR 2 | PWR | 1978 | 2018 | 988 | 933 | 177 | |
| 3 | ARKANSAS NUCLEAR DRY STRG | PWR | 1995 | 2015 | 192 | 192 | NA | VSC-24 under gnrl lic, starting 1995 |
| 4 | BEAVER VALLEY 1 | PWR | 1976 | 2016 | 833 | 1621 | 157 | |
| 5 | BEAVER VALLEY 2 | PWR | 1987 | 2027 | 1088 | 1088 | 157 | |
| 6 | BELLEFONTE 1 | PWR | ???? | ???? | 1058 | 1058 | 205 | |
| 7 | BELLEFONTE 2 | PWR | ???? | ???? | 1058 | 1058 | 205 | |
| 8 | BIG ROCK 1 | BWR | 1962 | 2000 | 441 | 441 | 84 | |
| 9 | BRAIDWOOD 1&2 | PWR | 1987 | 2027 | 2870 | 2834 | 193 | |
| 10 | BROWNS FERRY 1-2 | BWR | 1973 | 2014 | 3471 | 6942 | 764 | |
| 11 | BROWNS FERRY 3 | BWR | 1977 | 2016 | 3471 | 3471 | 764 | |
| 12 | BRUNSWICK 1 | BWR | 1976 | 2016 | 1803 | 1767 | 560 | |
| 13 | BRUNSWICK 1 BWR POOL | PWR | 1976 | 2016 | NA | 160 | NA | |
| 14 | BRUNSWICK 2 | BWR | 1974 | 2014 | 1839 | 1767 | 560 | |
| 15 | BRUNSWICK 2 BWR POOL | PWR | 1974 | 2014 | NA | 144 | NA | |
| 16 | BYRON 1&2 | PWR | 1985 | 2026 | 2870 | 2824 | 193 | |
| 17 | CALLAWAY 1 | PWR | 1984 | 2024 | 1340 | 1340 | 193 | |
| 18 | CALVERT CLIFFS 1-2 | PWR | 1975 | 2016 | 1830 | 1778 | 217 | |
| 19 | CALVERT DRY STORAGE | PWR | 1991 | 2011 | 1152 | 1152 | NA | NUHOMS-24 under 1992 site specific lic |
| 20 | CATAWBA 1 | PWR | 1985 | 2024 | 1419 | 2615 | 193 | |
| 21 | CATAWBA 2 | PWR | 1986 | 2026 | 1418 | 2615 | 193 | |
| 22 | CLINTON 1 | BWR | 1987 | 2026 | 2512 | 2512 | 624 | |
| 23 | COMANCHE PEAK 1-2 | PWR | 1990 | 2030 | 1693 | 1289 | 193 | |
| 24 | COOK 1&2 | PWR | 1975 | 2017 | 2050 | 3613 | 193 | |
| 25 | COOPER STATION | BWR | 1974 | 2014 | 2366 | 2366 | 548 | |
| 26 | CRYSTAL RIVER 3 | PWR | 1977 | 2016 | 1357 | 1357 | 177 | |
| 27 | DAVIS-BESSE 1 | PWR | 1977 | 2017 | 735 | 720 | 177 | |
| 28 | DAVIS-BESSE DRY STRG | PWR | 1995 | 2015 | 192 | 192 | NA | NUHOMS-24 under gnrl lic, starting 1995 |
| 29 | DIABLO CANYON 1 | PWR | 1984 | 2010 | 1324 | 1324 | 193 | |
| 30 | DIABLO CANYON 2 | PWR | 1985 | 2010 | 1324 | 1317 | 193 | |
| 31 | DRESDEN 1 | BWR | 1960 | 1978 | 720 | 720 | 464 | |
| 32 | DRESDEN 2 | BWR | 1970 | 2006 | 3537 | 3537 | 724 | |
| 33 | DRESDEN 3 | BWR | 1971 | 2011 | 3537 | 3537 | 724 | |
| 34 | DUANE ARNOLD | BWR | 1974 | 2014 | 2050 | 1898 | 368 | |
| 35 | ENRICO FERMI 2 | BWR | 1985 | 2025 | 2383 | 2383 | 764 | |
| 36 | FARLEY 1 | PWR | 1977 | 2017 | 1407 | 1407 | 157 | |
| 37 | FARLEY 2 | PWR | 1981 | 2021 | 1407 | 1407 | 157 | |
| 38 | FITZPATRICK | BWR | 1975 | 2014 | 2797 | 2797 | 560 | |
| 39 | FORT CALHOUN | PWR | 1973 | 2008 | 729 | 1083 | 133 | |
| 40 | FORT ST VRAIN | HTG | 1979 | 1989 | 1482 | 0 | 0 | |
| 41 | FORT ST VRAIN DRY STRG | HTG | 1991 | 2011 | 1482 | 1482 | NA | Foster Wheeler MVDS under 1991 site specific lic |
| 42 | GINNA | PWR | 1969 | 2009 | 1016 | 1083 | 121 | |
| 43 | GRAND GULF 1 | BWR | 1984 | 2022 | 2324 | 3872 | 800 | |
| 44 | HADDAM NECK | PWR | 1967 | 2007 | 1172 | 1167 | 157 | |
| 45 | HARRIS 1-2 | PWR | 1987 | 2026 | 4184 | 1128 | 157 | |
| 46 | HARRIS 1-2 BWR POOL | BWR | 1987 | 2026 | NA | 1573 | NA | |
| 47 | HATCH 1-2 | BWR | 1974 | 2018 | 3181 | 5830 | 560 | |
| 48 | HOPE CREEK | BWR | 1986 | 2026 | 4006 | 3998 | 764 | |
| 49 | HUMBOLDT BAY | BWR | 1963 | 1976 | 486 | 485 | 184 | |
| 50 | INDIAN POINT 1 | PWR | 1962 | 1980 | 756 | 756 | 120 | |
| 51 | INDIAN POINT 2 | PWR | 1973 | 2013 | 1374 | 1374 | 193 | |
| 52 | INDIAN POINT 3 | PWR | 1976 | 2015 | 1345 | 1340 | 193 | |
| 53 | KEWAUNEE | PWR | 1974 | 2013 | 990 | 990 | 121 | |
| 54 | LACROSSE | BWR | 1968 | 1987 | 440 | 440 | 72 | |
| 55 | LASALLE 1-2 | BWR | 1982 | 2023 | 5153 | 7780 | 764 | |
| 56 | LIMERICK 1-2 | BWR | 1985 | 2029 | 2040 | 6798 | 764 | |
| 57 | MAINE YANKEE | PWR | 1972 | 2008 | 1476 | 1464 | 217 | |
| 58 | MCGUIRE 1 | PWR | 1981 | 2021 | 1463 | 1581 | 193 | |
| 59 | MCGUIRE 2 | PWR | 1983 | 2023 | 1463 | 1460 | 193 | |
| 60 | MILLSTONE 1 | BWR | 1970 | 2010 | 3229 | 3229 | 580 | |
| 61 | MILLSTONE 2 | PWR | 1975 | 2015 | 1072 | 1299 | 217 | |
| 62 | MILLSTONE 3 | PWR | 1986 | 2025 | 756 | 756 | 193 | |
| 63 | MONTICELLO | BWR | 1971 | 2010 | 2237 | 2229 | 484 | |
| 64 | NINE MILE POINT 1 | BWR | 1969 | 2009 | 2776 | 2560 | 532 | |
| 65 | NINE MILE POINT 2 | BWR | 1987 | 2026 | 4049 | 2528 | 764 | |
| 66 | NORTH ANNA 1&2 | PWR | 1978 | 2020 | 1737 | 1677 | 157 | |
| 67 | NORTH ANNA DRY STRG | PWR | 1998 | 2018 | 256 | 256 | NA | TN-32 under 1998 site specific lic |
| 68 | OCONEE 1&2 | PWR | 1973 | 2013 | 1312 | 1311 | 177 | |
| 69 | OCONEE 3 | PWR | 1974 | 2014 | 825 | 818 | 177 | |
| 70 | OCONEE DRY STORAGE | PWR | 1990 | 2010 | 960 | 960 | NA | NUHOMS-24 under 1990 site specific lic |
| 71 | OYSTER CREEK 1 | BWR | 1969 | 2009 | 2600 | 2600 | 550 | |
| 72 | OYSTER CREEK DRY STRG | BWR | 1996 | 2016 | 416 | 416 | NA | NUHOMS-52 under gnrl lic, starting 1996 |

## Table 1-2 (Cont).

| STORAGE LOCATIONS: | WASTE TYPE | UTIL STRTUP YEAR | UTIL SHUTD YEAR | STRG CAPAC (ASSEMBLIES) LICEN | STRG CAPAC (ASSEMBLIES) MAX | FULL CORE ASMB | NOTES: |
|---|---|---|---|---|---|---|---|
| 73 PALISADES | PWR | 1971 | 2007 | 892 | 888 | 204 | |
| 74 PALISADES DRY STRG | PWR | 1993 | 2013 | 48 | 48 | NA | NUHOMS-24 under gnrl lic, starting 1996 |
| 75 PALO VERDE 1 | PWR | 1985 | 2024 | 665 | 1323 | 241 | |
| 76 PALO VERDE 2 | PWR | 1986 | 2025 | 665 | 1323 | 241 | |
| 77 PALO VERDE 3 | PWR | 1987 | 2027 | 665 | 1322 | 241 | |
| 78 PEACHBOTTOM 2 | BWR | 1974 | 2008 | 3819 | 3819 | 764 | |
| 79 PEACHBOTTOM 3 | BWR | 1974 | 2008 | 3819 | 3814 | 764 | |
| 80 PERRY 1 | BWR | 1986 | 2026 | 4020 | 4020 | 748 | |
| 81 PILGRIM 1 | BWR | 1972 | 2012 | 2320 | 2875 | 580 | |
| 82 POINT BEACH 1&2 | PWR | 1970 | 2013 | 1502 | 1500 | 121 | |
| 83 POINT BEACH DRY STRG | PWR | 1995 | 2015 | 192 | 192 | NA | VSC-24 under gnrl lic, starting 1995 |
| 84 PRAIRIE ISLAND 1&2 | PWR | 1973 | 2014 | 1386 | 1378 | 121 | |
| 85 PRAIRIE ISLAND DRY STRG | PWR | 1993 | 2013 | 320 | 320 | NA | TN-40 under 1993 site specific lic |
| 86 QUAD CITIES 1-2 | BWR | 1972 | 2012 | 7554 | 7533 | 724 | |
| 87 RANCHO SECO 1 | PWR | 1974 | 1989 | 1080 | 1080 | 177 | |
| 88 RANCHO SECO DRY STRG | PWR | 1996 | 2016 | 561 | 561 | NA | NUHOMS-MP187 under 1996 site specific lic |
| 89 RIVER BEND 1 | BWR | 1985 | 2025 | 2680 | 3172 | 624 | |
| 90 ROBINSON 2 | PWR | 1970 | 2010 | 544 | 537 | 157 | |
| 91 ROBINSON DRY STRG | PWR | 1986 | 2006 | 56 | 56 | NA | NUHOMS-07 under 1986 site specific lic |
| 92 SALEM 1 | PWR | 1976 | 2016 | 1170 | 1117 | 193 | |
| 93 SALEM 2 | PWR | 1981 | 2020 | 1170 | 1139 | 193 | |
| 94 SAN ONOFRE 1 | PWR | 1967 | 1992 | 216 | 216 | 157 | |
| 95 SAN ONOFRE 2 | PWR | 1982 | 2013 | 1542 | 1542 | 217 | |
| 96 SAN ONOFRE 3 | PWR | 1983 | 2013 | 1542 | 1542 | 0 | |
| 97 SEABROOK 1 | PWR | 1990 | 2026 | 1236 | 1236 | 193 | |
| 98 SEQUOYAH 1&2 | PWR | 1980 | 2021 | 1386 | 2091 | 193 | |
| 99 SHOREHAM | BWR | 1986 | 1987 | 2435 | 2685 | 560 | |
| 100 SOUTH TEXAS 1 | PWR | 1988 | 2027 | 1969 | 1958 | 193 | |
| 101 SOUTH TEXAS 2 | PWR | 1989 | 2028 | 1969 | 1958 | 193 | |
| 102 ST LUCIE 1 | PWR | 1976 | 2016 | 1706 | 1705 | 217 | |
| 103 ST LUCIE 2 | PWR | 1983 | 2023 | 1584 | 1076 | 217 | |
| 104 SUMMER 1 | PWR | 1982 | 2022 | 1276 | 1276 | 157 | |
| 105 SURRY 1&2 | PWR | 1972 | 2013 | 1044 | 1044 | 157 | |
| 106 SURRY DRY STORAGE | PWR | 1986 | 2006 | 533 | 533 | NA | CASTOR-32 (& other) under 1986 site spec lic |
| 107 SUSQUEHANNA 1-2 | BWR | 1982 | 2024 | 2840 | 5680 | 764 | |
| 108 SUSQUEHANNA DRY STRG | BWR | 1997 | 2017 | 416 | 416 | NA | NUHOMS-52 under gnrl lic, starting 1997 |
| 109 THREE MILE ISLAND 1 | PWR | 1974 | 2014 | 752 | 1284 | 177 | |
| 110 TROJAN | PWR | 1975 | 1992 | 1408 | 1395 | 193 | |
| 111 TURKEY POINT 3 | PWR | 1972 | 2007 | 1404 | 1376 | 157 | |
| 112 TURKEY POINT 4 | PWR | 1973 | 2007 | 1404 | 1376 | 0 | |
| 113 VERMONT YANKEE 1 | BWR | 1972 | 2012 | 2870 | 2860 | 368 | |
| 114 VOGTLE 1-2 | PWR | 1987 | 2029 | 2386 | 2283 | 193 | |
| 115 WASHINGTON NUCLEAR 2 | BWR | 1984 | 2023 | 2658 | 2654 | 764 | |
| 116 WATERFORD 3 | PWR | 1985 | 2024 | 1088 | 1070 | 217 | |
| 117 WATTS BAR 1&2 | PWR | ???? | ???? | 1312 | 1294 | 193 | |
| 118 WOLF CREEK 1 | PWR | 1985 | 2025 | 1340 | 1327 | 193 | |
| 119 YANKEE-ROWE 1 | PWR | 1960 | 1991 | 721 | 721 | 76 | |
| 120 ZION 1&2 | PWR | 1973 | 2013 | 2112 | 2929 | 193 | |
| 121 HANFORD SNF STRG | PWR | ???? | ???? | ???? | ???? | NA | |
| 122 HANFORD SNF STRG | BWR | ???? | ???? | ???? | ???? | NA | |
| 123 INEL SNF STRG | PWR | ???? | ???? | ???? | ???? | NA | |
| 124 INEL SNF STRG | BWR | ???? | ???? | ???? | ???? | NA | |
| 125 INEL SNF STRG | HTG | ???? | ???? | ???? | ???? | NA | |
| 126 SAVANNAH RIVER SNF STRG | PWR | ???? | ???? | ???? | ???? | NA | |
| 127 SAVANNAH RIVER SNF STRG | BWR | ???? | ???? | ???? | ???? | NA | |
| 128 WEST VALLEY SNF STRG | PWR | ???? | ???? | ???? | ???? | NA | |
| 129 WEST VALLEY SNF STRG | BWR | ???? | ???? | ???? | ???? | NA | |
| 130 MORRIS OPERATION | PWR | ???? | 2002 | ???? | 380 | NA | |
| 131 MORRIS OPERATION | BWR | ???? | 2002 | ???? | 2928 | NA | |
| 132 GENERAL ATOMICS | RSH | ???? | ???? | ???? | ???? | NA | |
| TOTAL | | | | | | | |

Source: Spent Fuel Storage Requirements: 1994-2042 (DOE/RL-0431.... June 1995
Spent Nuclear Fuel Discharges From US Reactors: 1994 (SR/CNEAF/96-01..... Feb 1996)
1-2: Joined pools; 1&2: Shared pools.... later shutdown reactor date applies
Max pool capacities: generally from SFSR; SNFD as noted
Dry storage capacities: generally from SFSR; SNFD or PIC as noted

## Table 1-3. Spent Nuclear Fuel and High-Level Waste Shipment Sites

| SHIPMENT SITE: | WASTE TYPE |
|---|---|
| 1 ARKANSAS NUCLEAR | PWR |
| 2 BEAVER VALLEY | PWR |
| 3 BELLEFONTE | PWR |
| 4 BIG ROCK | BWR |
| 5 BRAIDWOOD | PWR |
| 6 BROWNS FERRY | BWR |
| 7 BRUNSWICK | BWR |
| | PWR |
| 8 BYRON | PWR |
| 9 CALLAWAY | PWR |
| 10 CALVERT CLIFFS | PWR |
| 11 CATAWBA | PWR |
| 12 CLINTON | BWR |
| 13 COMANCHE PEAK | PWR |
| 14 COOK | PWR |
| 15 COOPER STATION | BWR |
| 16 CRYSTAL RIVER | PWR |
| 17 DAVIS-BESSE | PWR |
| 18 DIABLO CANYON | PWR |
| 19 DRESDEN | BWR |
| 20 DUANE ARNOLD | BWR |
| 21 ENRICO FERMI | BWR |
| 22 FARLEY | PWR |
| 23 FITZPATRICK | BWR |
| 24 FORT CALHOUN | PWR |
| 25 FORT ST VRAIN | HTG |
| 26 GINNA | PWR |
| 27 GRAND GULF | BWR |
| 28 HADDAM NECK | PWR |
| 29 HARRIS | PWR |
| | BWR |
| 30 HATCH | BWR |
| 31 HOPE CREEK | BWR |
| 32 HUMBOLDT BAY | BWR |
| 33 INDIAN POINT | PWR |
| 34 KEWAUNEE | PWR |
| 35 LACROSSE | BWR |
| 36 LASALLE | BWR |
| 37 LIMERICK | BWR |
| 38 MAINE YANKEE | PWR |
| 39 MCGUIRE | PWR |
| 40 MILLSTONE | BWR |
| 41 MONTICELLO | BWR |
| 42 NINE MILE POINT | BWR |
| 43 NORTH ANNA | PWR |
| 43 NORTH ANNA | PWR |
| 44 OCONEE | PWR |
| 45 OYSTER CREEK | BWR |
| 46 PALISADES | PWR |
| 47 PALO VERDE | PWR |

| FUEL STRG LOCATIONS | WASTE TYPE |
|---|---|
| 48 PEACHBOTTOM | BWR |
| 49 PERRY | BWR |
| 50 PILGRIM | BWR |
| 51 POINT BEACH | PWR |
| 52 PRAIRIE ISLAND | PWR |
| 53 QUAD CITIES | BWR |
| 54 RANCHO SECO | PWR |
| 55 RIVER BEND | BWR |
| 56 ROBINSON | PWR |
| 57 SALEM | PWR |
| 58 SAN ONOFRE | PWR |
| 59 SEABROOK | PWR |
| 60 SEQUOYAH | PWR |
| 61 SHOREHAM | BWR |
| 62 SOUTH TEXAS | PWR |
| 63 ST LUCIE | PWR |
| 64 SUMMER | PWR |
| 65 SURRY | PWR |
| 67 SUSQUEHANNA | BWR |
| 68 THREE MILE ISLAND | PWR |
| 69 TROJAN | PWR |
| 70 TURKEY POINT | PWR |
| 71 VERMONT YANKEE | BWR |
| 72 VOGTLE | PWR |
| 73 WASH NUCLEAR | BWR |
| 74 WATTS BAR | PWR |
| 75 WATERFORD | PWR |
| 76 WOLF CREEK | PWR |
| 77 YANKEE-ROWE | PWR |
| 78 ZION | PWR |
| 79 HANFORD | PWR |
| | BWR |
| | HLW |
| 80 INEL | PWR |
| | BWR |
| | HTG |
| | HLW |
| | NRF |
| 81 SAVANNAH | PWR |
| | BWR |
| | HLW |
| | FRF |
| 82 WEST VALLEY | BWR |
| | PWR |
| | HLW |
| 83 MORRIS | BWR |
| | PWR |
| 84 GENERAL ATOMICS | RSH |
| | MSC |

Waste Types:

BWR: Assemblies from boiling water reactors
PWR: Assemblies from pressurized water reactors
HTG: Assemblies from high-temp gas reactors
MSC: Miscellaneous spent fuel discharges thru Nov 1994 (@GA)
RSH: Spent fuel for research, thru Nov 1994 (@GA)
NRF: Naval reactor fuel
FRF: Foreign research fuel
HLW: High-level defense waste (not spent fuel)

# 2. THE INVENTORY OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE

The radioactive wastes which require geologic disposal and which could be shipped to a centralized storage facility at the Nevada Test Site (Area 25) to await permanent disposal are in three broad categories: SNF from commercial power plants, HLW from the nation's defense complex, and other wastes requiring geologic disposal. It is convenient to consider the current and projected inventory of these wastes with reference to their key relevant information sources. This, however, introduces some minor anomalies. For example, a portion of research and miscellaneous spent fuel is included in the current inventory of commercial SNF, since it is included in the key information source (prioritized spent fuel discharges) for this category. Also, the consideration of other wastes requires special attention to avoid double-counting.

## 2.1 Spent Nuclear Fuel from Commercial Plants

### The Current SNF Inventory

Through November 1994, 30,044 metric tons of SNF had been permanently discharged from U.S. reactors, and had received priority ranking for acceptance by DOE (see Table 2-1). Of the November 1994 total.

- About 10,809 MTU (36.0 percent) was in 59,400 assemblies discharged from 41 commercial boiling water reactors. The average BWR assembly weighs .182 tons or 364 pounds.

- About 19,149 MTU (63.7 percent) was in 44,600 assemblies discharged from 78 commercial pressurized water reactors. The average PWR assembly weighs .429 tons or 869 pounds.

- About 86 MTU (0.3 percent) was discharges from the high-temperature gas reactor at Fort St. Vrain, Colorado, or discharges of research or miscellaneous spent fuel.

Ranked spent fuel discharges do not include naval reactor fuel, foreign research fuel, or spent fuel discharged from defense reactors. Nor does it include the HLW that have accumulated at defense sites.

### The Future SNF Inventory

DOE has projected annual spent fuel discharges from 1994 through 2042 at commercial reactors,[4] under a case which assumes no-new-reactor orders and operations through the current NRC license term (with no early shut downs and no license extensions). The projected discharges include 56,655 MTU in 19,900 BWR and 36,800 PWR assemblies.

In this assessment, 1994 discharges are the "actuals" reported in DOE's 1995 Acceptance Priority Ranking through November 28, 1994. The differences between the actuals for 1994 and DOE's 1994 projections are included in the projected discharges for 1995, so that the projections for 1994 through 2042 are consistent with DOE's forecast for the no-new-orders, NRC license term case.

DOE's forecast is presented by the reactor from which the assemblies are discharged. This assessment identifies the pool location (separate, shared, or joined) to which the fuel would be discharged, but does not attempt to project future transfers of spent fuel to onsite dry storage facilities or to pools at other sites owned by the same utility or others.

### The Total SNF Inventory

Combining projected spent fuel discharges with those through November 28, 1994, the total inventory includes 86,699 MTU in 30,700 BWR and 55,900 PWR assemblies. This total, however, does not include projections of spent fuel from research reactors, or projected naval reactor fuel, foreign research fuel, or HLW from defense facilities.

### Alternative Inventory Projections

Alternative projections of waste requiring geologic disposal could be considered in alternative scenarios. Some of the contingencies that might be considered in alternative scenarios are briefly discussed below:

- **Reactors licensed for startup after 1993.**

  DOE's forecast for the no-new-orders, NRC license term case includes discharges for five reactors scheduled for startup after 1993, the base year for the DOE forecast:

  — Bellefonte 1, projected to discharge 2,193 PWR assemblies and 913 MTU between 2000 and 2039.

  — Bellefonte 2, projected to discharge 2,076 PWR assemblies and 864 MTU between 2003 and 2042.

  — Comanche Peak 2, projected to discharge 2,081 PWR assemblies and 856 MTU between 1994 and 2033.

  — Watts Bar 1, projected to discharge 1,725 PWR assemblies and 800 MTU between 1996 and 2035.

  — Watts Bar 2, projected to discharge 1,648 PWR assemblies and 763 MTU between 1998 and 2037.

  It is possible, even likely, that the above plants, though licensed, will never operate. In this case, projected discharges would be reduced by 9,723 PWR assemblies or 4,196 MTU, about 17.4 percent of the total inventory of 55,900 PWR assemblies in the no-new-orders case, and about 4.8 percent of total projected MTU.

- **Reactors shut down before their NRC license term**

  The economics of generating nuclear power in increasingly competitive electric power markets, as well as the cost of dealing with aging nuclear reactors[6] and/or problems in providing onsite storage capacity, could persuade utilities to shut down some reactors before their NRC license term. The transportation effects of such decisions, which would reduce the revenue base for the nuclear waste fund, and complicate the financing of plant decommissioning, could be considered in an alternative inventory scenario.

- **Reactor license extensions**

  Extension of operating licenses beyond the standard 40-year term has been periodically considered by the NRC and utilities. Extensions would be contingent on the solution of problems associated with aging reactors and onsite storage, but could augment the nuclear waste fund as well as funds for decommissioning. The transportation effects of possible license extensions could be considered in an alternative inventory scenario.

## 2.2 High-Level Wastes from the Defense Complex

High-level waste is generated by the chemical reprocessing of spent research and production reactor fuel, irradiated targets and naval propulsion fuel. It exists in a variety of physical or chemical forms, all of which must be stored behind heavy shielding and usually in underground tanks or bins. Since DOE decided in 1992 to phase out the domestic reprocessing of irradiated nuclear fuel for the recovery of enriched uranium or plutonium, little additional generation of HLW is expected.

Current DOE plans are to immobilize HLW through a vitrification process, and to package it in canisters for storage at the four sites where it was produced (Hanford, INEL, Savannah River, West Valley) and for shipment to the geologic repository for disposal. The canisters are expected to be about 2 feet in diameter and from 10 to 15 feet in length. However, since pretreatment and waste minimization processes at the INEL and Hanford sites have not yet been finalized, the dimensions and number of canisters to be produced from those sites is less certain than at Savannah River and West Valley.

DOE's Integrated Data Base Report[5] (the source for the above summary) provides a projection of the number of canisters of HLW expected to be produced at each of the four sites, noting that "projected inventories. . .(are) based on certain assumptions, and therefore should be considered only as current best estimates." An alternative projection, with substantially higher production estimates for Hanford and INEL, is provided in DOE's Waste Management Programmatic EIS.[7] This assessment combines the canister production rate from the first source with the canister production totals from the second (Figure 2-1). It is assumed that the canisters would be stored at the sites where they are produced, awaiting shipment to a centralized storage or permanent disposal facility.

## 2.3 Other Wastes Requiring Geologic Disposal

A variety of other radioactive wastes require permanent geologic disposal. Under DOE waste management plans or DOE agreements with states such as Idaho, these wastes could be shipped to a centralized above-ground facility for storage while awaiting permanent disposal. A recent DOE document[8] provides the best available information on the inventory of such wastes, which could total about 2,700 MTU, about 9.0 percent of the commercial spent fuel discharged through November 1994. This section briefly discusses the categories and projected inventory of "other wastes requiring geologic disposal," but the schedule, packages, and routes by which they would be shipped to Nevada are not included in this assessment.

- **Naval Reactor Fuel**

  Spent fuel from the power plants of the Navy's submarines and aircraft carriers is being shipped to INEL for storage, but, under an October 1995 agreement with the State of Idaho, must be removed from the state by 2035. The current inventory of such fuel at INEL is about 10.23 MTU, and an additional 55 tons may be accumulated.

- **Defense Production Reactor Fuel**

  About 2,100 MTU of SNF has been generated at Hanford's weapons production reactors (reactors N and K) and about 150 MTU at Savannah River. Prior to DOE's 1992 decision, this spent fuel would have been reprocessed—producing enriched uranium or plutonium as well as HLW. Under the 1992 decision, however, it will be packaged for shipment to a permanent geologic repository, perhaps via a centralized above-ground storage facility.

- **Spent Fuel from Research Reactors: DOE**

  Spent fuel has been discharged from research reactors at INEL (about 263.9 MTU), Savannah River (about 56.3 MTU), Hanford (about 32.4 MTU), Oak Ridge (about 1.8 MTU), and elsewhere (Battelle, Sandia, Los Alamos, Argonne-East: about 2.3 MTU). This material, which is in assemblies generally about one-quarter of the size of BWR assemblies will require geologic disposal.

- **Spent Fuel from Research Reactors: Non-DOE**

  About 5.5 MTU from non-DOE research reactors (about 90 percent from research reactors at universities, about 10 percent from research reactors at other federal agencies or commercial sites) will require geologic disposal. This total does not include the 3.2 MTU of spent fuel from the General Atomics research reactor near San Diego, which has acceptance priority under the standard contract.

- **Spent Fuel from Research Reactors: Foreign**

  About 21.7 MTU of spent fuel provided for research in foreign countries is being returned to the U.S. (arriving at various ports of entry) for management and disposal at a geologic repository. The fuel may be shipped for storage at DOE facilities (e.g., Hanford, INEL, Savannah River) pending subsequent transportation to a centralized storage or disposal site.

## Table 2-1. Spent Nuclear Fuel: Discharges, Assemblies, MTIHM
### Current Inventory: Discharges Through November 28, 1994
### Future Additions: Discharges 1995 through 2042

| | DISCHG | ASSMBL | MTU | MTU/A | LBS/A | A/DSCHG | MTU/D |
|---|---|---|---|---|---|---|---|
| CURRENT: | | | | | | | |
| BWR | 411 | 59418 | 10809 | 0.182 | 364 | 145 | 26 |
| PWR | 843 | 44602 | 19149 | 0.429 | 859 | 53 | 23 |
| HTG | 6 | 2208 | 24 | 0.011 | 22 | 368 | 4 |
| RSC | 32 | 72 | 3 | 0.044 | 89 | 2 | 0 |
| MSC | 3 | 0 | 59 | NA | 0 | 0 | NA |
| SUM | 1295 | 106300 | 30044 | 0.283 | 565 | 82 | 23 |
| FUTURE: | | | | | | | |
| BWR | 1872 | 110257 | 19873 | 0.180 | 360 | 59 | 11 |
| PWR | 3552 | 84915 | 36782 | 0.433 | 866 | 24 | 10 |
| HTG | 0 | 0 | 0 | NA | 0 | NA | NA |
| RSC | 0 | 0 | 0 | NA | 0 | NA | NA |
| MSC | 0 | 0 | 0 | NA | 0 | NA | NA |
| SUM | 5424 | 195172 | 56655 | 0.290 | 581 | 36 | 10 |
| TOTAL: | | | | | | | |
| BWR | 2283 | 169675 | 30682 | 0.181 | 362 | 74 | 13 |
| PWR | 4395 | 129517 | 55931 | 0.432 | 864 | 29 | 13 |
| HTG | 6 | 2208 | 24 | 0.011 | 22 | 368 | 4 |
| RSC | 32 | 72 | 3 | 0.044 | 89 | 2 | 0 |
| MSC | 3 | 0 | 59 | NA | 0 | 0 | NA |
| SUM | 6719 | 301472 | 86699 | 0.288 | 575 | 45 | 13 |

| | | DISCHG | ASSMBL | MTU | MTU/A | LBS/A | A/DSCHG | MTU/D |
|---|---|---|---|---|---|---|---|---|
| BWR: | Current | 411 | 59418 | 10809 | 0.182 | 364 | 145 | 26 |
| | Future | 1872 | 110257 | 19873 | 0.180 | 360 | 59 | 11 |
| | Total | 2283 | 169675 | 30682 | 0.181 | 362 | 74 | 13 |
| PWR: | Current | 843 | 44602 | 19149 | 0.429 | 859 | 53 | 23 |
| | Future | 3552 | 84915 | 36782 | 0.433 | 866 | 24 | 10 |
| | Total | 4395 | 129517 | 55931 | 0.432 | 864 | 29 | 13 |
| HTG: | Current | 6 | 2208 | 24 | 0.011 | 22 | 368 | 4 |
| | Future | 0 | 0 | 0 | NA | 0 | NA | NA |
| | Total | 6 | 2208 | 24 | 0.011 | 22 | 368 | 4 |
| RSC: | Current | 32 | 72 | 3 | 0.044 | 89 | 2 | 0 |
| | Future | 0 | 0 | 0 | NA | 0 | NA | NA |
| | Total | 32 | 72 | 3 | 0.044 | 89 | 2 | 0 |
| MSC: | Current | 3 | 0 | 59 | NA | 0 | 0 | NA |
| | Future | 0 | 0 | 0 | NA | 0 | NA | NA |
| | Total | 3 | 0 | 59 | NA | 0 | 0 | NA |
| SUM: | Current | 1295 | 106300 | 30044 | 0.283 | 565 | 82 | 23 |
| | Future | 5424 | 195172 | 56655 | 0.290 | 581 | 36 | 10 |
| | Total | 6719 | 301472 | 86699 | 0.288 | 575 | 45 | 13 |

Source: DOE Acceptance Priority Ranking: Nov 28, 1994
Spent Fuel Storage Req: 1994-2042 (Tables B.1a & 1b),
via PIC: DISCHG, ACCPT94V, ACCPT95X

**Figure 2-1a. Cumulative Projected Production of HLW Canisters at West Valley, Savannah River, Hanford, and Idaho National Engineering Lab**

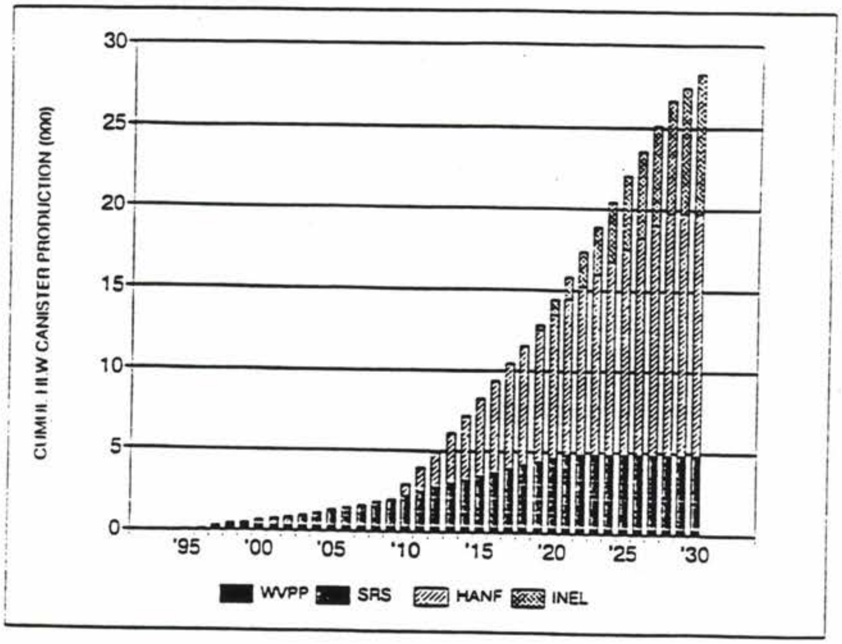
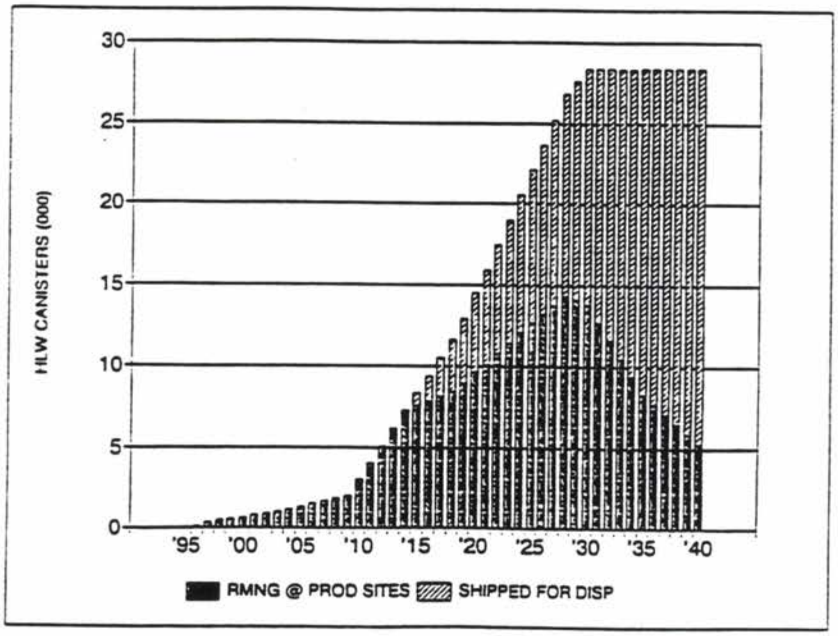



**Figure. 2-1b. Cumulative Projected HLW Canisters—Shipped and Remaining at Production Sites**



# 3. ACCEPTANCE STARTUP AND RATE

When the federal government is obligated to take title to SNF, and the annual rate at which it must pick up waste for transportation to and management at a federally-licensed facility are matters of current legal and legislative controversy:

**Acceptance Startup Year**

DOE has argued that acceptance would begin when a federally-licensed facility is available.[9] Since current legislation does not authorize construction of a centralized above-ground storage facility in Nevada, and since the suitability of Yucca Mountain as a permanent disposal site is uncertain, a date at which acceptance would begin cannot be specified.

Industry, on the other hand, has argued that the standard contract established by the NWPA requires the federal government to begin acceptance in 1998, in return for payments to the nuclear waste fund of 1 mill per kilowatt hour of nuclear generated electricity.[10]

This assessment does not specify the acceptance start year; acceptance begins in "year 1" and extends through "year 31". Assuming a 1998 startup year, and the acceptance rate specified in proposed legislation (see below), at least 84,100 MTU of SNF would be accepted by the end of the year 2027 (the 30th acceptance year)—reducing spent fuel in temporary storage to about 850 MTU. This spent fuel, plus about 1,610 MTU generated between 2027 and 2042 (under DOE's no-new-orders, NRC license term forecast[4]) is included in the "31st acceptance year," though in fact the fuel would be accepted in small quantities over a 22-year period between 2028 and 2050.

Changing the startup year to 2003, 84,100 MTU of SNF would not be accepted until the end of the year 2032 (the 30th acceptance year)—at which point the SNF in temporary storage would be about 1,715 MTU. This spent fuel, plus about 750 MTU generated between 2032 and 2042, is included in the "31st acceptance year", though in fact the fuel would be accepted in small quantities over a 17-year period between 2033 and 2050.

**Acceptance Rate**

DOE has suggested[11] that spent fuel would be accepted at a rate of 400 MTU in the first acceptance year, 600 MTU in the second, and 900 MTU in years three through ten. Only after year 10, other DOE reports[12] suggest, would acceptance and pick up increase to 3,000 MTU annually.

By contrast, proposed legislation would require acceptance of at least 1,200 MTU in the first and second acceptance years, 2,000 MTU in the third and fourth acceptance years, 2,700 MTU in the fifth acceptance year, and 3,000 MTU in the sixth and subsequent acceptance years.

This assessment uses the acceptance rate required by proposed legislation. The implication is that at least 9,100 MTU would be accepted for pickup and transport to a centralized storage facility over the first five acceptance years, and 15,000 MTU over each subsequent five-year period. Compared with acceptance rates implied by DOE reports, proposed legislation (e.g., S-1936) would increase pick up by

5,400 MTU over the first five years, by 10,500 MTU over the second five years, and by 3,000 MTU over the third five years.

**SNF Acceptance and Pick Up (MTU)**

| | DOE | S-1936 | Difference |
|---|---|---|---|
| Years 1 - 5 | 3,700 | 9,100 | 5,400 |
| Years 6 - 10 | 4,500 | 15,000 | 10,500 |
| Years 11 - 15 | 12,000 | 15,000 | 3,000 |
| Years 16 - 20 | 15,000 | 15,000 | 0 |
| Years 1 - 15 | 20,200 | 39,100 | 18,900 |

### Shipment of High-Level Wastes

This assessment assumes that the start date for shipment of canisters of vitrified high-level waste from DOE defense sites in year 15—that is, 15 years after the start date for spent fuel shipments, or 2015 assuming that spent fuel shipments begin in the year 2000. Once begun, this assessment assumes that HLW canisters would be shipped at an annual rate of 800 in the first five years, 900 in the second five, and 600 in subsequent years. At these rates, shipments would continue through 2049, roughly 20 years beyond the conclusion of SNF shipments.

Would a permanent geologic repository be available in year 15 (i.e., in 2015 if SNF shipments begin in the year 2000, in 2025 if SNF shipments begin in 2010), and could or would HLW be shipped to Nevada for centralized above-ground storage while awaiting permanent disposal? The answer is uncertain. The October 1995 settlement agreement between the State of Idaho and the DOE suggests (Section C3) that all HLW as well as naval reactor fuel and foreign research reactor fuel must be moved out of Idaho (i.e., to Nevada) by January 2035, and a possible interpretation of proposed legislation would allow shipment of HLW for centralized above-ground storage if a geologic repository is unavailable. As mentioned, this assessment assumes HLW shipments begin year 15 after the start of SNF shipments, whether the Nevada destination is a centralized storage facility or a permanent repository.

# 4. ACCEPTANCE PRIORITY

## Spent Fuel Discharges and Prioritization

The first spent fuel permanently discharged from a commercial nuclear plant occurred on June 21, 1968 and included five assemblies from the Big Rock Point boiling water reactor in northern Michigan. These assemblies, plus 80 others discharged from Big Rock in the late 1960s and early 1970s. are now stored at West Valley, in western New York State. The next spent fuel discharge from a commercial nuclear plant occurred on September 6, 1969 and included 94 assemblies from the Dresden 1 boiling water reactor in northeastern Illinois. These assemblies have been transferred for storage in the Dresden 2 and 3 spent fuel pools. The most recent spent fuel discharge in the current listing occurred on November 28, 1994 and included 204 assemblies from the Fitzpatrick boiling water reactor, north of Syracuse, New York, near the southeast corner of Lake Ontario.

Overall, there have been 1,108 discharges from commercial nuclear reactors through November 28, 1994—each of which is ranked for acceptance by year, month and day, and many of which have been subsequently separated into portions stored at various temporary locations. Assuming that DOE accepts "oldest-fuel-first," spent fuel would be picked up in the order in which it was discharged. This is the assumption in this assessment, though utilities are free to apply priorities to other fuel in their system. or to sell or auction priorities to other utilities. Also, proposed legislation might give priority to fuel at shut down reactors. which might help certain utilities to shut down their spent fuel pools earlier, and avoid the significant expense of continued pool operations at shut-down plants.

## The Use of Spent Fuel Priorities

Though difficult to predict, some examples illustrate how utilities might use the priorities of spent fuel in their system:

- Pacific Gas and Electric has 29.2 MTU in BWR assemblies stored at Humboldt Bay, whose reactor was shut down in 1976, and 427.7 MTU in PWR assemblies stored at Diablo Canyon. whose reactors are scheduled for shut down in 2008 and 2010. The spent fuel at Humboldt Bay was discharged in the early and mid-1970's, giving it priority for pickup in the first two acceptance years, while that at Diablo Canyon was discharged after 1985, giving it priority for pickup in years 7 to 12.

  Pacific Gas and Electric could use the priority of its fuel at Humboldt Bay to empty and shut down the Humboldt Bay pool, thus avoiding the expense of its continued operation. Or, it could use the priority of its fuel at Humboldt Bay to ship from Diablo Canyon, thus providing additional pool capacity at the still-operating Diablo Canyon plants.

- Consumers Power Company has 44.7 MTU in BWR assemblies stored at Big Rock (whose reactor is scheduled for shut down in the year 2000), and 316.8 MTU in PWR assemblies stored at Palisades (whose reactor is scheduled for shut down in 2007). While Consumers Power has 181.1 MTU of spent fuel with rankings which qualify for pickup in the first five acceptance years, almost all (91.9 percent) is stored at Palisades rather than at the Big Rock spent fuel pool.

Consumers Power could choose to use the priority of fuel in its system to empty the Big Rock pool after the Big Rock reactor shuts down in 2000, thus eliminating the expense of its continued operation. The Palisades dry storage facility would be required to enable its reactor to continue operation through its NRC license term.

- Northern States Power has 198.7 MTU in BWR assemblies stored at Morris, 147.5 MTU in BWR assemblies stored at Monticello (whose plant is scheduled for shut down in 2010), and 502.0 MTU stored at Prairie Island, whose plants are scheduled for shut down in 2013 and 2014, but which has very limited onsite storage capacity (wet or dry) to support continued plant operations. While Northern States Power has 191.8 MTU of spent fuel with rankings which qualify for pickup in the first three acceptance years, over half is stored at Morris (46.9 percent) or Monticello (5.0 percent) rather than at Prairie Island.

  Northern States could choose to use the priority of its spent fuel at Morris and Monticello to ship from Prairie Island, making additional storage capacity available there. While the capacity limitations at the Monticello spent fuel pool are much less severe than those at Prairie Island, the dimensions of the pool at Monticello (which was designed for BWR assemblies) preclude the transfer of PWR assemblies from Prairie Island. With confidence regarding an acceptance/shipment start date, Northern States might choose to purchase priority positions from one or more utilities with more sufficient onsite storage capacity.

# 5. SHIPMENT GROUPS

## Spent Fuel Forms and Ages

Spent fuel discharged from boiling water reactors is in 52 different types of assemblies.[13] As of July 1, 1996, 8.6 percent of the MTU discharged from boiling water reactors is over 20 years old, 41.4 percent is between 10 and 20 years old, and 50.0 percent is less than 10 years old.

Spent fuel discharged from pressurized water reactors is in 54 different types of assemblies. As of July 1, 1996, 5.3 percent of the MTU discharged from boiling water reactors is over 20 years old, 37.4 percent is between 10 and 20 years old, and 57.3 percent is less than 10 years old.

Under an oldest-fuel-first acceptance prioritization, spent fuel which is over 20 years old on July 1, 1996 would be picked up in the first and second acceptance years. Spent fuel which is between 10 and 20 years old would be picked up in the second through seventh acceptance years, while fuel less than 10 years old would be picked up in the seventh through twelfth acceptance years. If acceptance begins in January 1998, the 40 PWR assemblies discharged from the Trojan plant in May 1986 would be picked up in 2005—meaning that Portland General Electric will have stored these assemblies in an operating spent fuel pool for 19 years, and for 13 years after the Trojan plant shut down in 1992.

## Criteria for Cask Loading

How would the discharges at various storage locations be grouped for loading into transportation casks for shipment in a particular acceptance year?

- Would discharges whose priority ranking places them in different acceptance years be mixed in the same transportation cask? Under an oldest-fuel-first acceptance prioritization, the assumption in this assessment is "no."

- Would BWR or PWR discharges of different assembly types be mixed in the same transportation cask? The assumption in this assessment is "yes, as necessary." Thus, for example, the 335 assemblies at Big Rock, which include seven BWR assembly types fabricated by three companies (General Electric, Siemens and Nuclear Fuel Services), could be mixed in the same transportation cask if they fall into the same acceptance year.

- Would BWR and PWR assemblies be mixed in the same transportation cask? The question arises at storage locations such as Brunswick and Harris, whose pools have sections for storage of BWR and PWR assemblies, and at locations such as Morris, West Valley, and INEL, where BWR, PWR, and (in the case of INEL) HTG assemblies have been shipped for temporary storage. The assumption in this assessment is "no"—BWR and PWR assemblies would not be mixed in the same transportation cask.

- Would BWR or PWR assemblies discharged from different reactors be mixed in the same transportation cask? The question arises at Morris, which stores BWR assemblies discharged from Cooper Station and Dresden 2, or at McGuire 2, which stores PWR assemblies discharged from the three Oconee reactors as well as the McGuire 2 reactor, or at INEL, which stores PWR assemblies discharged at TMI 2, Surry 1 and 2, Turkey Point 3, and Point Beach. The assumption in this assessment is "no"—BWR or PWR assemblies discharged from different reactors would not be mixed in the same transportation cask.

Among the four shipment grouping criteria discussed above, the last may be considered too restrictive in its application in certain cases. An example is the BWR assemblies stored in the joined Hatch 1 and 2 spent fuel pools, near the Altamaha River about 75 miles west of Savannah, Georgia. These pools contain about 900 BWR assemblies of the 8G5 type, about 750 of the 8GP type, and about 1,450 of the 8GB type,[13] each of which has been discharged in substantial numbers from both the Hatch 1 and Hatch 2 reactors. There may be no impediment in mixing such assemblies in the same transportation cask, if they fall into the same acceptance year.

While shipment grouping is considered in this assessment, it is a factor which as a limited effect on the number of transportation casks shipped from a particular site in a particular acceptance year. More elaborate grouping criteria sometimes result in a few additional one or two partially-filled casks shipped from a particular site in a particular acceptance year.

# 6. CASK OPTIONS

**Rail Transport Casks**

Several casks are potentially available for rail shipment of SNF or HLW, some of which may also be used for above-ground storage of these materials:

- The NAC STC cask, designed by Nuclear Assurance Corporation, would have a capacity of 26 PWR assemblies at least 6½ years old, or 57 BWR assemblies at least eight years old. The cask would weigh at least 125 tons loaded. The PWR version has been certified by NRC for storage and transport, while the BWR version was scheduled for license submission in the fall of 1995. No NAC STC casks have been fabricated and none are currently available for delivery to storage or shipment sites. It is estimated that fabrication and delivery would take about two years after the order for a certified cask is made.

- The IF-300 cask, designed by General Electric, has a capacity of 7 PWR or 18 BWR assemblies. The cask weighs about 70 tons loaded. Four such casks have been fabricated. Two have been used by Carolina Power and Light for transfer of PWR and BWR assemblies among their Robinson, Brunswick, and Harris facilities. Two are owned by Vectra Technologies, formerly Pacific Nuclear Corporation. The IF-300 is certified for transport only, and no new fabrication is permitted under its current NRC certificate of compliance, which expired in May 1995.

- The TN-8 and TN-9 casks, designed by Transnuclear Inc., have capacities for 3 PWR or 7 BWR assemblies. Assemblies transported in TN-8/9 casks are uncanistered—meaning that, on arrival at its destination, the transportation cask must be moved to a spent fuel pool, where bare fuel assemblies are removed for pool storage or canistering. Though four such casks are available, they are not currently certified for use in the U.S. The TN-8 and TN-9 casks weigh just under 40 tons loaded. They are designed for transport only, not for storage, and the current certificate of compliance expired in May 1996.

- The Hi-Star 100 cask, designed by Holtec International, has a capacity of 24 PWR and 68 BWR assemblies. It is designed for storage as well as transport. None are currently available, as its NRC license application is currently under review. The cask weight, empty or loaded, is currently considered proprietary.

- The Vectra MP-187 cask, designed by Vectra Technologies for storage as well as transport, would have a capacity of 24 PWR assemblies. Its NRC license application is currently under review. The cask is intended for storage and transport of spent fuel at the Rancho Seco plant (near Sacramento, California) which was shut down in 1989.

- The small MPC (multiple-purpose canister) cask, designed by Westinghouse Electric for transport, storage, and (possibly) permanent disposal, would have a capacity of 12 PWR or 24 BWR assemblies. The large MPC cask, also designed by Westinghouse Electric for transport, storage, and (possibly) permanent disposal, would have a capacity of 21 PWR or 40 BWR assemblies.

Through FY 1995, MPC cask design and licensing was supported by DOE via the Nuclear Waste Fund, but this support was not continued in appropriations for FY 1995. While the U.S. Navy is considering an adaptation of the MPC design for the transport and storage of naval reactor fuel, the schedule for its design and licensing for use with SNF is uncertain. It appears unlikely that such casks could be delivered for a 1998 acceptance date.

- DOE has expressed its intention to adapt the MPC design for transport and storage of five canisters of vitrified HLW, each of which would be about 2 feet in diameter and 10 to 15 feet in length.[14] (The 48" diameter cavity of the MPC-75 might accommodate four two-foot diameter canisters, while the 58" diameter cavity of the MPC-125 might accommodate six two-foot diameter canisters.)[15] DOE has not begun detailed design or licensing of such a cask, however.

**Dry Storage of Canistered Spent Fuel**

Several designs for dry storage of canistered spent fuel have been approved by NRC. In these designs, spent fuel canisters are loaded and sealed in an operating spent fuel pool, then inserted into a nearby concrete or metal facility for onsite storage. The Electric Power Research Institute is currently developing a "dry transfer" facility, by which the sealed canisters could be transferred to a transport cask without return to a spent fuel pool. If successful, dry transfer could enable certain spent fuel pools to be shut down, even while spent fuel remains onsite in dry storage. Dry storage designs include:

- The NUHOMS concrete modules, designed by Vectra Technologies for storage of canistered PWR or BWR assemblies. The NUHOMS-7 design was licensed in 1986 and has a capacity of 7 PWR assemblies, while the NUHOMS-24P design was licensed in 1989 for storage of 24 PWR assemblies. A standardized version of the NUHOMS-24P and NUHOMS-52B (for 52 BWR assemblies) received an NRC certificate of compliance in January 1995.[16] The NUHOMS-7 design is in use at Robinson 2, while the NUHOMS-24P design is in use at Oconee, Calvert Cliffs, and Rancho Seco.

- The VSC-24 ventilated cask, designed by Pacific Sierra Nuclear for storage of 24 PWR assemblies. The design received its NRC certificate of compliance in 1993 and is in use at the Palisades nuclear plant, about 40 miles west of Kalamazoo near the eastern shore of Lake Michigan.

**Legal-Weight Truck Transport Casks**

Several designs are potentially available for legal-weight truck shipment of SNF and HLW. In contrast to dry storage casks and recently-designed rail casks, legal-weight truck casks are designed to transport uncanistered assemblies—meaning that, on its arrival at its destination, the cask must be placed in a spent fuel pool or hot cell, where the assemblies are removed for pool storage or canistered for dry storage.

- The GA-4 and GA-9 casks, designed by General Atomics, would have capacity for four PWR or nine BWR assemblies. The design is currently in review by NRC. The cask would weigh 27 tons, loaded. Adding the truck and transportation tackle, shipments would barely meet legal highway weight (80,000 lbs.).

There is some question whether General Atomics would find it advantageous to produce the GA-4/9 casks for a shipment campaign which emphasizes rail transport and reduces the inventory shipped by truck. Ironically, the number of smaller capacity truck shipments in a shipment campaign emphasizing rail transport could be as large or larger than the number truck shipments in a campaign which uses the higher capacity GA-4/9 casks combined with less rail transport.

- The NLI-1/2 cask designed by National Lead Industries, but not currently certified for domestic use, and the NAC-LWT cask designed by Nuclear Assurance Corporation have capacity to transport a single 860 pound PWR assembly or two 360 pound BWR assemblies. Such casks have been used in most spent fuel transport to date. These casks weigh 24 to 26 tons loaded.

**Transport Cask Options: This Assessment**

This assessment limits the array of transport cask options to essentially four:

- A 75-ton rail transport and storage cask similar to the MPC-75 design.
- A 125-ton rail transport and storage cask similar to the MPC-125 design.
- A high-capacity legal-weight truck transport cask similar to the GA-4/9 designs.
- A standard legal-weight truck transport cask similar to the NLI-1/2 or NAC-LWT designs.
- In addition, we have included a 100+ ton rail transport and storage cask for canisters of vitrified HLW—an adaption of the MPC-75/125 designs.

Note that, with the exception of the standard legal-weight truck transport casks, none of the above cask options are licensed by NRC, in production, or currently-available for delivery and use. The GA-4/9 cask design is in review in NRC, but, even if it is licensed, its production is uncertain. Despite considerable DOE investment in the 1990's, the designs for the MPC-75 and 125 casks are conceptual, and have not yet been submitted to NRC for licensing.

This assessment considers the high-capacity and standard capacity truck casks as alternatives for legal-weight truck transport. We estimate truck shipments using either cask, but do not attempt to estimate the mix of high and standard capacity casks that could be used in legal-weight truck shipments.*

* Map presentation of annual cask shipments (Sections 16-20) assume the use of standard capacity legal-weight truck casks in the "current capabilities" scenario, and the high-capacity, legal-weight truck cask in the "MPC base case" and "maximum rail" transportation choice scenarios.

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# 7. CASK LOADING

## Key Factors in Cask Loading

The facilities at each storage location must be able to load the cask option selected. The key requirements include:

- A crane at the spent fuel pool with operating capacity to safely lift the loaded cask.
- A cask loading area in the spent fuel pool of sufficient dimension to accommodate the upended cask and with a floor capable of supporting the cask during loading.
- A pool depth sufficient to maintain necessary water coverage while assemblies are moved over the upended cask during loading.
- A receiving area of sufficient dimension to accommodate the loading of the upended cask onto the rail car or truck, and a receiving area door of sufficient height to accommodate the rail car or truck along with its horizontally-positioned transport cask.
- In addition, sites with canistered spent fuel stored in concrete modules or vaults (e.g., Robinson, Oconee, Calvert Cliffs, Palisades, Rancho Seco) must have facilities necessary to remove the canisters and load them (wet or dry) into the selected transport cask.

## DOE's "FICA" Database

DOE's "Facility Interface Capability Assessment (FICA)" project[17] assessed the capability of each commercial SNF storage facility to handle shipping casks. The assessment, which was conducted in the late 1980s and has not been systematically updated, found one or more limitations at many storage locations (particularly in handling larger and heavier rail casks). Some limitations, however, might be overcome by modifications to facility licenses, administrative controls or physical aspects of the facility.

## Application of FICA Data in this Assessment

This assessment has reviewed the FICA data to consider the capability of each storage location to handle the cask options selected (Table 7-1). The key considerations were operating crane capacity, cask loading area dimensions, and pool depth. The assessment recognizes that facilities at some locations have been upgraded since the FICA assessment—particularly with regard to operating crane capacity at sites where onsite dry storage has been developed. The assessment also recognizes that facility limitations are often not absolute; current limitations may be eliminated or reduced through modification of facility licenses, administrative controls or physical aspects of the cask-handling building.

At the same time, the utility must decide that it is advantageous to invest in the changes necessary to enable their facilities to handle cask option "A" rather than cask options "B," or cask option "B" rather than cask options "C" or "D." These decisions "at the margin" will be made in the context of other factors (near-site rail infrastructure, site community characteristics, utility choice criteria) which are discussed in the following sections.

## Table 7-1. Cask Loading Factors: by Storage Location

| | CASK LOADG FACTOR: | | | |
|---|---|---|---|---|
| FUEL STRG LOCATION: | CRD | CRO | CDI | CLG |
| 1 ARKANSAS NUCLEAR 1 | 100 | 100 | R125 | R125 |
| 2 ARKANSAS NUCLEAR 2 | 100 | 100 | R125 | R125 |
| 3 ARKANSAS NUCLEAR DRY STRG | NA | NA | NA | NA |
| 4 BEAVER VALLEY 1 | 125 | 60 | R125 | R125 |
| 5 BEAVER VALLEY 2 | 125 | 100 | R125 | R125 |
| 6 BELLEFONTE 1 | ND | ND | ND | ND |
| 7 BELLEFONTE 2 | ND | ND | ND | ND |
| 8 BIG ROCK 1 | 75 | 24 | LWT | LWT |
| 9 BRAIDWOOD 1 | 125 | 110 | R125 | R125 |
| 10 BROWNS FERRY 1-2 | 125 | 106 | R75 | LWT |
| 11 BROWNS FERRY 3 | 125 | 106 | R75 | LWT |
| 12 BRUNSWICK 1 | 125 | 75 | R125 | R125 |
| 13 BRUNSWICK 1 PWR POOL | 125 | 75 | R125 | R125 |
| 14 BRUNSWICK 2 | 125 | 75 | R125 | R125 |
| 15 BRUNSWICK 2 PWR POOL | 125 | 75 | R125 | R125 |
| 16 BYRON 1 | 125 | 110 | R125 | R125 |
| 17 CALLAWAY 1 | 150 | 125 | R125 | R125 |
| 18 CALVERT CLIFFS 1-2 | 150 | 25 | R125 | R75 |
| 19 CALVERT DRY STORAGE | NA | NA | NA | NA |
| 20 CATAWBA 1 | 125 | 125 | R125 | R125 |
| 21 CATAWBA 2 | 125 | 125 | R125 | R125 |
| 22 CLINTON 1 | 125 | 100 | R125 | R125 |
| 23 COMANCHE PEAK 1 | 130 | 130 | R125 | R125 |
| 24 COOK 1 | 150 | 60 | R125 | R125 |
| 25 COOPER STATION | 100 | 100 | LWT | LWT |
| 26 CRYSTAL RIVER 3 | 120 | 72 | R125 | R125 |
| 27 DAVIS-BESSE 1 | 140 | 125 | R125 | R125 |
| 28 DAVIS-BESSE DRY STRG | NA | NA | NA | NA |
| 29 DIABLO CANYON 1 | 125 | 67 | R125 | R125 |
| 30 DIABLO CANYON 2 | 125 | 67 | R125 | R125 |
| 31 DRESDEN 1 | 75 | 24 | LWT | R125 |
| 32 DRESDEN 2 | 75 | 75 | LWT | LWT |
| 33 DRESDEN 3 | 75 | 75 | LWT | LWT |
| 34 DUANE ARNOLD | 100 | 85 | R125 | R75 |
| 35 ENRICO FERMI 2 | 125 | 100 | R125 | LWT |
| 36 FARLEY 1 | 125 | 125 | R125 | R125 |
| 37 FARLEY 2 | 125 | 125 | R125 | R125 |
| 38 FITZPATRICK | 125 | 62 | R125 | R75 |
| 39 FORT CALHOUN | 75 | 40 | R125 | R125 |
| 40 FORT ST VRAIN | 50 | 50 | LWT | R125 |
| 41 FORT ST VRAIN DRY STRG | NA | NA | NA | NA |
| 42 GINNA | 40 | 30 | R125 | LWT |
| 43 GRAND GULF 1 | 150 | 125 | R125 | R125 |
| 44 HADDAM NECK | 100 | 100 | R75 | LWT |
| 45 HARRIS 1 | 150 | 75 | R125 | R125 |
| 46 HARRIS 1 BWR POOL | 150 | 97 | LWT | LWT |
| 47 HATCH 1-2 | 125 | 125 | R125 | LWT |
| 48 HOPE CREEK | 150 | 130 | R125 | R125 |
| 49 HUMBOLDT BAY | 75 | 60 | R125 | R125 |
| 50 INDIAN POINT 1 | 75 | 60 | LWT | LWT |
| 51 INDIAN POINT 2 | 40 | 32 | R75 | LWT |
| 52 INDIAN POINT 3 | 75 | 40 | R75 | LWT |
| 53 KEWAUNEE | 125 | 120 | LWT | LWT |
| 54 LACROSSE | 50 | 36 | LWT | LWT |
| 55 LASALLE 1-2 | 125 | 100 | R125 | R125 |
| 56 LIMERICK 1-2 | 125 | 110 | R125 | R125 |
| 57 MAINE YANKEE | 125 | 125 | R125 | R125 |
| 58 MCGUIRE 1 | 125 | 100 | LWT | R125 |
| 59 MCGUIRE 2 | 125 | 100 | LWT | R125 |
| 60 MILLSTONE 1 | 110 | 110 | LWT | R125 |
| 61 MILLSTONE 2 | 100 | 100 | R125 | R125 |
| 62 MILLSTONE 3 | 125 | 125 | R125 | R125 |
| 63 MONTICELLO | 85 | 85 | LWT | LWT |
| 64 NINE MILE POINT 1 | 125 | 100 | R125 | LWT |
| 65 NINE MILE POINT 2 | 125 | 100 | R125 | LWT |
| 66 NORTH ANNA 1&2 | 125 | 105 | R125 | R125 |
| 67 NORTH ANNA DRY STRG | NA | NA | NA | NA |
| 68 OCONEE 1&2 | 100 | 100 | LWT | R125 |
| 69 OCONEE 3 | 100 | 100 | LWT | R125 |
| 70 OCONEE DRY STORAGE | NA | NA | NA | NA |
| 71 OYSTER CREEK 1 | 100 | 100 | R125 | R75 |
| 72 OYSTER CREEK DRY STRG | NA | NA | NA | NA |
| 73 PALISADES | 100 | 25 | LWT | LWT |
| 74 PALISADES DRY STORAGE | NA | NA | NA | NA |
| 75 PALO VERDE 1 | 150 | 150 | R125 | R125 |
| 76 PALO VERDE 2 | 150 | 150 | R125 | R125 |
| 77 PALO VERDE 3 | 150 | 150 | R125 | R125 |
| 78 PEACHBOTTOM 2 | 125 | 100 | R75 | LWT |
| 79 PEACHBOTTOM 3 | 125 | 100 | R75 | LWT |
| 80 PERRY 1 | 125 | 125 | R125 | R125 |
| 81 PILGRIM 1 | 100 | 26 | R75 | LWT |
| 82 POINT BEACH 1&2 | 125 | 125 | R75 | R125 |
| 83 POINT BEACH DRY STRG | NA | NA | NA | NA |
| 84 PRAIRIE ISLAND 1&2 | 125 | 125 | R125 | R125 |
| 85 PRAIRIE ISLAND DRY STRG | NA | NA | NA | NA |
| 86 QUAD CITIES 1 | 125 | 75 | R125 | LWT |
| 87 RANCHO SECO 1 | 100 | 97 | R125 | R125 |
| 88 RANCHO SECO DRY STRG | NA | NA | NA | NA |
| 89 RIVER BEND 1 | 125 | 125 | R125 | R125 |
| 90 ROBINSON 2 | 125 | 77 | R75 | R125 |
| 91 ROBINSON DRY STORAGE | NA | NA | NA | NA |
| 92 SALEM 1 | 110 | 110 | R125 | R125 |
| 93 SALEM 2 | 110 | 110 | R125 | R125 |
| 94 SAN ONOFRE 1 | 105 | 70 | R75 | LWT |
| 95 SAN ONOFRE 2 | 125 | 125 | R125 | R125 |
| 96 SAN ONOFRE 3 | 125 | 125 | R125 | R125 |
| 97 SEABROOK 1 | 125 | 125 | R125 | R125 |
| 98 SEQUOYAH 1 | 125 | 80 | R125 | R125 |
| 99 SHOREHAM | 125 | 123 | R75 | LWT |
| 100 SOUTH TEXAS 1 | 150 | 150 | R125 | R125 |
| 101 SOUTH TEXAS 2 | 150 | 150 | R125 | R125 |
| 102 ST LUCIE 1 | 105 | 25 | R125 | R125 |
| 103 ST LUCIE 2 | 150 | 100 | R125 | R125 |
| 104 SUMMER 1 | 125 | 125 | R125 | R125 |
| 105 SURRY 1&2 | 125 | 125 | R125 | R125 |
| 106 SURRY DRY STORAGE | NA | NA | NA | NA |
| 107 SUSQUEHANNA 1-2 | 125 | 125 | R125 | R125 |
| 108 SUSQUEHANNA DRY STRG | NA | NA | NA | NA |
| 109 THREE MILE ISLAND 1 | 110 | 110 | R75 | R125 |
| 110 TROJAN | 125 | 100 | R125 | R125 |
| 111 TURKEY POINT 3 | 105 | 25 | R125 | R75 |
| 112 TURKEY POINT 4 | 105 | 25 | R125 | R75 |
| 113 VERMONT YANKEE 1 | 110 | 110 | LWT | LWT |
| 114 VOGTLE 1-2 | 125 | 91 | R125 | R125 |
| 115 WASH NUCLEAR 2 | 125 | 125 | R125 | LWT |
| 116 WATTS BAR 1&2 | ND | ND | ND | ND |
| 117 WATERFORD 3 | 125 | 125 | R125 | LWT |
| 118 WOLF CREEK 1 | 150 | 125 | R125 | R125 |
| 119 YANKEE-ROWE 1 | 75 | 37 | R75 | R125 |
| 120 ZION 1&2 | 125 | 110 | R125 | LWT |
| 121 HANFORD SNF STRG | ND | ND | ND | ND |
| 122 HANFORD SNF STRG | ND | ND | ND | ND |
| 123 INEL SNF STRG | ND | ND | ND | ND |
| 124 INEL SNF STRG | ND | ND | ND | ND |
| 125 INEL SNF STRG | ND | ND | ND | ND |
| 126 SAVANNAH RV SNF STRG | ND | ND | ND | ND |
| 127 SAVANNAH RV SNF STRG | ND | ND | ND | ND |
| 128 WEST VALLEY SNF STRG | ND | ND | ND | ND |
| 129 WEST VALLEY SNF STRG | ND | ND | ND | ND |
| 130 MORRIS | 125 | 68 | R125 | R125 |
| 131 MORRIS | 125 | 68 | R125 | R125 |
| 132 GENERAL ATOMICS | ND | ND | ND | ND |

Cask Loading Factors:
- CRD: design crane capacity (tons)
- CRD: operating crane capacity (tons)
- CDI: cask set-down (loading) diameter (max cask option)
- CLG: cask length (loading) req (max cask option)

Shipment Cask Options:
- R125: Large MPC for up to 21 PWR or 40 BWR
- R75: Small MPC for up to 12 PWR or 24 BWR
- LWT: Legal-weight truck casks.... GA-4/9 if avail, NLI-1/2 or NAC LWT otherwise

# 8. NEAR-SITE INFRASTRUCTURE

### Sites with Onsite Rail

At many storage locations, a rail line extends to the plant site and to the cask receiving area in the fuel handling building and/or the dry storage facility or barge loading platform. At some such locations, however, the onsite rail line requires upgrading for spent fuel rail shipments.

### Sites without Onsite Rail

Locations without onsite rail may choose to transport the rail cask by heavy-haul truck or barge to an offsite railhead where the cask can be loaded onto a rail car for cross-country shipment. Such a decision, however, can introduce complications which could persuade a utility to choose to ship by legal-weight truck, or at least to hesitate before choosing to ship by rail.

- The additional load/unload operation in heavy-haul truck or barge transport is both costly and logistically complex.
- Heavy-haul truck transport involves state regulatory agencies in ways that legal-highway-weight transport does not.
- The communities along the heavy-haul route may object to such shipments.

### Branch Rail Line Abandonments

Due to branch rail line abandonments, a number of storage locations which had onsite rail when the reactor was constructed do not have onsite rail now, or may not have onsite rail by the time a national shipment campaign begins. For example:

- The Central Railroad of New Jersey branch rail line, which provided onsite rail access when the Oyster Creek plant was constructed in 1969, has since been abandoned. The nearest currently available railhead is on the Conrail line at Lakehurst, New Jersey, and would be reached via a somewhat circuitous 30-mile heavy-haul truck shipment.
- The Elgin Joliet and Eastern branch rail line which has provided onsite rail access to General Electric's storage facility at Morris, Illinois is being considered for abandonment. The nearest available offsite railhead is on the Santa Fe Railroad at Coal City, and would be reached via a seven-mile heavy-haul truck shipment.

### DOE's "NSTI" Database

DOE's Near-Site Transportation Infrastructure (NSTI) project[18] assessed the existing capabilities and upgrade potentials of transportation networks near 76 spent fuel storage sites. The assessment was conducted in 1989, and has not been systematically updated. Also, the NSTI final report makes clear that it does not recommend which transportation mode or shipping route should be used at the 76 sites, or imply that the utility or plant operator for any facility or transportation system has expressed the intention of completing the upgrades assessed (Table 8-1).

**Onsite Rail, Plus Rail Cask Loading**

In fact, the utility's transportation choice will not be made on the basis of either near-site transportation or storage facility infrastructure, but on the combination of these factors with other considerations. This assessment generally assumes that a site will ship by rail if onsite rail is available and if the storage location facilities are able to load a 75 or 125-ton rail cask. In other words, it is generally assumed that a utility will find it advantageous to ship by rail if the additional investment required is small. For example,

- Arkansas Nuclear 1 and 2, located near Russellville, Arkansas, about 65 miles northwest of Little Rock, is a site which has operating onsite rail, and two separate pools—each capable of loading casks up to 9'6" in diameter and 19'2" in length, and each with an operating crane capacity of 100 tons. In this case, rail shipment using 75-ton casks would appear to require limited additional investment in pool facilities or near-site infrastructure, and it is assumed that this would be the choice of Arkansas Power and Light.

- Perry, located on the south shore of Lake Erie about 35 miles northeast of Cleveland, has operating onsite rail with modest upgrade requirements and two separate pools—each capable of loading casks up to 10'0" in diameter and 20'11" in length, and each with an operating crane capacity of 125 tons. In this case, rail shipment using 125-ton casks would appear to require limited additional investment in pool facilities or near-site infrastructure, and it is assumed this would be the choice of Cleveland Electric Illuminating Company.

**No Onsite Rail or Rail Cask Loading**

This assessment generally assumes that a site will ship by truck if on-site rail is not available and if current storage location facilities are unable to load a 75 or 125-ton rail cask. In other words, it is generally assumed that a utility will ship by legal-weight truck if the additional cost (in facility upgrades or logistical complication) to ship by rail is large. For example:

- Indian Point, located on the Hudson River about 35 miles north of Times Square, does not have onsite rail, though an offsite railhead is less than five miles distant. The pool at reactor #1, which was shut down in 1980, is capable of loading casks only 3'1" in diameter and 12'11" in length. The pools at reactors 2 and 3 are capable of loading casks of only 7'6" and 8'0" in diameter and 15'10" to 16'2" in length. The operating capacities of the pool cranes are 40 tons or less. In this case, rail shipment would appear to require substantial investment in pool dimensions, crane capacity and heavy-haul logistics. It is assumed that Consolidated Edison would avoid this investment, and ship by legal-weight truck.

- Ginna, located on Lake Ontario about 15 miles east of Rochester, New York, does not have onsite rail, though an offsite railhead is less than five miles distant. Its pools is capable of loading casks of 8'7" in diameter, but only 16'9" in length, and its operating crane capacity is only 30 tons. In this case, rail shipment would appear to require substantial investment in pool dimensions, crane capacity and heavy-haul logistics. It is assumed that Rochester Gas and Electric would avoid this investment, and ship by legal-weight truck.

**Near-Site Transportation/Cask Loading Combinations**

Many sites have combinations of characteristics that complicate the utility's transportation choice:

- Onsite rail is available but pool facilities are unable to load a 75 or 125-ton rail cask.

- Pool facilities are sufficient but onsite rail is unavailable, or, if available, requires expensive upgrading.

- Pool dimensions are sufficient, but operating crane capacity is insufficient to lift a loaded 75- or 125-ton rail cask.

- Crane capacity could be improved, but requires substantial investment in equipment and drop tests.

- An offsite railhead is available but would require an additional loading (to a heavy-haul truck), plus highway travel through nearby communities, plus state heavy-haul permits.

In such circumstances, utilities must choose among available transportation cask options and make the consequent investment in pool facilities or near-site infrastructure to support the choice. DOE/OCRWM, which is responsible for the national shipment campaign, has an interest in and influence on the utility's choice, but cannot force utility investment beyond what the utility considers reasonable and appropriate. Each utility also has an interest in the success of the national shipment campaign—that is, an interest beyond minimizing the cost of moving spent fuel off its particular sites. In sum, choices among available transportation cask options will be made pool by pool and site by site, based on each utility's choice criteria and in the context of federal policy and the various facility, site and transportation network circumstances at the time the choice must be made. For planning purposes, this assessment specifies the available cask options (section 6), and considers three sets of possible utility transportation choices (section 11). Before reviewing the transportation scenarios, we consider several other choice factors—federal policy, utility choice criteria, and changing circumstances.

## Table 8-1. Near-Site Infrastructure: by Storage Location

| | FUEL STRG LOCATION: | NEAR-SITE FACTOR: OSR | OP? | OSS | OFD |
|---|---|---|---|---|---|
| 1 | ARKANSAS NUCLEAR 1 | Y | Y | 0 | 0 |
| 2 | ARKANSAS NUCLEAR 2 | Y | Y | 0 | 0 |
| 3 | ARKANSAS NUCLEAR DRY STRG | Y | Y | 0 | 0 |
| 4 | BEAVER VALLEY 1 | Y | Y | 0 | 0 |
| 5 | BEAVER VALLEY 2 | Y | Y | 0 | 0 |
| 6 | BELLEFONTE 1 | ND | ND | ND | ND |
| 7 | BELLEFONTE 2 | ND | ND | ND | ND |
| 8 | BIG ROCK 1 | N | NA | 0 | 13 |
| 9 | BRAIDWOOD 1 | Y | Y | 10 | 0 |
| 10 | BROWNS FERRY 1-2 | N | NA | 20 | 9 |
| 11 | BROWNS FERRY 3 | N | NA | 20 | 9 |
| 12 | BRUNSWICK 1 | Y | Y | 0 | 0 |
| 13 | BRUNSWICK 1 PWR POOL | Y | Y | 0 | 0 |
| 14 | BRUNSWICK 2 | Y | Y | 0 | 0 |
| 15 | BRUNSWICK 2 PWR POOL | Y | Y | 0 | 0 |
| 16 | BYRON 1 | Y | Y | 0 | 0 |
| 17 | CALLAWAY 1 | N | NA | 0 | 15 |
| 18 | CALVERT CLIFFS 1-2 | N | NA | 0 | 37 |
| 19 | CALVERT DRY STORAGE | N | NA | 0 | 37 |
| 20 | CATAWBA 1 | Y | N | 0 | 0 |
| 21 | CATAWBA 2 | Y | N | 0 | 0 |
| 22 | CLINTON 1 | Y | N | 0 | 0 |
| 23 | COMANCHE PEAK 1 | Y | Y | 125 | 0 |
| 24 | COOK 1 | Y | N | 100 | 0 |
| 25 | COOPER STATION | Y | Y | 0 | 0 |
| 26 | CRYSTAL RIVER 3 | Y | Y | 80 | 0 |
| 27 | DAVIS-BESSE 1 | Y | Y | 0 | 0 |
| 28 | DAVIS-BESSE DRY STRG | Y | Y | 0 | 0 |
| 29 | DIABLO CANYON 1 | N | NA | 0 | 19 |
| 30 | DIABLO CANYON 2 | N | NA | 0 | 19 |
| 31 | DRESDEN 1 | Y | Y | 25 | 0 |
| 32 | DRESDEN 2 | Y | Y | 25 | 0 |
| 33 | DRESDEN 3 | Y | Y | 25 | 0 |
| 34 | DUANE ARNOLD | Y | Y | 0 | 0 |
| 35 | ENRICO FERMI 2 | Y | N | 125 | 0 |
| 36 | FARLEY 1 | Y | Y | 45 | 0 |
| 37 | FARLEY 2 | Y | Y | 45 | 0 |
| 38 | FITZPATRICK | Y | Y | 10 | 0 |
| 39 | FORT CALHOUN | N | NA | 0 | 6 |
| 40 | FORT ST VRAIN | Y | N | 100 | 0 |
| 41 | FORT ST VRAIN DRY STRG | Y | N | 100 | 0 |
| 42 | GINNA | N | NA | 0 | 4 |
| 43 | GRAND GULF 1 | N | NA | 0 | 24 |
| 44 | HADDAM NECK | N | NA | 0 | 14 |
| 45 | HARRIS 1 | Y | Y | 0 | 0 |
| 46 | HARRIS 1 BWR POOL | Y | Y | 0 | 0 |
| 47 | HATCH 1-2 | Y | Y | 0 | 0 |
| 48 | HOPE CREEK | N | NA | 0 | 23 |
| 49 | HUMBOLDT BAY | Y | Y | 150 | 0 |
| 50 | INDIAN POINT 1 | N | NA | 0 | 3 |
| 51 | INDIAN POINT 2 | N | NA | 0 | 3 |
| 52 | INDIAN POINT 3 | N | NA | 0 | 3 |
| 53 | KEWAUNEE | N | NA | 0 | 10 |
| 54 | LACROSSE | Y | N | 100 | 0 |
| 55 | LASALLE 1-2 | Y | Y | 0 | 0 |
| 56 | LIMERICK 1-2 | Y | N | 50 | 0 |
| 57 | MAINE YANKEE | Y | Y | 0 | 0 |
| 58 | MCGUIRE 1 | Y | N | 0 | 0 |
| 59 | MCGUIRE 2 | Y | N | 0 | 0 |
| 60 | MILLSTONE 1 | Y | N | 115 | 0 |
| 61 | MILLSTONE 2 | Y | N | 115 | 0 |
| 62 | MILLSTONE 3 | Y | N | 115 | 0 |
| 63 | MONTICELLO | Y | Y | 0 | 0 |
| 64 | NINE MILE POINT 1 | Y | Y | 125 | 0 |
| 65 | NINE MILE POINT 2 | Y | Y | 125 | 0 |
| 66 | NORTH ANNA 1&2 | Y | Y | 50 | 0 |
| 67 | NORTH ANNA DRY STRG | Y | Y | 50 | 0 |
| 68 | OCONEE 1&2 | N | NA | 0 | 35 |
| 69 | OCONEE 3 | N | NA | 0 | 35 |
| 70 | OCONEE DRY STORAGE | N | NA | 0 | 35 |
| 71 | OYSTER CREEK 1 | N | NA | 0 | 30 |
| 72 | OYSTER CREEK DRY STRG | N | NA | 0 | 30 |
| 73 | PALISADES | N | NA | 10 | 13 |
| 74 | PALISADES DRY STORAGE | N | NA | 10 | 13 |
| 75 | PALO VERDE 1 | Y | Y | 0 | 0 |
| 76 | PALO VERDE 2 | Y | Y | 0 | 0 |
| 77 | PALO VERDE 3 | Y | Y | 0 | 0 |
| 78 | PEACHBOTTOM 2 | N | NA | 0 | 35 |
| 79 | PEACHBOTTOM 3 | N | NA | 0 | 35 |
| 80 | PERRY 1 | Y | Y | 40 | 0 |
| 81 | PILGRIM 1 | N | NA | 0 | 12 |
| 82 | POINT BEACH 1&2 | N | NA | 0 | 16 |
| 83 | POINT BEACH DRY STRG | N | NA | 0 | 16 |
| 84 | PRAIRIE ISLAND 1&2 | Y | N | 25 | 0 |
| 85 | PRAIRIE ISLAND DRY STRG | Y | N | 25 | 0 |
| 86 | QUAD CITIES 1 | Y | N | 0 | 0 |
| 87 | RANCHO SECO 1 | Y | N | 0 | 0 |
| 88 | RANCHO SECO DRY STRG | Y | N | 0 | 0 |
| 89 | RIVER BEND 1 | Y | N | 175 | 0 |
| 90 | ROBINSON 2 | Y | Y | 0 | 0 |
| 91 | ROBINSON DRY STORAGE | Y | Y | 0 | 0 |
| 92 | SALEM 1 | N | NA | 0 | 23 |
| 93 | SALEM 2 | N | NA | 0 | 23 |
| 94 | SAN ONOFRE 1 | Y | Y | 200 | 0 |
| 95 | SAN ONOFRE 2 | Y | Y | 200 | 0 |
| 96 | SAN ONOFRE 3 | Y | Y | 200 | 0 |
| 97 | SEABROOK 1 | Y | N | 135 | 0 |
| 98 | SEQUOYAH 1 | Y | Y | 10 | 0 |
| 99 | SHOREHAM | N | NA | 0 | 10 |
| 100 | SOUTH TEXAS 1 | Y | Y | 85 | 0 |
| 101 | SOUTH TEXAS 2 | Y | Y | 85 | 0 |
| 102 | ST LUCIE 1 | N | NA | 0 | 10 |
| 103 | ST LUCIE 2 | N | NA | 0 | 10 |
| 104 | SUMMER 1 | Y | Y | 0 | 0 |
| 105 | SURRY 1&2 | N | NA | 0 | 30 |
| 106 | SURRY DRY STORAGE | N | NA | 0 | 30 |
| 107 | SUSQUEHANNA 1-2 | Y | Y | 0 | 0 |
| 108 | SUSQUEHANNA DRY STRG | Y | Y | 0 | 0 |
| 109 | THREE MILE ISLAND 1 | Y | Y | 0 | 0 |
| 110 | TROJAN | Y | Y | 0 | 0 |
| 111 | TURKEY POINT 3 | N | NA | 0 | 30 |
| 112 | TURKEY POINT 4 | N | NA | 0 | 30 |
| 113 | VERMONT YANKEE 1 | Y | Y | 75 | 0 |
| 114 | VOGTLE 1-2 | Y | N | 25 | 0 |
| 115 | WASH NUCLEAR 2 | Y | Y | 0 | 0 |
| 116 | WATTS BAR 1&2 | | | | |
| 117 | WATERFORD 3 | Y | Y | 25 | 0 |
| 118 | WOLF CREEK 1 | Y | N | 10 | 0 |
| 119 | YANKEE-ROWE 1 | N | NA | 0 | 7 |
| 120 | ZION 1&2 | Y | Y | 0 | 0 |
| 121 | HANFORD SNF STRG | ND | ND | ND | ND |
| 122 | HANFORD SNF STRG | ND | ND | ND | ND |
| 123 | INEL SNF STRG | ND | ND | ND | ND |
| 124 | INEL SNF STRG | ND | ND | ND | ND |
| 125 | INEL SNF STRG | ND | ND | ND | ND |
| 126 | SAVANNAH RV SNF STRG | ND | ND | ND | ND |
| 127 | SAVANNAH RV SNF STRG | ND | ND | ND | ND |
| 128 | WEST VALLEY SNF STRG | ND | ND | ND | ND |
| 129 | WEST VALLEY SNF STRG | ND | ND | ND | ND |
| 130 | MORRIS | Y | Y | 0 | 0 |
| 131 | MORRIS | Y | Y | 0 | 0 |
| 132 | GENERAL ATOMICS | ND | ND | ND | ND |

Near-Site Infrastructure Considerations:
- OSR: onsite rail (yes, no, not applic)
- OP?: onsite rail operating? (yes, no, not applic)
- OSS: onsite rail upgrade cost (000$)
- OFD: distance to offsite rail (miles)

Shipment Cask Options:
- R125: Large MPC for up to 21 PWR or 40 BWR
- R75: Small MPC for up to 12 PWR or 24 BWR
- LWT: Legal-weight truck casks.... GA-4/9 if avail. NLI-1/2 or NAC LWT otherwise

# 9. OTHER TRANSPORTATION CHOICE FACTORS

Utility transportation choice decisions will reflect factors in addition to current near-site infrastructure and pool capabilities—e.g., federal policy, utility choice criteria, changes in near-site infrastructure cask handling capabilities, or site community characteristics.

## Federal Policies

Federal policies affect utility transportation choices. For example,

- Via the nuclear waste fund, DOE has invested in the design of the GA-4/9 cask and the MPC 75 and 125-ton casks, and has set the parameters for these designs. However, as of FY 1996, DOE withdrew its financial support for design, and indicated that it does not intend to support certification or fabrication of these or other transportation or transportation/storage casks.

- Via the nuclear waste fund, DOE could fund modifications to spent fuel pools or near-site infrastructure at origin sites—modifications which would enable these sites to choose transportation options considered more desirable from the perspective of the national shipment campaign. However, in its draft scope for acquisition of transportation services,[2] DOE states that "OCRWM will not fund any on-site infrastructure modifications or improvements to the purchasers' facilities" (page 1).

- In its May 28, 1996 notice,[2] DOE proposes to delegate major responsibilities for waste acceptance, transportation and storage to contractors operating under competitive fixed price contracts. The resulting transportation choices negotiated with utilities could be quite different from those reached under another decision framework.

- DOE intends to provide the final route links to a permanent repository or centralized storage site in Nevada, and has conducted major studies of alternative heavy-haul and rail routes for this link. In the process, DOE would enable origin sites to choose rail over legal-weight truck transport, without, however, providing an incentive for origin sites to ship by rail.

## Utility Choice Criteria

Utilities will have different sets of transportation choice criteria, based on their financial positions, their nuclear waste and other transportation experiences, their relationships with nearby communities, etc. Given the same origin site circumstances, utility "A" might choose to upgrade for rail shipment while utility "B," approaching the same decision from a different perspective, might choose to avoid upgrades and ship by truck.

## Changes At or Near Origin Sites

Changes at or near origin sites will affect utility transportation choices at the time those choices must be made—generally, five to ten years from now. For example,

- The development of dry storage facilities often involves investment to enable pools to handle sealed spent fuel canisters, if not loaded transportation/storage casks. The resulting capabilities, many of which were not anticipated in DOE's 1989 FICA study, will be available for off-site transportation as well.

- While mainline railroads are receiving increasing freight traffic, branch lines—some serving nuclear plant sites—are being abandoned. For example,

  — The branch line of the Central Railroad which extended along US-9 through the Oyster Creek (New Jersey) site when the plant was constructed in the late 1960s has since been abandoned. Rail casks would now be heavy-hauled to Conrail's railhead in Lakehurst, New Jersey, along a 30-mile route which avoids the towns of Forked River, Tom's River, and Pinewold. Or, rail casks might be heavy-hauled across US-9 for barge shipment to an off-site railhead.

  — Burlington Northern's rail spur to the Cooper Station plant site on the Missouri River about 60 miles south of Omaha may be abandoned when it is no longer needed for shipments to Morris. Rail shipments might be heavy-hauled 30 miles to a Burlington Northern railhead in Nebraska City, or barged down the Missouri River through St. Joseph and Kansas City to a Union Pacific railhead in Boonville, Missouri.

  — The Elgin, Joliet, and Eastern rail spurs to the Morris and Dresden sites about 40 miles southwest of Chicago may be abandoned, as may Conrail's spur to West Valley, about 35 miles south of Buffalo, New York.

- Community conditions (resident population, community character, etc.) in near-site communities may also change, affecting the utility's transportation choice.

# 10. TRANSPORTATION CHOICES

Given the factors discussed in Sections 6 through 9, how would the transportation choice actually be made? Using Monticello, Big Rock Point, Point Beach, Salem/Hope Creek, and Enrico Fermi as case study sites, this section illustrates the transportation choice decision as it might be addressed by utilities. Section 11 presents three scenarios of transportation choices for all shipment sites. Appendix A compares the three transportation choice scenarios considered in this assessment with two developed by DOE.

### Monticello

Given the cask options identified in Section 6, and the factors discussed in Sections 7 through 9, how would Northern States Power (NSP) choose to ship from its Monticello plant, located on the Mississippi River about 35 miles northwest of Minneapolis? Monticello has operating onsite rail which does not require upgrade for shipment of spent nuclear fuel. It has the operating crane capacity (85 tons) but currently has neither the cask set-down diameter (6'4") nor the maximum cask length (16'5") required to load a small MPC.

- Would NSP upgrade its spent fuel pool loading area and depth in order the ship by small MPC using its onsite rail?
- Would NSP avoid upgrade investments and ship by legal-weight truck, probably using Interstate 94 towards Minneapolis and Interstate 494 to circle the city on its western side?

The current capabilities and MPC base case scenarios assume that NSP chooses to ship by legal-weight truck. The maximum rail scenario, as well as scenarios identified by DOE, assume that NSP chooses to upgrade in order to ship by small MPC.

### Big Rock Point

Given the cask options identified in Section 6, and the factors discussed in sections 7 through 9, how would Consumers Power Company choose to ship from its Big Rock Point plant, located on the upper reaches of Lake Michigan? Big Rock does not have onsite rail; rail shipments would require heavy-haul to the Tuscola and Saginaw Bay railhead in Petoskey about 13 miles east of the plant site. Neither the operating crane capacity (24 tons) nor cask set-down diameter (5'11") nor maximum cask length (15'11") at Big Rock Point currently meet requirements for loading a small MPC.

- Would Consumer's Power upgrade its crane and spent fuel loading area and depth in order to heavy-haul small rail casks for shipment from Petoskey?
- Would Consumers Power avoid investment in cask handling upgrades and heavy-haul operations, choosing to ship by legal-weight truck, probably south on I-75 to Flint, then southwest on I-69 through Lansing and west on I-95 through Battle Creek and Kalamazoo?

The current capabilities and MPC base case scenarios assume that Consumers Power chooses to ship by legal-weight truck. The maximum rail scenario (as well as DOE's Transportation Strategy Study

2) assumes that Consumers Power will upgrade its facilities and heavy-haul to Petoskey in order to ship small MPCs by rail.

### Point Beach

Given the cask options identified in Section 6, and the factors discussed in Sections 7 through 9, how would Wisconsin Electric Power choose to ship from its Point Beach plant site, located on the western shore of Lake Michigan about 85 miles north of Milwaukee? Point Beach does not have onsite rail; rail shipment would require heavy-haul to a railhead, such as the Fox Valley and Western railhead Wisconsin Central in Kewaunee.[19] It has the operating crane capacity (125 tons) and maximum cask length (18'8") but not the cask set-down diameter (7'10") required to load a large MPC.

- Would Wisconsin Electric upgrade the cask set-down area in its spent fuel loading area in order to heavy-haul large rail casks for shipment from Kewaunee?

- Would Wisconsin Electric ship by legal-weight truck in order to avoid the cost of heavy-hauling small MPC casks to the Kewaunee railhead?

The current capabilities scenario assumes that Wisconsin Electric chooses to ship by legal-weight truck, via I-43 from Manitowoc through Sheboygan to Milwaukee. The MPC base case and maximum rail scenarios (as well as scenarios identified by DOE) assume that Wisconsin Electric chooses to upgrade its cask loading area and heavy-haul off site in order to ship large MPCs by rail.

### Salem and Hope Creek

Given the cask options identified in Section 6, and the factors discussed in Sections 7 through 9, how would Public Service Gas and Electric (PSG&E) choose to ship from its Salem and Hope Creek plants on the New Jersey side of the Delaware River, about 12 miles south of Wilmington, Delaware? The sites do not have onsite rail; rail shipment would require heavy-haul 23 miles north to a railhead on the West Jersey Railroad in the Town of Salem. Hope Creek has the cask set-down diameter (11'0"), maximum cask length (19'9") and operating crane capacity (130 tons) required to load a large MPC. Salem has the cask set-down diameter (10'0") and maximum cask length (21'4") but insufficient operating crane capacity (110 tons) to load a large MPC.

- Would PSG&E upgrade operating crane capacity at its Salem facilities in order to heavy-haul large rail casks 23 miles for shipment by rail?

- Would PSG&E ship by legal-weight truck in order to avoid the cost of heavy-hauling or barging small MPC casks?

The current capabilities scenario assumes that PSG&E chooses to ship by legal-weight truck from both its Hope Creek and Salem plants. The MPC base case and maximum rail scenarios assume that PSG&E upgrades operating crane capacity at Salem in order to use the large MPC cask, which in the MPC base case would be heavy-hauled 23 miles to the Salem railhead on the West Jersey railroad, and in the maximum rail scenario would be barged up the Delaware River to a Conrail railhead in Wilmington.

**Enrico Fermi**

Given the cask options identified in Section 6 and the factors discussed in Section 7 through 9, how would Detroit Edison Company choose to ship from its Enrico Fermi plant on the western shore of Lake Erie, about midway between Detroit, Michigan and Toledo, Ohio? The Fermi site has onsite rail which is not operating and would require significant investment to upgrade for shipment of spent nuclear fuel. While its cask set-down diameter (9'0") meets requirements for a large MPC, its operating crane capacity (100 tons) currently meets requirements only for the small MPC, and its maximum cask length (14'9") currently meets requirements for neither the large nor small MPC.

- Would Detroit Edison upgrade the rail spur, the maximum cask length in its spent fuel loading facilities and its operating crane capacity in order to ship large MPC casks by rail?
- Would it ship by legal-weight truck in order to avoid or postpone some or all of these expenses?

The current capabilities scenario assumes that Detroit Edison chooses to ship by legal-weight truck, probably using I-275 to access I-94 for travel across the southern portion of the state. The MPC base case scenario assumes that Detroit Edison upgrades it facilities and rail spur in order to ship large MPCs north to Detroit and west through Lansing and Battle Creek on Grand Trunk Western rail lines. The maximum rail scenario assumes that Detroit Edison upgrades its facilities but not its rail spur at Fermi, choosing to barge rail casks east across Lake Erie to a railhead in Buffalo.

**Table 10-1. Transportation Choice Factors and Scenarios: By Storage Location**

| | | CASK LOADG FACTOR: | | | | NEAR-SITE FACTOR: | | | | TRANSP CHOICE: | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FUEL STRG LOCATION: | WASTE TYPE | CRD | CRO | CDI | CLG | OSR | OP? | OS$ | OFD | CCP | MPC | MXR | TS2 | APD |
| MONTICELLO | BWR | 85 | 85 | LWT | LWT | Y | Y | 0 | 0 | LWT | LWT | R75 | R75 | R75 |
| BIG ROCK 1 | BWR | 75 | 24 | LWT | LWT | N | NA | 0 | 13 | LWT | LWT | R75 | R75 | LWT |
| POINT BEACH 1&2 | PWR | 125 | 125 | R75 | R125 | N | NA | 0 | 16 | LWT | R125 | R125 | R125 | R125 |
| POINT BEACH DRY STRG | PWR | NA | NA | NA | NA | N | NA | 0 | 16 | LWT | R125 | R125 | R125 | R125 |
| HOPE CREEK | BWR | 150 | 130 | R125 | R125 | N | NA | 0 | 23 | LWT | R125 | R125 | R125 | R125 |
| SALEM 1 | PWR | 110 | 110 | R125 | R125 | N | NA | 0 | 23 | LWT | R125 | R125 | R125 | R75 |
| SALEM 2 | PWR | 110 | 110 | R125 | R125 | N | NA | 0 | 23 | LWT | R125 | R125 | R125 | R75 |
| ENRICO FERMI 2 | BWR | 125 | 100 | R125 | LWT | Y | N | 125 | 0 | LWT | R125 | R125 | R125 | R125 |

Site/Facility Charac: CRD: design crane capacity (tons)
CRD: operating crane capacity (tons)
CDI: cask set-down (loading) diameter (max cask option)
CLG: cask length (loading) req (max cask option)

OSR: onsite rail (yes, no, not applic)
OP?: onsite rail operating? (yes, no, not applic)
OS$: onsite rail upgrade cost (000$)
OFD: distance to offsite rail (miles)

Shipment Cask Options: R125: Large MPC for up to 21 PWR or 40 BWR
R75: Small MPC for up to 12 PWR or 24 BWR
LWT: Legal-weight truck casks.... GA-4/9 if avail, NLI-1/2 or NAC LWT otherwise

Transp Choice: MPC: MPC "Base Case" (NWPO: Jan 1994)
CCP: Current Capabilities (NWPO: May 1996)
MXR: Maximum Rail (NWPO: May 1996)

TR2: NV Transp Stategy, Study 2 (DOE: Feb 1996, Table F-3 & PIC)
APD: MPC Prelim Evaluation (DOE: Mar 1993, Appendix D)

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# 11. TRANSPORTATION MODE AND CASK CHOICES: THREE SCENARIOS

Considering the factors discussed in sections 8, 9, and 10, this assessment identifies three transportation choice scenarios, each specifying the assumed utility choice among available cask options (see Section 7) for each storage location (see Section 2). These scenarios, detailed in Table 11-1, assume that the utility's transportation choice does not change during the shipment campaign.

### The MPC Base Case Scenario

The "MPC base case" set of utility transportation choices reflects previous work conducted by the state of Nevada to represent the most likely highway and rail routes for shipments of nuclear waste to Yucca Mountain using DOE's proposed Multi-Purpose Canister system for nuclear waste storage, transportation, and disposal.[20] For this assessment, the previous MPC base case transportation choice assumptions were reviewed; rail shipments by small and large MPC were specified; transportation choices for defense sites (e.g., Hanford, INEL, SRS, West Valley) and certain other storage locations (e.g., General Atomics research fuel) were specified.

In the MPC base case scenario, spent fuel stored at 17 commercial plant sites (listed below) is shipped by legal-weight truck; all other commercial plant sites ship by small or large MPC. If the high-capacity GA-4/9 cask is not available, the scenario assumes that legal-weight truck shipments would use a cask similar in capacity to the NLI-1/2 or NAC LWT.

| | | |
|---|---|---|
| Big Rock | Haddam Neck | Peachbottom |
| Crystal River | Humboldt Bay | Pilgrim |
| Fitzpatrick | Indian Point | St. Lucie |
| Fort Calhoun | LaCrosse | Vermont Yankee |
| Fort St. Vrain | Monticello | Yankee Rowe |
| Ginna | Palisades | |

Spent fuel stored at Hanford, INEL, and West Valley, as well as research fuel stored at sites such as General Atomics are shipped by legal-weight truck in the MPC base case scenario. However, HLW vitrified and stored in canisters at Hanford, INEL and Savannah River is shipped by rail in an MPC adapted for this purpose.

### The Current Capabilities Scenario

Assuming that utilities may be reluctant to make major investments to upgrade cask loading capabilities or near-site infrastructure, the current capabilities scenario identifies 15 additional commercial sites which could choose to ship by legal-weight truck, and assumes that the high-capacity GA-4/9 cask is not available:

| | | |
|---|---|---|
| Browns Ferry | Dresden/Morris | Oconee |
| Calvert Cliffs | Fermi | Oyster Creek |
| Cook | Grand Gulf | Point Beach |
| Cooper Station | Hope Creek/Salem | Surry |
| Diablo Canyon | Kewaunee | Turkey Point |

Furthermore, the current capabilities scenario identifies 14 sites which might choose to ship by small MPC, rather than by large MPC as assumed in the MPC base case:

| | | |
|---|---|---|
| Arkansas Nuclear | Duane Arnold | Nine Mile Point |
| Beaver Valley | Harris | North Anna |
| Braidwood | La Salle | Rancho Seco |
| Byron | Limerick | Zion |
| Clinton | McGuire | |

Obviously, the current capabilities scenario generates a larger number of shipments with greater highway impacts than does the MPC base case.

### The Maximum Rail Scenario

Considering the upgrade potentials at each storage location, and assuming effective incentives for utilities to make the upgrades, the "maximum rail scenario" identifies 14 commercial sites (of the 17 which ship by truck in the MPC base case) which might ship by rail:

| | | |
|---|---|---|
| Big Rock | LaCrosse | Fitzpatrick |
| Crystal River | Monticello | Palisades |
| Fort Calhoun | Pilgrim | Peachbottom |
| Haddam Neck | Vermont Yankee | St. Lucie |
| Humboldt Bay | Yankee Rowe | |

The sites in columns 1 and 2 above are assumed to upgrade for shipment by small MPC, while those in column 3 are assumed to upgrade for shipment by large MPC. The upgrades reduce the number of commercial sites which ship by truck to three: Ginna, Indian Point, Fort St. Vrain—all of which are assumed to use the high-capacity GA-4/9 cask.

In addition, the maximum rail scenario assumes that Three Mile Island upgrades for shipment by large MPC, rather than by small MPC as in the MPC base case.

### DOE's Transportation Choice Assumptions

While DOE has not estimated annual shipments by route segment, several DOE studies consider transportation choices on a site-by-site basis: a 1996 "preliminary transportation strategy study for a potential Nevada repository",[21] and a 1993 evaluation of the use of MPCs in DOE's waste management system.[22] Appendix A reviews the transportation choice assumptions in these DOE studies, comparing them with the transportation choice scenarios outlined above.

## Table 11-1. Utility Transportation Choice Scenarios: by Storage Location

| FUEL STRG LOCATION: | TRANSP CHOICE: CCP | MPC | MXR |
|---|---|---|---|
| 1 ARKANSAS NUCLEAR 1 | R75 | R125 | R125 |
| 2 ARKANSAS NUCLEAR 2 | R75 | R125 | R125 |
| 3 ARKANSAS NUCLEAR DRY STRG | R75 | R125 | R125 |
| 4 BEAVER VALLEY 1 | R75 | R125 | R125 |
| 5 BEAVER VALLEY 2 | R75 | R125 | R125 |
| 6 BELLEFONTE 1 | R125 | R125 | R125 |
| 7 BELLEFONTE 2 | R125 | R125 | R125 |
| 8 BIG ROCK 1 | LWT | LWT | R75 |
| 9 BRAIDWOOD 1 | R75 | R125 | R125 |
| 10 BROWNS FERRY 1-2 | LWT | R125 | R125 |
| 11 BROWNS FERRY 3 | LWT | R125 | R125 |
| 12 BRUNSWICK 1 | R75 | R75 | R75 |
| 13 BRUNSWICK 1 PWR POOL | R75 | R75 | R75 |
| 14 BRUNSWICK 2 | R75 | R75 | R75 |
| 15 BRUNSWICK 2 PWR POOL | R75 | R75 | R75 |
| 16 BYRON 1 | R75 | R125 | R125 |
| 17 CALLAWAY 1 | LWT | R125 | R125 |
| 18 CALVERT CLIFFS 1-2 | LWT | R125 | R125 |
| 19 CALVERT DRY STORAGE | LWT | R125 | R125 |
| 20 CATAWBA 1 | R125 | R125 | R125 |
| 21 CATAWBA 2 | R125 | R125 | R125 |
| 22 CLINTON 1 | R75 | R125 | R125 |
| 23 COMANCHE PEAK 1 | R125 | R125 | R125 |
| 24 COOK 1 | LWT | R125 | R125 |
| 25 COOPER STATION | LWT | R75 | R75 |
| 26 CRYSTAL RIVER 3 | LWT | LWT | R75 |
| 27 DAVIS-BESSE 1 | R125 | R125 | R125 |
| 28 DAVIS-BESSE DRY STRG | R125 | R125 | R125 |
| 29 DIABLO CANYON 1 | LWT | R125 | R125 |
| 30 DIABLO CANYON 2 | LWT | R125 | R125 |
| 31 DRESDEN 1 | LWT | R75 | R75 |
| 32 DRESDEN 2 | LWT | R75 | R75 |
| 33 DRESDEN 3 | LWT | R75 | R75 |
| 34 DUANE ARNOLD | R75 | R125 | R125 |
| 35 ENRICO FERMI 2 | LWT | R125 | R125 |
| 36 FARLEY 1 | R125 | R125 | R125 |
| 37 FARLEY 2 | R125 | R125 | R125 |
| 38 FITZPATRICK | LWT | LWT | R125 |
| 39 FORT CALHOUN | LWT | LWT | R75 |
| 40 FORT ST VRAIN | LWT | LWT | LWT |
| 41 FORT ST VRAIN DRY STRG | LWT | LWT | LWT |
| 42 GINNA | LWT | LWT | LWT |
| 43 GRAND GULF 1 | LWT | R125 | R125 |
| 44 HADDAM NECK | LWT | LWT | R75 |
| 45 HARRIS 1 | R75 | R125 | R125 |
| 46 HARRIS 1 BWR POOL | R75 | R125 | R125 |
| 47 HATCH 1-2 | R125 | R125 | R125 |
| 48 HOPE CREEK | LWT | R125 | R125 |
| 49 HUMBOLDT BAY | LWT | LWT | R75 |
| 50 INDIAN POINT 1 | LWT | LWT | LWT |
| 51 INDIAN POINT 2 | LWT | LWT | LWT |
| 52 INDIAN POINT 3 | LWT | LWT | LWT |
| 53 KEWAUNEE | LWT | R125 | R125 |
| 54 LACROSSE | LWT | LWT | R75 |
| 55 LASALLE 1-2 | R75 | R125 | R125 |
| 56 LIMERICK 1-2 | R75 | R125 | R125 |
| 57 MAINE YANKEE | R125 | R125 | R125 |
| 58 MCGUIRE 1 | R75 | R125 | R125 |
| 59 MCGUIRE 2 | R75 | R125 | R125 |
| 60 MILLSTONE 1 | R75 | R75 | R75 |
| 61 MILLSTONE 2 | R75 | R75 | R75 |
| 62 MILLSTONE 3 | R75 | R75 | R75 |
| 63 MONTICELLO | LWT | LWT | R75 |
| 64 NINE MILE POINT 1 | R75 | R125 | R125 |
| 65 NINE MILE POINT 2 | R75 | R125 | R125 |
| 66 NORTH ANNA 1&2 | R75 | R125 | R125 |

| FUEL STRG LOCATION: | TRANSP CHOICE: CCP | MPC | MXR |
|---|---|---|---|
| 67 NORTH ANNA DRY STRG | R75 | R125 | R125 |
| 68 OCONEE 1&2 | LWT | R125 | R125 |
| 69 OCONEE 3 | LWT | R125 | R125 |
| 70 OCONEE DRY STORAGE | LWT | R125 | R125 |
| 71 OYSTER CREEK 1 | LWT | R125 | R125 |
| 72 OYSTER CREEK DRY STRG | LWT | R125 | R125 |
| 73 PALISADES | LWT | LWT | R125 |
| 74 PALISADES DRY STORAGE | LWT | LWT | R125 |
| 75 PALO VERDE 1 | R125 | R125 | R125 |
| 76 PALO VERDE 2 | R125 | R125 | R125 |
| 77 PALO VERDE 3 | R125 | R125 | R125 |
| 78 PEACHBOTTOM 2 | LWT | LWT | R125 |
| 79 PEACHBOTTOM 3 | LWT | LWT | R125 |
| 80 PERRY 1 | R125 | R125 | R125 |
| 81 PILGRIM 1 | LWT | LWT | R75 |
| 82 POINT BEACH 1&2 | LWT | R125 | R125 |
| 83 POINT BEACH DRY STRG | LWT | R125 | R125 |
| 84 PRAIRIE ISLAND 1&2 | R125 | R125 | R125 |
| 85 PRAIRIE ISLAND DRY STRG | R125 | R125 | R125 |
| 86 QUAD CITIES 1 | R75 | R75 | R75 |
| 87 RANCHO SECO 1 | R75 | R125 | R125 |
| 88 RANCHO SECO DRY STRG | R75 | R125 | R125 |
| 89 RIVER BEND 1 | R125 | R125 | R125 |
| 90 ROBINSON 2 | R75 | R75 | R75 |
| 91 ROBINSON DRY STORAGE | R75 | R75 | R75 |
| 92 SALEM 1 | LWT | R125 | R125 |
| 93 SALEM 2 | LWT | R125 | R125 |
| 94 SAN ONOFRE 1 | R125 | R125 | R125 |
| 95 SAN ONOFRE 2 | R125 | R125 | R125 |
| 96 SAN ONOFRE 3 | R125 | R125 | R125 |
| 97 SEABROOK 1 | R125 | R125 | R125 |
| 98 SEQUOYAH 1 | R125 | R125 | R125 |
| 99 SHOREHAM | NA | NA | NA |
| 100 SOUTH TEXAS 1 | R125 | R125 | R125 |
| 101 SOUTH TEXAS 2 | R125 | R125 | R125 |
| 102 ST LUCIE 1 | LWT | LWT | R125 |
| 103 ST LUCIE 2 | LWT | LWT | R125 |
| 104 SUMMER 1 | R125 | R125 | R125 |
| 105 SURRY 1&2 | LWT | R125 | R125 |
| 106 SURRY DRY STORAGE | LWT | R125 | R125 |
| 107 SUSQUEHANNA 1-2 | R125 | R125 | R125 |
| 108 SUSQUEHANNA DRY STRG | R125 | R125 | R125 |
| 109 THREE MILE ISLAND 1 | R75 | R75 | R125 |
| 110 TROJAN | R125 | R125 | R125 |
| 111 TURKEY POINT 3 | LWT | R125 | R125 |
| 112 TURKEY POINT 4 | LWT | R125 | R125 |
| 113 VERMONT YANKEE 1 | LWT | LWT | R75 |
| 114 VOGTLE 1-2 | R75 | R75 | R75 |
| 115 WASH NUCLEAR 2 | R125 | R125 | R125 |
| 116 WATTS BAR 1&2 | R125 | R125 | R125 |
| 117 WATERFORD 3 | R125 | R125 | R125 |
| 118 WOLF CREEK 1 | R125 | R125 | R125 |
| 119 YANKEE-ROWE 1 | LWT | LWT | R75 |
| 120 ZION 1&2 | R75 | R125 | R125 |
| 121 HANFORD SNF STRG | LWT | LWT | LWT |
| 122 HANFORD SNF STRG | LWT | LWT | LWT |
| 123 INEL SNF STRG | LWT | LWT | LWT |
| 124 INEL SNF STRG | LWT | LWT | LWT |
| 125 INEL SNF STRG | LWT | LWT | LWT |
| 126 SAVANNAH RV SNF STRG | LWT | LWT | LWT |
| 127 SAVANNAH RV SNF STRG | LWT | LWT | LWT |
| 128 WEST VALLEY SNF STRG | LWT | LWT | R125 |
| 129 WEST VALLEY SNF STRG | LWT | LWT | R125 |
| 130 MORRIS | LWT | R125 | R125 |
| 131 MORRIS | LWT | R125 | R125 |
| 132 GENERAL ATOMICS | LWT | LWT | LWT |

Transp Choice:
CCP: Current Capabilities (NWPO: May 1996)
MPC: MPC "Base Case" (NWPO: Jan 1994)
MXR: Maximum Rail (NWPO: May 1996)

Shipment Cask Options:
R125: Large MPC for up to 21 PWR or 40 BWR
R75: Small MPC for up to 12 PWR or 24 BWR
LWT: Legal-weight truck casks.... GA-4/9 if avail NLI-1/2 or NAC LWT otherwise

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# 12. CASK SHIPMENTS

The assessment of shipment groups (section 5) determines the assemblies and MTU to be picked up for shipment from a particular storage location in a particular acceptance year. The identification of cask options (section 6) determines the transportation casks available under the particular scenario, and the transportation choice assessment (sections 7 through 11) determines the cask option selected for shipment from each storage location.

The next step in the assessment process is to determine the number of cask shipments from each storage location in each acceptance/pickup year.

- Cask shipments of spent fuel from BWR or PWR reactors are estimated by dividing the number of assemblies in the shipment group by the assembly capacity of the selected cask—rounding up to accommodate any fractions required to ship all assemblies in the group.

- Cask shipments of other spent fuel (e.g., spent fuel from research reactors or HTG assemblies from the Fort St. Vrain reactor) are estimated by dividing the MTU in the shipment group by the average MTU per cask for BWR and PWR assemblies shipped during the same period—generally about .40 MTU per T-1/2 cask, 1.655 MTU per T-4/9 cask, 4.28 MTU per R75 cask and 7.41 MTU per R125 cask. In effect, the assumption is that casks for HTG, research and other wastes will be as efficient as those designed for transport of BWR and PWR assemblies.

- Cask shipments for HLW assume that an MPC-like cask to accommodate five two-foot diameter canisters will be designed and certified for transport of HLW. The estimated shipments of HLW canisters from a particular site is thus divided by five—rounding up to accommodate any remaining canisters in the shipment group.

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# 13. ROUTING CRITERIA

Having determined the number of shipments of a particular cask type from each site each acceptance year, we must then determine the highway or rail shipment route. Aggregating shipments from each origin site, a community along a particular route segment in Pennsylvania, or in Indiana or Missouri could then understand, for example, that in the second acceptance year it should expect "x" shipments of certain cask types originating from certain storage locations, while in the fifth acceptance year it should expect "y" shipments from a somewhat different set of storage locations. This information should help state and local agencies conduct their planning in the context of the national shipment campaign.

In most cases, the routing decision will be made by the carrier, under certain constraints. Most notable is the requirement (based on 49 CFR§397.101(a), referred to as HM 164), that in transporting radioactive waste by truck, drivers must reduce transit time by using interstate highways or state-designated alternative routes.

In addition to the HM 164 requirement, we also assume that certain routing practices will be followed by shippers and carriers. For example, we assume that shippers will generally choose the closest Class I (highest volume) rail carrier, and that rail carriers will prefer Class A (highest volume) mainline rail segments.

### Default (Quickest) Routes

To assist in identifying possible routes for waste shipments, DOE (through the Oak Ridge National Laboratory) has developed and made available two computer-assisted models, HIGHWAY and INTERLINE. In determining the truck shipment routes for this study, the HIGHWAY model[23] was used to calculate the "quickest route" (minimizing travel time) subject to HM 164 requirements. In determining the rail shipment routes, the INTERLINE model[24] was used to calculate the quickest route. In both cases, the models were run without other special limitations, such as avoidance of population centers and recognition of the BN/Santa Fe merger or the anticipated UP/SP merger.*

### Consolidated Southern Routes

A second alternative for each route scenario was also developed to consolidate the rail and highway shipments into fewer routes, both to minimize the number of affected communities and to avoid certain seasonal weather conditions or problematic highway segments (e.g., the Eisenhower Tunnel and Glenwood Canyon on I-70 west of Denver). The consolidated route orients truck shipments from the Northeast, Southeast, and Midwest to I-40 in Oklahoma City, generally avoiding I-70 west of Kansas City and I-80 west of Omaha. Compared to their roles under the default routing criteria, I-44 between St. Louis and Oklahoma and I-70 east of St. Louis play more significant roles as a feeders to the consolidated southern route across the western states.

* BN: Burlington Northern; UP: Union Pacific; SP: Southern Pacific

The consolidated route orients rail shipments from the Northeast, Southeast, and Midwest to the Santa Fe rail lines extending southwest from Kansas City through Amarillo and across New Mexico, and Arizona to Daggett in southeastern California. It thereby avoids the UP and SP lines west of Kansas City and Omaha. The route increases feeder shipments along the Burlington Northern lines between Chicago and Kansas City, and on the Norfolk Southern lines between Cleveland and Kansas City, but reduces shipments on the Chicago and North Western lines between Chicago and Omaha. Otherwise, it has limited effects on routing patterns east of the Missouri River.

# 14. ROUTE IDENTIFICATION AND MAPPING

As currently developed, the HIGHWAY and INTERLINE models describe, but do not map, shipment routes. Figure 14-1 presents the HIGHWAY description of a cross-country truck shipment route to Yucca Mountain, using Oyster Creek (NJ) as the trip origin for illustration purposes:

- The first line of the output shows the origin ("OYSTER CREEK NP, NJ") and the departure date and time.
- The second line shows (reading from left to right ):
  — the distance to the nearest "node" or intersection (12.0 miles);
  — the route to that intersection (U.S. Highway 9, or "U9");
  — the name of the node ("TOMS RIVER" at the intersection of "TGSP," or the Garden State Parkway, and "X82," or exit 82, in "NJ");
  — the cumulative distance from the origin (12.0 miles);
  — the cumulative time required to complete travel from the origin to this node ("0:16"); and
  — the date and time of arrival at the node ("2/01 @ 16:19").
- Each line thereafter includes similar information for subsequent links in the route from Oyster Creek to Yucca Mountain.
- According to the model output, the 2,688-mile route from eastern New Jersey to southern Nevada would pass through Pennsylvania, Ohio, Indiana, Illinois, Iowa, Nebraska, Colorado, and Utah; travel time at an average speed of 53.4 miles per hour would be just over 2 days (50.4 hours).

Figure 14-2 presents the INTERLINE description of a cross-country rail route to Yucca Mountain, again using Oyster Creek (NJ) as the trip origin for illustration purposes:

- For each node along the route, the listing indicates the rail carrier, the node number and name, the state in which the node is located, and the cumulative route distance.
- According to the model output, the default rail route under the MPC base case from Oyster Creek to Yucca Mountain would use Conrail lines to travel to Chicago where shipments would be transferred to the Chicago and North Western to Fremont, Nebraska, and from there on the UP to Caliente or Valley. The total travel distance, excluding new rail construction* or heavy-haul segments at either end, is 2,847 miles.

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* Note that INTERLINE assumes construction of a rail spur from Valley to Yucca Mountain, operated by the U.S. government (USG). In this analysis, we assume construction and use of an intermodal transfer facility and a heavy-haul route for all rail shipments.

### Mapping HIGHWAY or INTERLINE Route Descriptions

In route mapping, each segment in the model output is identified on a master map of the nation's major highways or railroads. The mapped route can then be shown in relation to state boundaries, county boundaries, or other more detailed information. Mapped routes for all shipment origins reveal combined shipment impacts for each route segment (see Figure 14-1).

**Figure 14-1. HIGHWAY Model Output (Oyster Creek to Yucca Mountain: LWT Truck Base Case Route)**

Routing through:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | | | OYSTER CREEK | NP | | | NJ | 0.0 | 0:00 | 2/01 @ 16:03 |
| 12.0 | U9 | | TOMS RIVER | NW | TGSP | X82 | NJ | 12.0 | 0:16 | 2/01 @ 16:19 |
| 2.0 | TGSP | | PLEASANT PLNS | S | TGSP | X83 | NJ | 14.0 | 0:18 | 2/01 @ 16:21 |
| 12.0 | TGSPS | | GLENDOLA | SW | TGSP | I195 | NJ | 26.0 | 0:31 | 2/01 @ 16:34 |
| 30.0 | I195 | | ALLENTOWN | NW | TNJT | I195 | NJ | 56.0 | 1:04 | 2/01 @ 17:07 |
| 10.0 | INJTS | | HEDDING | SE | TNJT | I276 | NJ | 66.0 | 1:15 | 2/01 @ 17:17 |
| 7.0 | I276# | | BRISTOL | N | I276 | X29 | PA | 73.0 | 1:23 | 2/01 @ 17:25 |
| 31.0 | I276S | | PORT KENNEDY | SE | I276 | I76 | PA | 104.0 | 1:56 | 2/01 @ 17:59 |
| 166.0 | I76 S | | BREEZEWOOD | SW | I70 | I76 | PA | 270.0 | 5:27 | 2/01 @ 21:30 |
| 86.0 | I70 S | I76 S | YOUNGWOOD | SW | I70 | I76 | PA | 356.0 | 7:01 | 2/01 @ 23:04 |
| 39.0 | I70 | | LABORATORY | NE | I70 | I79 | PA | 395.0 | 7:44 | 2/01 @ 23:46 |
| 3.0 | I70 | I79 | WASHINGTON | N | I70 | I79 | PA | 398.0 | 7:47 | 2/01 @ 23:49 |
| 27.0 | I70 | | WHEELING | SE | I470 | I70 | WV | 425.0 | 8:17 | 2/02 @ 0:19 |
| 12.0 | I470 | | ST CLAIRSVILLE | E | I470 | I70 | OH | 437.0 | 8:30 | 2/02 @ 0:32 |
| 116.0 | I70 | | COLUMBUS | E | I270 | I70 | OH | 553.0 | 11:06 | 2/02 @ 3:08 |
| 21.0 | I270 | | COLUMBUS | W | I270 | I70 | OH | 574.0 | 11:29 | 2/02 @ 3:31 |
| 157.0 | I70 | | INDIANAPOLIS | E | I465 | I70 | IN | 731.0 | 14:50 | 2/02 @ 6:52 |
| 5.0 | I465 | | INDIANAPOLIS | SE | I465 | I74 | IN | 736.0 | 14:56 | 2/02 @ 6:58 |
| 13.0 | I465 | I74 | INDIANAPOLIS | SW | I465 | I70 | IN | 749.0 | 15:10 | 2/02 @ 7:12 |
| 132.0 | I70 | | TEUTOPOLIS | NW | I57 | I70 | IL | 831.0 | 17:34 | 2/02 @ 10:36 |
| 6.0 | I57 | I70 | EFFINGHAM | SW | I57 | I70 | IL | 837.0 | 18:11 | 2/02 @ 11:12 |
| 78.0 | I70 | | EDWARDSVILLE | SE | I270 | I55 | IL | 965.0 | 19:36 | 2/02 @ 12:37 |
| 29.0 | I270 | | ST LOUIS | NW | I270 | I70 | MO | 994.0 | 20:07 | 2/02 @ 13:09 |
| 227.0 | I70 | | KANSAS CITY | SE | I435 | I70 | MO | 1221.0 | 24:45 | 2/02 @ 17:47 |
| 33.0 | I435 | | KANSAS CITY | W | I435 | I70 | KS | 1254.0 | 25:21 | 2/02 @ 18:22 |
| 47.0 | I70 S | TKSTS | TOPEKA | E | I470 | I70 | KS | 1301.0 | 26:12 | 2/02 @ 19:14 |
| 5.0 | I470S | TKSTS | TOPEKA | S | I335 | I470 | KS | 1306.0 | 26:18 | 2/02 @ 19:19 |
| 7.0 | I470 | | TOPEKA | W | I470 | I70 | KS | 1313.0 | 26:25 | 2/02 @ 19:27 |
| 1049.0 | I70 | | COVE FORT | W | I15 | I70 | UT | 2362.0 | 48:53 | 2/03 @ 16:54 |
| 242.0 | I15 | | LAS VEGAS | | | | NV | 2604.0 | 54:17 | 2/03 @ 21:18 |
| 86.0 | U95 | | AMARGOSA VALLY | | U95 | S373 | NV | 2690.0 | 55:59 | 2/03 @ 23:00 |

## Figure 14-2. INTERLINE Model Output, Rail Base Case, Oyster Cr to Yucca Mtn.

| RR | NODE | STATE | DIST | |
|---|---|---|---|---|
| CR | 1275-TOMS RIVER | NJ | 0. | |
| CR | 1337-TRENTON | NJ | 83. | |
| CR | 1454-CONSHOHOCKEN | PA | 116. | |
| CR | 1525-READING | PA | 160. | |
| CR | 2350-HARRISBURG | PA | 213. | |
| CR | 2291-ALTOONA | PA | 355. | |
| CR | 2254-JOHNSTOWN | PA | 391. | |
| CR | 2066-BESSEMER | PA | 458. | |
| CR | 2124-PITTSBURGH | PA | 471. | |
| CR | 2125-ROCHESTER | PA | 497. | |
| CR | 2798-ALLIANCE | OH | 553. | |
| CR | 2763-RAVENNA | OH | 570. | |
| CR | 2728-CLEVELAND | OH | 611. | |
| CR | 2633-ELYRIA | OH | 638. | |
| CR | 3442-TOLEDO | OH | 717. | |
| CR | 3526-GOSHEN | IN | 839. | |
| CR | 3525-ELKHART | IN | 849. | |
| CR | 4022-SOUTH BEND | IN | 864. | |
| CR | 4067-PORTER | IN | 909. | |
| CR | 4070-GARY | IN | 925. | |
| CR | 4073-CLARKE | IN | 929. | |
| CR | 4074-INDIANA HARBOR | IN | 932. | |
| CR | 4232-SOUTH CHICAGO | IL | 939. | |
| CR | 4217-CHICAGO | IL | 952. | |
| - - - | - - - - - - - - | - - | - - - | TRANSFER |
| CNW | 4217-CHICAGO | IL | 952. | |
| CNW | 4234-PROVISO | IL | 966. | |
| CNW | 4311-DE KALB | IL | 1008. | |
| CNW | 4324-NELSON | IL | 1053. | |
| CNW | 10304-CLINTON | IA | 1086. | |
| CNW | 10289-CEDAR RAPIDS | IA | 1167. | |
| CNW | 10265-MARSHALLTOWN | IA | 1234. | |
| CNW | 10246-NEVADA | IA | 1261. | |
| CNW | 10271-AMES | IA | 1272. | |
| CNW | 10176-MISSOURI VALLEY | IA | 1405. | |
| CNW | 10198-CALIFORNIA JCT | IA | 1411. | |
| CNW | 11340-FREMONT | NE | 1439. | |
| - - - | - - - - - - - - | - - | - - - | TRANSFER |
| UP | 11340-FREMONT | NE | 1439. | |
| UP | 11406-GRAND ISLAND | NE | 1548. | |
| UP | 11410-GIBBON | NE | 1574. | |
| UP | 11352-NORTH PLATTE | NE | 1652. | |
| UP | 11358-O FALLONS | NE | 1701. | |
| UP | 13703-JULESBURG | CO | 1769. | |
| UP | 13465-CHEYENNE | WY | 1915. | |
| UP | 13462-LARAMIE | WY | 1967. | |
| UP | 13494-GRANGER | WY | 2243. | |
| UP | 13568-OGDEN | UT | 2382. | |
| UP | 13595-SALT LAKE CITY | UT | 2417. | |
| UP | 13630-LYNNDYL | UT | 2530. | |
| UP | 14766-VALLEY | NV | 2847. | |
| - - - | - - - - - - - - | - - | - - - | TRANSFER |
| USG | 14766-VALLEY | NV | 2847. | |
| USG | 16333-YUCCA MOUNTAIN | NV | 2946. | |

# 15. SIX ROUTING CASE EXAMPLES

This section describes possible routes to Yucca Mountain from six shipment origin sites. The level of description may be termed "regional" rather than "national" or "local." Key routes, rail carriers, and urban centers are identified, but local features are not. The sites selected are among those which are assumed to make different transportation choices under the current capabilities and maximum rail scenarios, and/or different near-site options for accessing a railhead under the MPC base case and maximum rail scenarios. The description focuses on the possible route, not on the cask options, the transportation choice or the routing criteria. The question of the number and type of prospective shipments along particular route segments is addressed in sections 17 and 18.

### Oyster Creek (NJ) to Yucca Mountain (NV)

How might shipments from the Oyster Creek (NJ) nuclear plant, located in Ocean County near Barnegat Bay about 55 miles due east of Philadelphia, travel to Yucca Mountain? Under the "current capabilities" scenario, the transportation choice of GPU Nuclear for shipments from Oyster Creek is legal-weight truck—using the high-capacity GA-9 cask if available, or a transportation cask for two BWR assemblies otherwise:

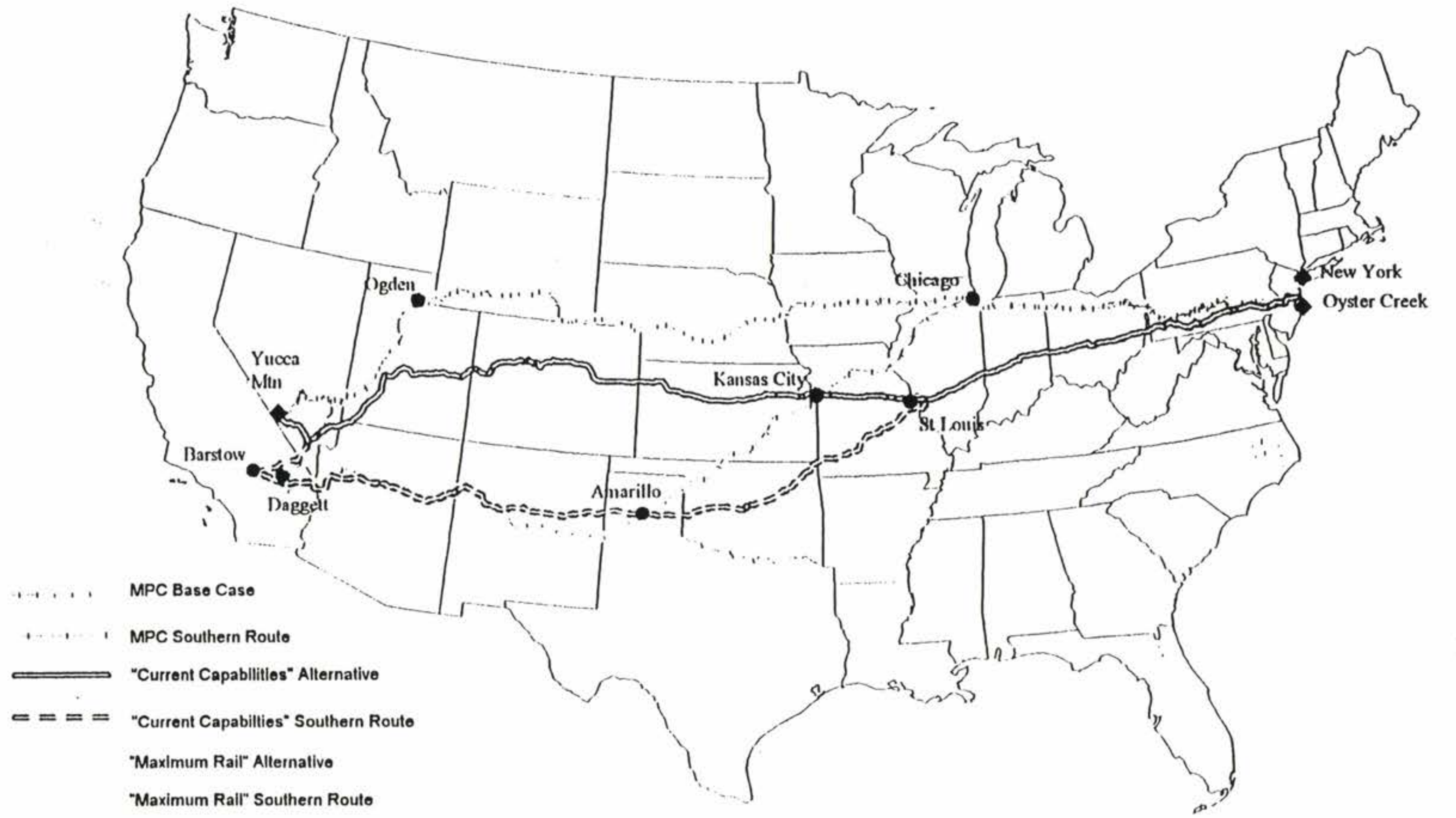
- The "default route" for truck shipments from Oyster Creek would use US 9 and SR-539 to access the Garden State Parkway (a state highway, constructed to interstate standards) northbound at Forked River. The route then continues to I-195 north of Allenwood, to the New Jersey Turnpike and I-276 north of Philadelphia, and to the Pennsylvania Turnpike (I-70 and I-76) through Pennsylvania. From Youngwood in western Pennsylvania, the route continues on I-70 (except for bypasses around major cities) to I-15 in Utah, then through Las Vegas to US 95 and Yucca Mountain.

  The "consolidated southern" option for truck shipments from Oyster Creek would depart from the default route east of St. Louis, continuing on I-70/255 (rather than the I-270 bypass) through East St. Louis, then via I-44 through Tulsa, Oklahoma. From there, the route would follow I-35 to Oklahoma City, I-40 to Barstow, California and I-15 to Las Vegas, US 95 and Yucca Mountain.

Under the "MPC base case" and "maximum rail" scenarios, GPU Nuclear's transportation choice for shipments from Oyster Creek is a large rail cask similar to DOE's 125-ton MPC, containing up to 40 BWR assemblies. However, while the MPC base case assumes heavy-haul transport to the Conrail railhead at Toms River (NJ), the maximum rail scenario would involve barge shipment to Conrail facilities in New York City.[19]

- The "default route" for rail shipments uses different Conrail lines from Toms River (NJ) or New York City to Trenton (NJ).

**Figure 15-1. Alternative Nuclear Waste Transportation Routes: Oyster Creek NP**



- From Trenton, the default route for rail shipments uses Conrail lines to Chicago (via Conshohocken, PA, Pittsburgh, Cleveland, and Toledo). In Chicago, shipments are transferred to the Chicago and North Western line for travel to Fremont, NB. In Fremont, shipments are transferred to the Union Pacific line for transport (via Grand Island, Cheyenne, Ogden, and Salt Lake City) to an intermodal facility at Caliente or Valley, Nevada.

- The consolidated southern route for rail shipments would depart from the default route in Chicago. In Chicago, shipments would be transferred to the merged Burlington Northern and Southern Pacific lines for travel to Daggett, California (via Kansas City, Amarillo, and Flagstaff). In Daggett, rail shipments would be transferred to the Union Pacific for travel north through Las Vegas to an intermodal transfer facility at Valley or Caliente.

**Fermi (MI) to Yucca Mountain (NV)**

How might shipments from the Fermi (MI) nuclear plant, located at the western end of Lake Erie, between Toledo and Detroit, travel to Yucca Mountain? Under the "current capabilities" scenario, the transportation choice of Detroit Edison for shipments from Fermi is legal-weight truck—using the high-capacity GA-9 cask if available, or a transportation cask for two BWR assemblies otherwise:

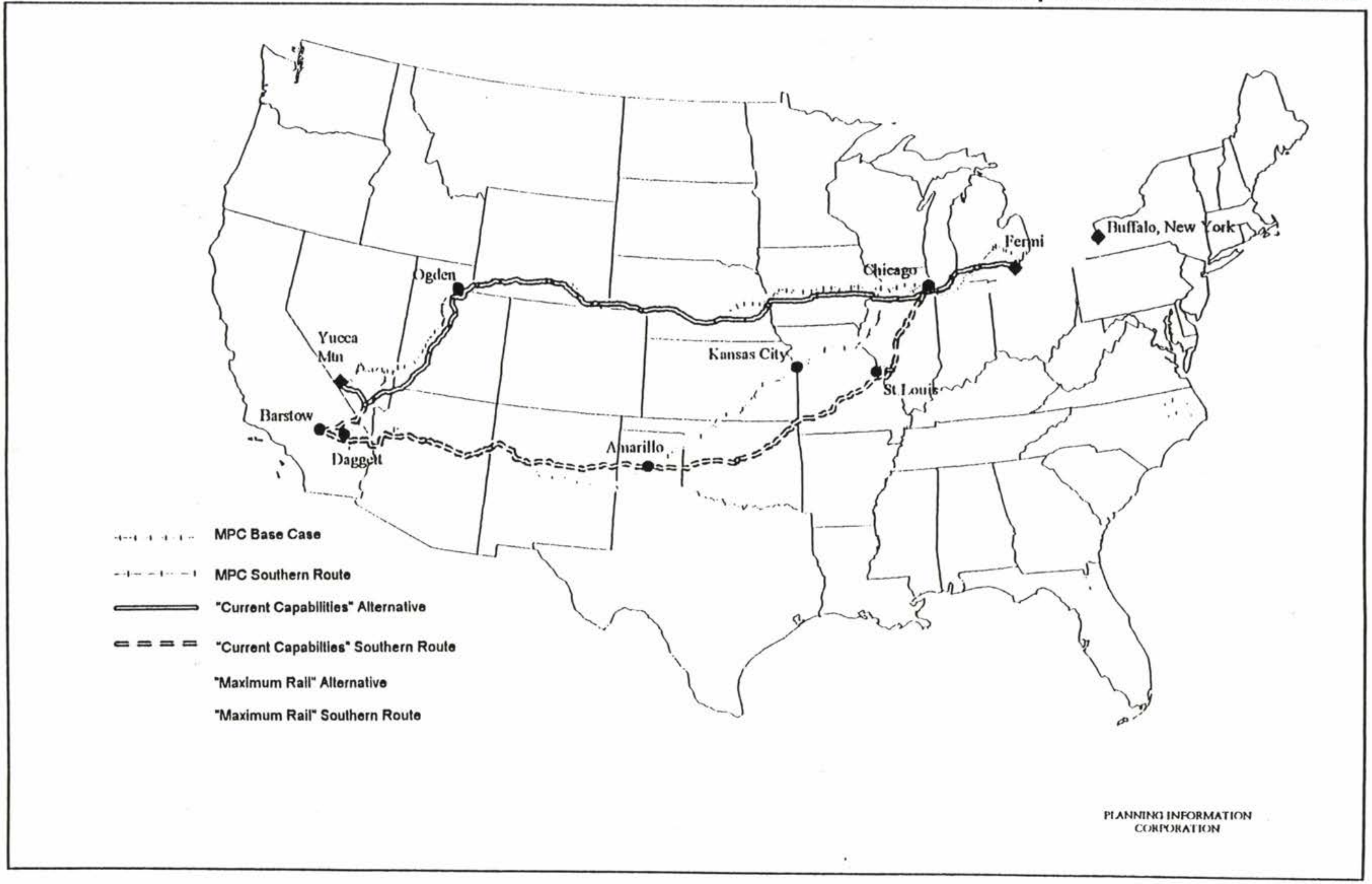
- The "default route" for truck shipments from Fermi would use Interstate 275 (the Detroit metro beltway) to access Interstate 94, which is used to travel across the State of Michigan, passing near Ann Arbor, Jackson, Battle Creek, Kalamazoo, and other cities and towns. The route links with I-80 east of Gary, Indiana, which is used to travel past Chicago and across Iowa, Nebraska, and Wyoming. In Salt Lake City, the default route then links with I-15, which is used for travel south through St. George (UT) and Las Vegas to Yucca Mountain.

- The consolidated southern route for truck shipments from Fermi departs from the default route west of Joliet, Illinois, where, rather than continuing west on I-80, it would access I-55 for travel through Springfield to St. Louis. In St. Louis, the southern route would access I-44 for travel west through Oklahoma City, Amarillo, Albuquerque, and Flagstaff to Barstow, California. In Barstow, the route would access I-15 for travel north to Las Vegas and Yucca Mountain.

Under the "MPC base case" and "maximum rail" scenarios, the transportation choice of Detroit Edison for shipments from Fermi is a large rail cask similar to DOE's 125-ton MPC, containing up to 40 BWR assemblies. However, while the MPC base case assumes use of a substantially upgraded on-site rail spur, the maximum rail scenario would involve barge shipment from the western end of Lake Erie to Conrail facilities in Buffalo (NY) at the eastern end.[19]

- The "default route" for rail shipments from Fermi would use the Grand Trunk Western (GTW) line through Detroit to Blue Island, Illinois where shipments would transfer to the Indiana Harbor Belt line. From Blue Island, the route would travel to the Argo and Proviso yards near Chicago, transferring to the Chicago & North Western (CNW) for transport through Cedar Rapids, Iowa to the UP line at Fremont, Nebraska. From Fremont, Union Pacific lines would be used for travel across Nebraska, Wyoming, and Utah to intermodal facilities at Caliente or Valley.

**Figure 15-2. Alternative Nuclear Waste Transportation Routes: Fermi NP**



- The consolidated southern route for rail shipments from Fermi would depart from the default roue at the Argo yards near Chicago, where, rather than transferring to the Chicago and Northwestern line, shipments would be transferred to the consolidated Burlington Northern and Santa Fe lines for travel southwest through Galesburg (IL), Kansas City, Amarillo, and Flagstaff to Daggett (CA). In Daggett, rail shipments would be transferred to the UP for travel north through Las Vegas to an intermodal transfer facility at Valley or Caliente.

- Rail shipments from Buffalo (after barge shipment from Fermi, under the maximum rail scenario) would use Conrail lines for travel along the southern shore of Lake Erie through Erie (PA), Cleveland, and Toledo. Shipments would continue on Conrail through Elkhart and South Bend (IN) to the Argo yards near Chicago, where the route would link with routes for rail shipments directly from Fermi.

**Browns Ferry (AL) to Yucca Mountain (NV)**

How might shipments from the Browns Ferry plants, located across the Tennessee River from the City of Decatur, travel to Yucca Mountain? Under the 'current capabilities" scenario, the transportation choice of the Tennessee Valley Authority for shipments from Browns Ferry is legal-weight truck—using the high-capacity GA-9 cask if available, or a transportation cask for two BWR assemblies otherwise:

- The "default route" for truck shipments from Browns Ferry would use I-65 to travel north to Nashville, where it would link to I-24 for travel across southwestern Kentucky and southern Illinois to St. Louis. In St. Louis the default route would access I-70 for travel across Missouri to Kansas City, across Kansas and eastern Colorado to Denver, and across western Colorado (through the Eisenhower tunnel and Glenwood Canyon) into Utah. About 160 miles south of Salt Lake City, I-70 links with I-15, which is used for travel south through St. George and Las Vegas to Yucca Mountain.

- The consolidated southern option for truck shipments from Browns Ferry departs from the default route in Nashville, where, rather than continuing west on I-24, it would access I-40 for travel west through Memphis, Little Rock, Oklahoma City, Amarillo, and Albuquerque to Barstow, California. In Barstow, the route would access I-15 for travel north to Las Vegas and Yucca Mountain.

Under the "MPC base case" and "maximum rail" scenarios, the transportation choice of Tennessee Valley Authority for rail shipments from Browns Ferry is a large rail cask similar to DOE's 125-ton MPC, containing up to 40 BWR assemblies. However, while the MPC base case involves heavy-haul transport across the Tennessee River to a Norfolk Southern railhead in Decatur, the maximum rail scenario involves barge shipment down the Tennessee River to Paducah, Kentucky and down the Ohio river to the Illinois Central railhead at Cairo, Illinois:[19]

- The "default route" for rail shipment from Decatur uses Norfolk Southern lines for travel across northern Alabama and Tennessee to Cairo (IL), St. Louis, and Kansas City. In Kansas City, shipments would be transferred to the UP for travel across Nebraska and Wyoming, through Ogden and Salt Lake City (UT) to an intermodal facility at Caliente or Valley.

## Figure 15-3. Alternative Nuclear Waste Transportation Routes: Browns Ferry NP

- The consolidated southern route from Decatur would depart from the default route in Kansas City, where, instead of transferring to the UP, shipments would be transferred to the merged Burlington Northern and Santa Fe lines for travel to Daggett, CA (via Amarillo and Flagstaff). In Daggett, rail shipments would be transferred to the UP for travel north through Las Vegas to an intermodal facility at Valley or Caliente.

- Under the maximum rail scenario, rail shipment on the default or consolidated southern route would begin in Cairo, after barge shipment along the Tennessee and Ohio Rivers.

**Cooper Station (NE) to Yucca Mountain (NV)**

How might shipments from the Cooper Station site, on the Missouri River about 65 miles south of Omaha, travel to Yucca Mountain? Under "current capabilities" scenario, the transportation choice of Nebraska Public Power for shipments from Cooper Station is legal-weight truck—using the high-capacity GA-9 cask if available, or a transportation cask for two BWR assemblies otherwise:

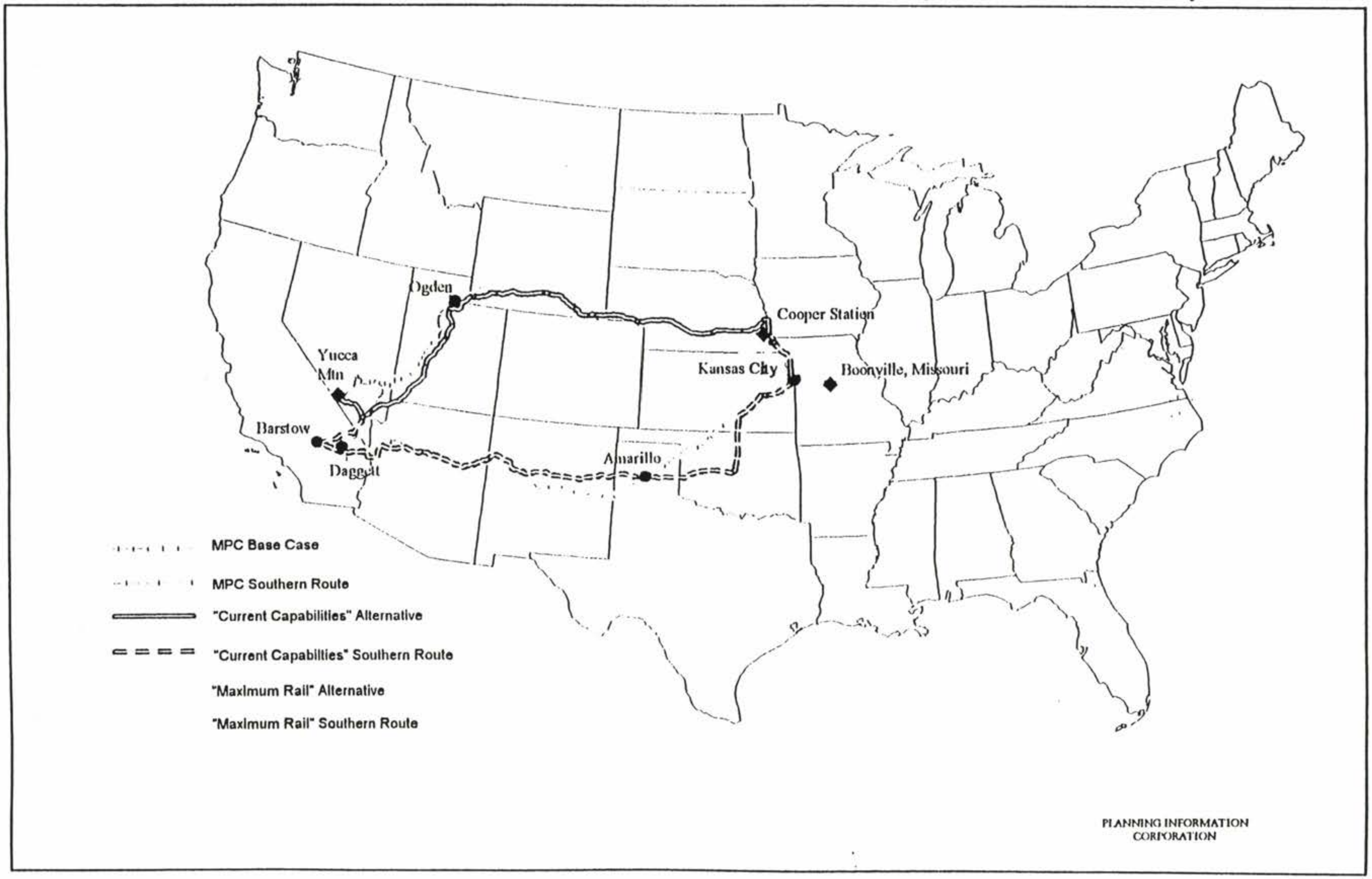
- The "default route" for truck shipments from Cooper Station would follow US 135 west and US 75 north to link with I-80 in Omaha. From Omaha, the route would use I-80 for travel across Nebraska, Wyoming, and Utah, linking with I-15 in Salt Lake City, for travel south through St.. George and Las Vegas to Yucca Mountain.

- The consolidated southern route for truck shipments from Cooper Station would follow US 135 east across the Missouri River, and US 59 south to I-29, continuing south on I-29 through St.. Joseph (MO) to Kansas City. In Kansas City, the southern route would access I-35, which it would follow south through Wichita (KS) to Oklahoma City, where it would access I-40 for continued travel west.

Under the "MPC base case" and "maximum rail" scenarios, Nebraska Public Power's transportation choice for shipments from Cooper Station is a small rail cask similar to DOE's 75-ton MPC, containing up to 24 BWR assemblies. However, while the "MPC base case" assumes heavy-haul transport north to a Burlington Northern railhead in Nebraska City (about 50 miles east of Lincoln), or across the Missouri River and south to a Burlington Northern railhead at Phelps City (MO), the maximum rail scenario assumes barge shipment down the Missouri River to a UP railhead in Boonville, about 120 miles east of Kansas City and about 20 miles west of Columbia (MO):[19]

- The "default route" for rail shipments from Cooper Station involves heavy-haul north to the Burlington Northern railhead at Nebraska City. Burlington Northern lines would be used for travel to Omaha, where shipments would be transferred to the UP railroad for travel west across Nebraska, Wyoming, and Utah, then south through Ogden and Salt Lake City to an intermodal facility at Caliente or Valley.

## Figure 15-4. Alternative Nuclear Waste Transportation Routes: Cooper Station NP



- The consolidated southern route for rail shipments from Cooper Station involves heavy-haul east across the Missouri River to the Burlington Northern railhead at Phelps City (MO). The route uses Burlington Northern lines for travel southeast to Kansas City, and Santa Fe lines (now merged with Burlington Northern) for travel southwest and west to Daggett, California, where shipments would be transferred to the UP for travel north through Las Vegas to an intermodal facility at Valley or Caliente.

- Default route rail shipments from Boonville (after barge shipment from Cooper Station) would use UP lines for travel through Kansas City to Gibbon (NE), about 120 miles west of Lincoln, then west across Nebraska and Wyoming, and south from Ogden (UT) to an intermodal facility at Caliente or Valley.

- Consolidated southern route rail shipments from Boonville would transfer to Santa Fe lines in Kansas City, using these for travel through Amarillo to Daggett, California, where they would transfer back to UP lines for travel north through Las Vegas to an intermodal facility at Valley or Caliente.

**Grand Gulf (MS) to Yucca Mountain (NV)**

How might shipments from the Grand Gulf (MS) nuclear plant, located on the Mississippi River about 30 miles south of Vicksburg, travel to Yucca Mountain? Under the "current capabilities scenario, the transportation choice of Systems Energy Resources for shipments from Grand Gulf is legal-weight truck—using the high-capacity GA-9 cask if available, or a transportation cask for two BWR assemblies otherwise:

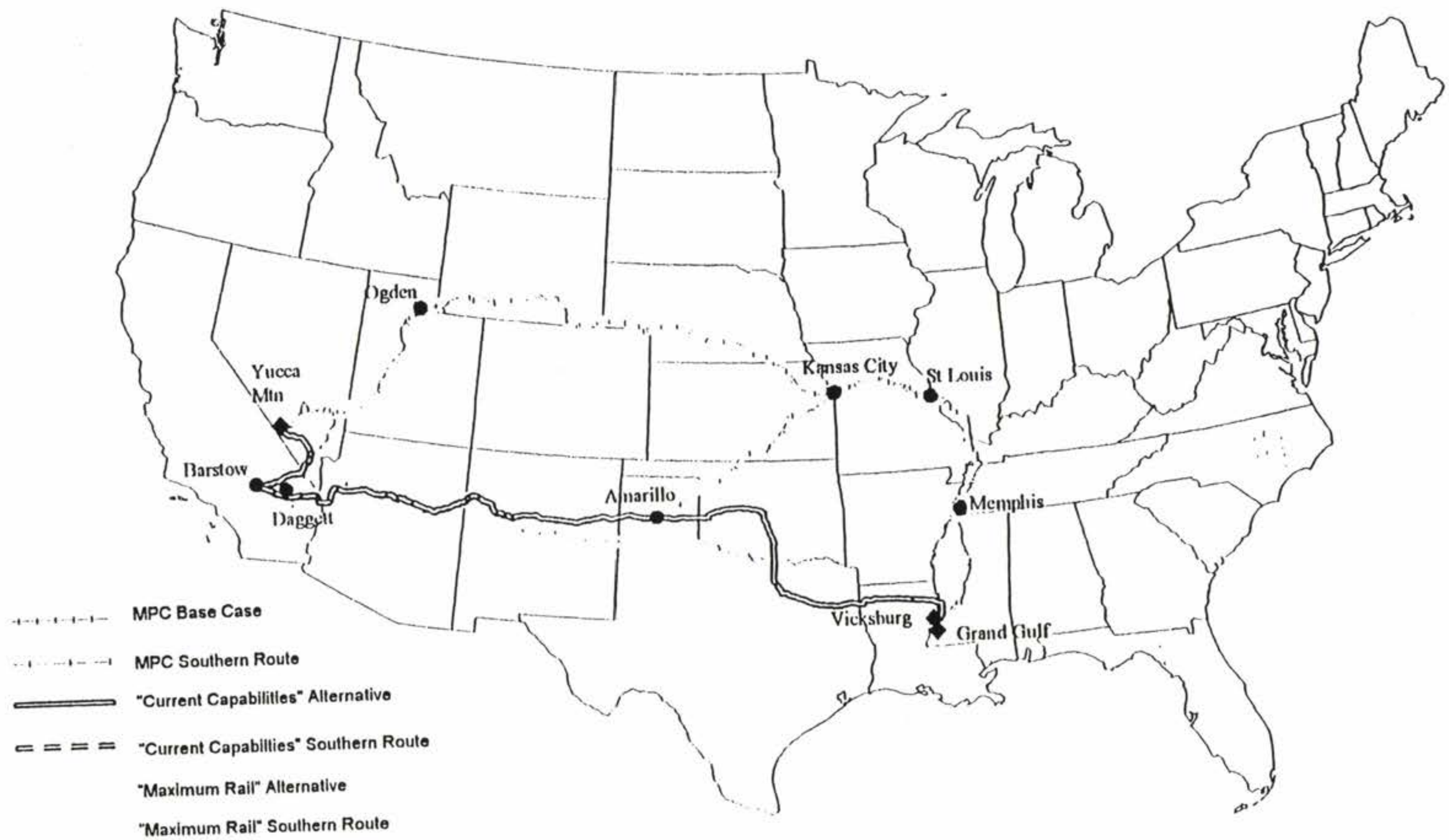
- The default and consolidated southern route for truck shipments from Grand Gulf would follow US 61 north to Vicksburg, where it would link with I-20 for travel west through Shreveport (LA) to Dallas and Fort Worth, where it would access I-35 north to Oklahoma City and I-40 for continued travel west to Barstow, California, where it would access I-15 for travel north through Las Vegas to Yucca Mountain.

Under the MPC base case and maximum rail scenarios, the transportation choice of Systems Energy Resources for shipments from Grand Gulf is a large rail cask similar to DOE's 125-ton MPC, containing up to 40 BWR assemblies:

- The "default route" for rail shipments from Grand Gulf involves heavy-haul north on US 61 and east on I-20 to the Illinois Central railhead at Jackson (MS). The route uses Illinois Central lines for travel north through Memphis to St.. Louis, where shipments would be transferred to UP lines for travel west to Kansas City and across Nebraska, Wyoming, and Utah, then south from Ogden through Salt Lake City to the intermodal facility at Caliente or Valley.

- The consolidated southern route for rail shipments from Grand Gulf departs from the default route in Kansas City where, instead of continuing on the UP, shipments would be transferred to Santa Fe lines for travel southwest to Amarillo and west to Daggett, California, where they would be transferred back to UP lines for travel north through Las Vegas to an intermodal facility at Valley or Caliente.

**Figure 15-5. Alternative Nuclear Waste Transportation Routes: Grand Gulf NP**



**Diablo Canyon (CA) to Yucca Mountain (NV)**

How might shipments from the Diablo Canyon (CA) nuclear plant, located on the Pacific Ocean near San Luis Obispo, about 85 miles northwest of Santa Barbara, travel to Yucca Mountain? Under the "current capabilities" scenario, the transportation choice of Pacific Gas and Electric for shipments from Diablo Canyon is legal-weight truck—using the high-capacity GA-4 cask if available, or a transportation cask for a single PWR assembly otherwise:

- The route for truck shipments from Diablo Canyon would follow US-101 north through San Luis Obispo to Paso Robles, and CA 46 east to access I-5 at Lost Hills. The route would follow I-5 southeast towards Los Angeles, accessing I-210 (Foothill Parkway) for passage across LA's northern suburbs—Burbank, Glendale, Pasadena, Glendora, etc. The route accesses I-10 (San Bernadino Freeway) near Pomona, which is used for travel east through Montclair and Ontario to I-15, which is used for travel north through Las Vegas to Yucca Mountain.

Under the MPC base case and maximum rail scenarios, Pacific Gas and Electric's transportation choice for shipments from Diablo Canyon is a large rail cask similar to DOE's 125-ton MPC, containing up to 21 PWR assemblies. However, while the MPC base case assumes heavy-haul transport to the Southern Pacific railhead in San Luis Obispo, the maximum rail scenario involves a 150-mile barge shipment south to Point Conception and east through the Santa Barbara Channel to the railhead of the Ventura County Railway Company at Port Hueneme near Oxnard:[19]

- Rail shipments from San Luis Obispo would use Santa Fe lines for travel through Santa Barbara, Ventura, Oxnard, Burbank, and east Los Angeles to San Bernadino, where they would be transferred to the UP for travel north through Las Vegas to an intermodal facility at Valley or Caliente.

## Figure 15-6. Alternative Nuclear Waste Transportation Routes: Diablo Canyon NP

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# 16. THE NATIONAL SHIPMENT CAMPAIGN: LIFE OF OPERATIONS

What are the overall effects of the national shipment campaign, aggregated for each origin site and all major rail and highway segments over the entire prospective 30-year shipment campaign? What are the effects under the "current capabilities" scenario of transportation choices, or under the "MPC base case" or "maximum rail" scenarios? What are the effects of using a high capacity cask for legal-weight truck shipments,* rather than the currently-available casks limited to one PWR or 2 BWR assemblies?

This section uses maps to present the rail and highway segments affected, and tables to present the total (life of operations) cask shipments in the 30-year shipment campaign. Both maps and tables reflect factors discussed in previous sections—e.g., the current and projected inventory, the acceptance rate and pickup schedule. Under these assumptions, shipments of HLW from DOE sites begin in year 17 and extend through year 44; only those shipments in years 17 through 31 (54 percent of the total) are included in this summary. Subsequent sections consider implications for Nevada (section 17), regional routing alternatives (section 18), the phasing of shipments during the 30-year campaign (section 19), and transportation operations variables (section 20).

### Mapping Routes and Cask Shipments

To visualize the cask shipment findings of a multi-faceted assessment process, this study has developed a map presentation in which route segments are scaled according to the number of projected shipments on each segment over the 30-year shipment campaign. The scale is consistent among cask options and among transportation choice scenarios. That is, in this presentation, 100 prospective cask shipments are shown at the same map scale whether the shipments are truck casks containing 1 PWR or 2 BWR assemblies, high-capacity truck casks containing 4 PWR or 9 BWR assemblies, a small rail cask containing 12 PWR or 24 BWR assemblies or a large rail cask containing 21 PWR or 40 BWR assemblies.** The amount of waste shipped in these casks ranges from about 800 pounds in the case of the small truck cask to about 14,800 pounds in the case of the large rail cask, a factor of 18. Another map presentation might be developed to show the amount of waste shipped, rather than the number of cask shipments.

### Rail and Highway Routes Affected

Figure 16-1 shows the rail and highway routes affected by default routing under the current capabilities scenario of transportation choices, scaling the routes according to the number of projected shipments on each segment over the 30-year shipment campaign. Figures 16-2 and 16-3 present similar results for the "MPC base case" and "maximum rail" scenarios of transportation choices. Over the 30-year shipment campaign (and assuming default routing), about 18,800 miles of the nation's railroads carry

* A cask similar to the GA-4/9 cask designed by General Atomics, with capacity for 4 PWR or 9 BWR uncanistered assemblies.

** Also, no attempt has been made to project rail consists. The maps indicate the number of casks shipped on each rail route segment, not the number of trains containing cask shipments.

shipments of SNF or HLW, a figure which increases to 21,200 miles under the MPC base case and to 23,500 under the maximum rail scenario of transportation choices.* Rail rather than highway shipment from certain sites (e.g., Turkey Point, FL, Diablo Canyon, CA, Kewanee, WI) adds significantly to total affected rail route mileage, but from other sites (e.g., Dresden, IL, Browns Ferry, AL) has much less effect.

Over the 30-year shipment campaign (again, assuming default routing) about 13,700 miles of the nation's highways carry shipments of SNF or HLW, a figure which decreases to 10,200 miles under the MPC base case and to 4,200 under the maximum rail scenario of transportation choices. Rail rather than highway shipment from certain sites (e.g., Grand Gulf, MS, Surry, VA, Peachbottom, PA) significantly reduces highway route mileage, but from other sites (e.g., Calvert Cliffs, MD, Salem, NJ) has much less effect.

### Total Cask Shipments

Table 16-1 presents total cask shipments over the 30-year campaign, under the current capabilities, MPC base case and maximum rail scenarios. Rail cask shipments of SNF** increase from about 9,900 in the current capabilities scenario of transportation choices to about 11,200 under the MPC base case and 14,100 under the maximum rail scenario. The changes reflect both the number of sites shipping by rail (and their projected inventory) and the type of rail cask used. Compared to the current capabilities scenario, the MPC base case and maximum rail scenarios include more rail shipment sites (*increasing* the number of rail cask shipments) making greater use of the large MPC (*reducing* the number of rail cask shipments). Shipments of uncanistered fuel in currently-available legal-weight truck casks are estimated at 79,300 under the current capabilities scenario of transportation choices, a figure which decreases to 26,100 under the MPC base case and to 4,700 under the maximum rail scenario. The decreases reflect the number of sites shipping by truck rather than by rail, and the projected inventory requiring shipment.

The high-capacity legal-weight truck cask (if available and consistently used throughout the 30-year shipment campaign) dramatically reduces the number of truck cask shipments from 79,300 to 31,400 under the current capabilities scenario, from 26,100 to 6,300 under the MPC base case, and from 4,700 to 1,150 under the maximum rail scenario. Even so, truck cask shipments of SNF would comprise about 71 percent of total cask shipments under the current capabilities scenario, about 31 percent under the MPC base case scenario, and over 6 percent under the maximum rail scenario of transportation choices.

### The Use of Affected Rail and Highway Routes

How intensively would the nation's rail and highway networks be used by the national shipment campaign? Over the 30-year campaign, each affected rail route mile would receive an average of about 1,500 cask shipments under the current capabilities scenario, with similar figures for a somewhat more extensive affected rail route network under the MPC base case and maximum rail scenarios. More intensively used rail route segments, however, could receive up to 8.5 times the national average.

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* Route mileage excludes 162 miles of heavy-haul from an intermodal transfer facility at Caliente.

** An additional 2,700 rail cask shipments of HLW are expected between years 17 and 31.

Over the 30-year shipment campaign, each affected rail route mile would receive an average of 13,700 cask shipments under the current capabilities scenario (using currently-available legal-weight truck casks), or about 1,500 shipments (using the high-capacity legal-weight truck cask) under the MPC base case, or about 700 under the maximum rail scenario. Again, more intensively used highway route segments could receive up to six times the national average.

### A State-Level Review

Perspectives on nuclear waste transportation are highly correlated with the degree to which waste will be shipped out of, through or to one's own community—that is, the degree to which one's community serves as an origin, corridor or destination for shipments of these highly-toxic and long-lived radioactive materials. Origin communities have lived with nuclear sites for years, even decades, have directly benefited from the electricity and jobs produced, and, with shipment, have the opportunity to rid themselves of the resulting wastes. Corridor communities provide transportation routes for wastes whose origin and destination are elsewhere. Under safe, routine conditions, waste shipments will not linger in corridor communities, but they require attention by public officials and raise anxieties among residents. Destination communities receive the wastes generated elsewhere. In the case of spent nuclear fuel and high-level waste, there is only one prospective destination community, and the waste received, even if safely contained, will remain toxic for centuries.

Under the MPC base case scenario of transportation choices (assuming default routing) only seven states are neither origins, corridors, nor the destination for shipments of SNF or HLW (see Figure 16-4). Together, these jurisdictions comprise 2.4 percent of the nation's population. Another seven states located along the perimeter of the country are origins but not corridors for shipments of SNF and HLW. Together, these states comprise 18 percent of the nation's population. It should be observed, however, that many communities within these states will consider themselves as corridors rather than as origins for shipments of nuclear waste. Still another seven states (three east of the Mississippi River) plus the District of Columbia are corridors but not origins for shipments of SNF and HLW. Together, these states comprise seven percent of the nation's population.

Most states are both origins and corridors for prospective shipments of SNF and HLW under the MPC base case scenario of transportation choices with default routing. Together, these 28 states comprise 71 percent of the nation's population. Five of the 28 are origins for shipments from one (or in the case of Nebraska, two) nuclear site, but are corridors for shipments from 20 sites or more. These states are Iowa, Kansas, Missouri, Nebraska, and Arizona. Together, they comprise 6.2 percent of the nation's population.

Under the MPC base case scenario with default routing, 8 states are corridors for shipments from 25 or more sites. These states, including five with commercial reactors and two east of the Mississippi, comprise 11 percent of the nation's population. Illinois is a corridor state for 47 sites and an origin state for eight sites.

Nevada is the destination state, the end of the funnel for the national shipment campaign and the intended permanent disposal site for the nation's SNF and HLW. Nevada has 0.5 percent of the nation's population. Similar to origin-only states, parts of Nevada are likely to consider themselves more as corridors than as the destination for shipments of SNF and HLW. But these communities are corridors for all shipment sites, and are in the destination state where the wastes will be permanently stored, not an origin state that has previously chosen to developed nuclear power and is now removing the resulting wastes. Section 17 provides additional detail regarding cask shipments into the destination state.

**Table 16-1. Route Miles Affected and Cask Shipments**
**• Life of Operations (YR 1-31) . . . Default Routing**
**• Currently-Available and High-Capacity Truck Cask**

| | RAIL | HWY:T1/2 | TOT:T1/2 | HWY:T4/9 | TOT:T4/9 |
|---|---|---|---|---|---|
| ROUTE MILES: | | | | | |
| Current Capabilities | 18805 | 13695 | 32500 | 13695 | 32500 |
| MPC Base Case | 21210 | 10224 | 31434 | 10224 | 31434 |
| Maximum Rail | 23507 | 4178 | 27685 | 4178 | 27685 |
| CASK SHIPMENTS: | | | | | |
| Current Capabilities | 12636 | 79345 | 91981 | 31370 | 44006 |
| MPC Base Case | 13916 | 26093 | 40009 | 6322 | 20238 |
| Maximum Rail | 16792 | 4722 | 21514 | 1150 | 17942 |
| CASK SHIP PER RT-MILE: | | | | | |
| Current Capabilities | 1496 | 13356 | 6493 | 3154 | 2194 |
| MPC Base Case | 1463 | 6505 | 3103 | 1536 | 1487 |
| Maximum Rail | 1494 | 2764 | 1686 | 703 | 1375 |

**Table 16-2. States by Origin/Corridor Status**

| Neither Origins Nor Corridors | Origin Only States | Corridor Only States | Major Corridor States* | |
|---|---|---|---|---|
| Rhode Island | Michigan | Indiana | Utah | (65/0) |
| District of Columbia | Wisconsin | Kentucky | Nebraska | (60/2) |
| Delaware | Maine | Oklahoma | Wyoming | (58/0) |
| Alaska | New Jersey | West Virginia | Illinois | (47/8) |
| Hawaii | Florida | New Mexico | Iowa | (32/1) |
| Montana | Louisiana | Utah | Kansas | (28/1) |
| North Dakota | Washington | Wyoming | Missouri | (27/1) |
| South Dakota | | | Indiana | (25/0) |
| Percent of U.S. population: | 18 percent | 7 percent | 11 percent | |

* (60/2): corridor for 60 sites, origin for 2.

**Figure 16-1. Life of Operations Rail and Highway Cask Shipments Current Capabilities Transportation Choices/Default Routing**

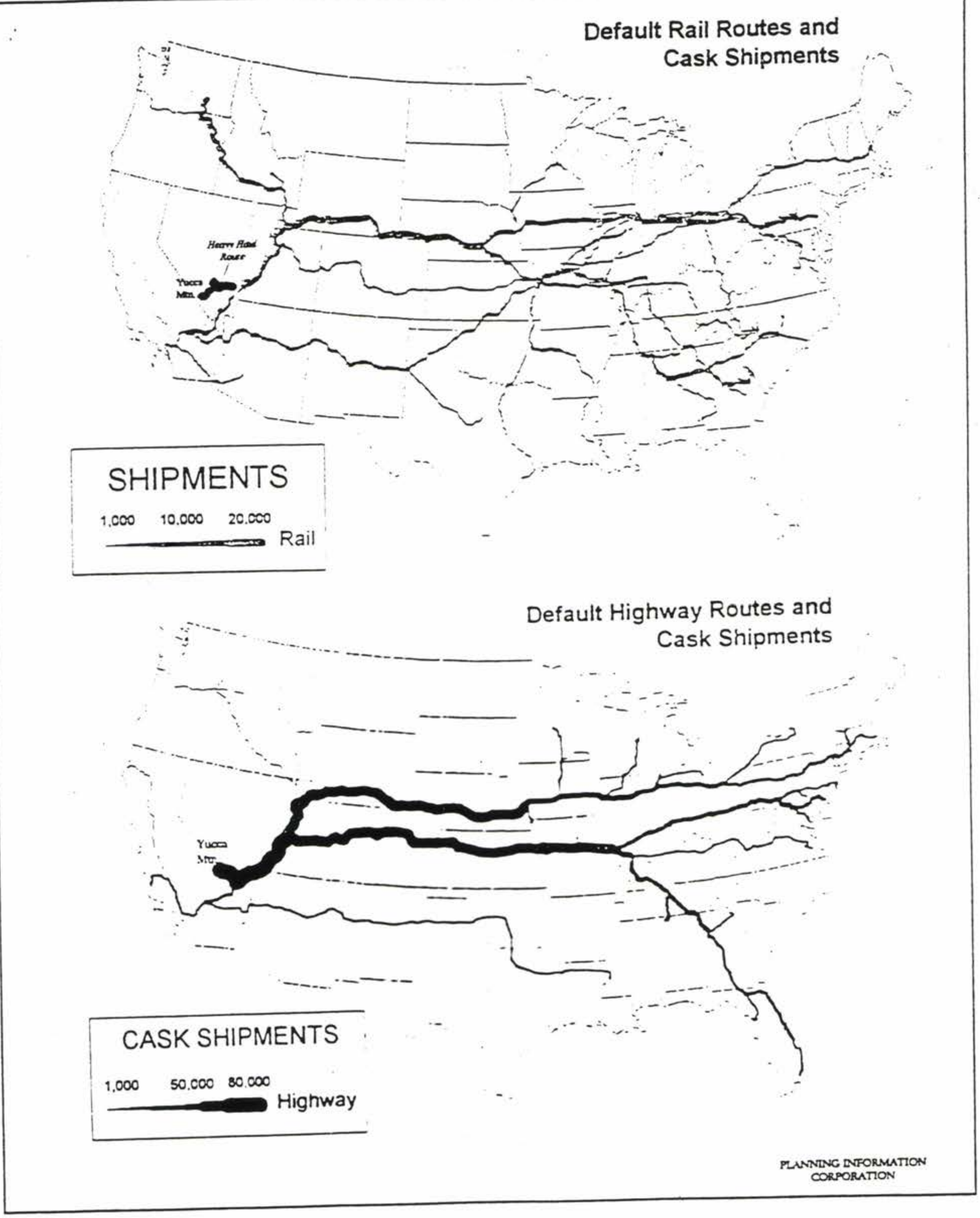


**Figure 16-2. Life of Operations Rail and Highway Cask Shipments MPC Base Case Transportation Choices/Default Routing**

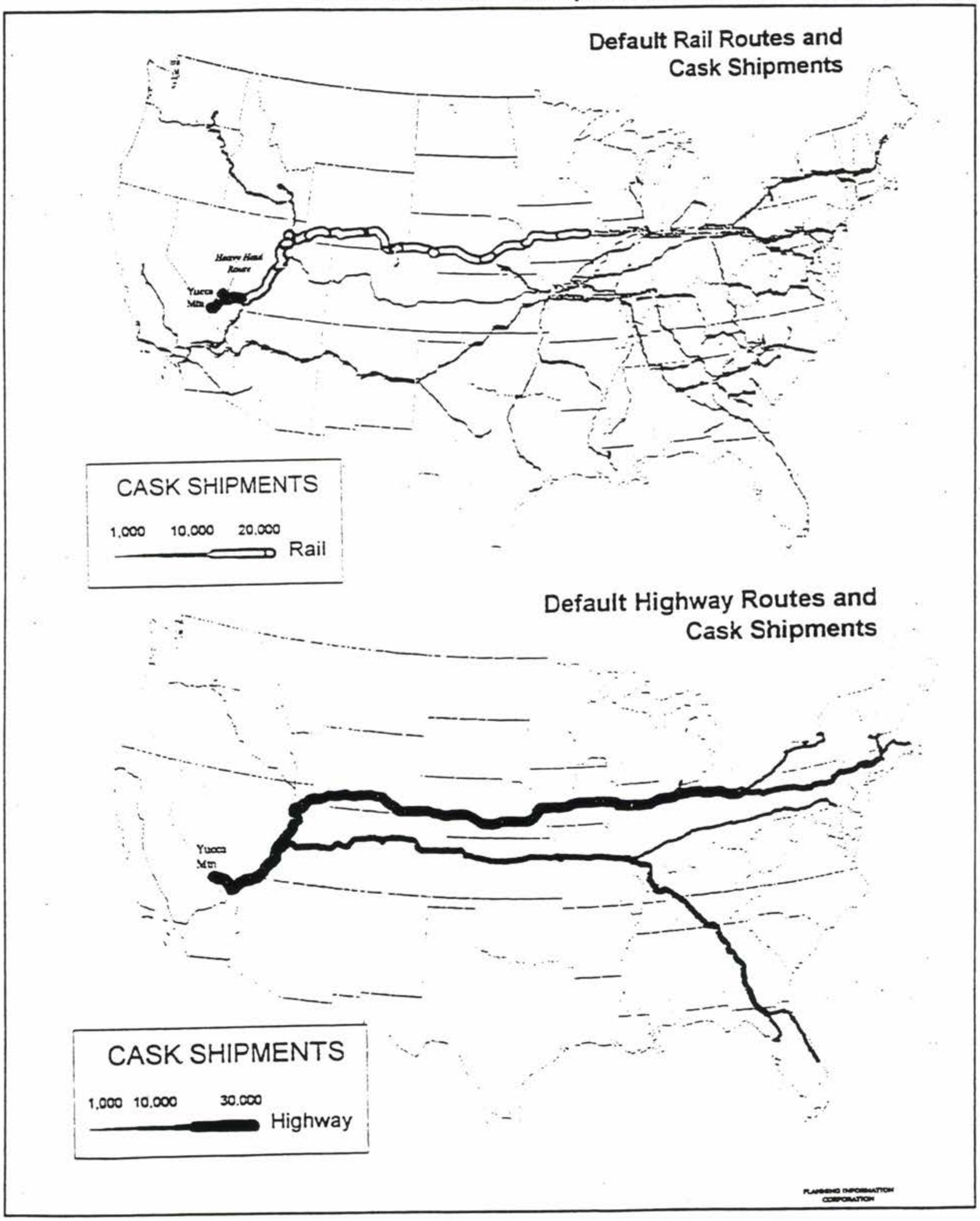
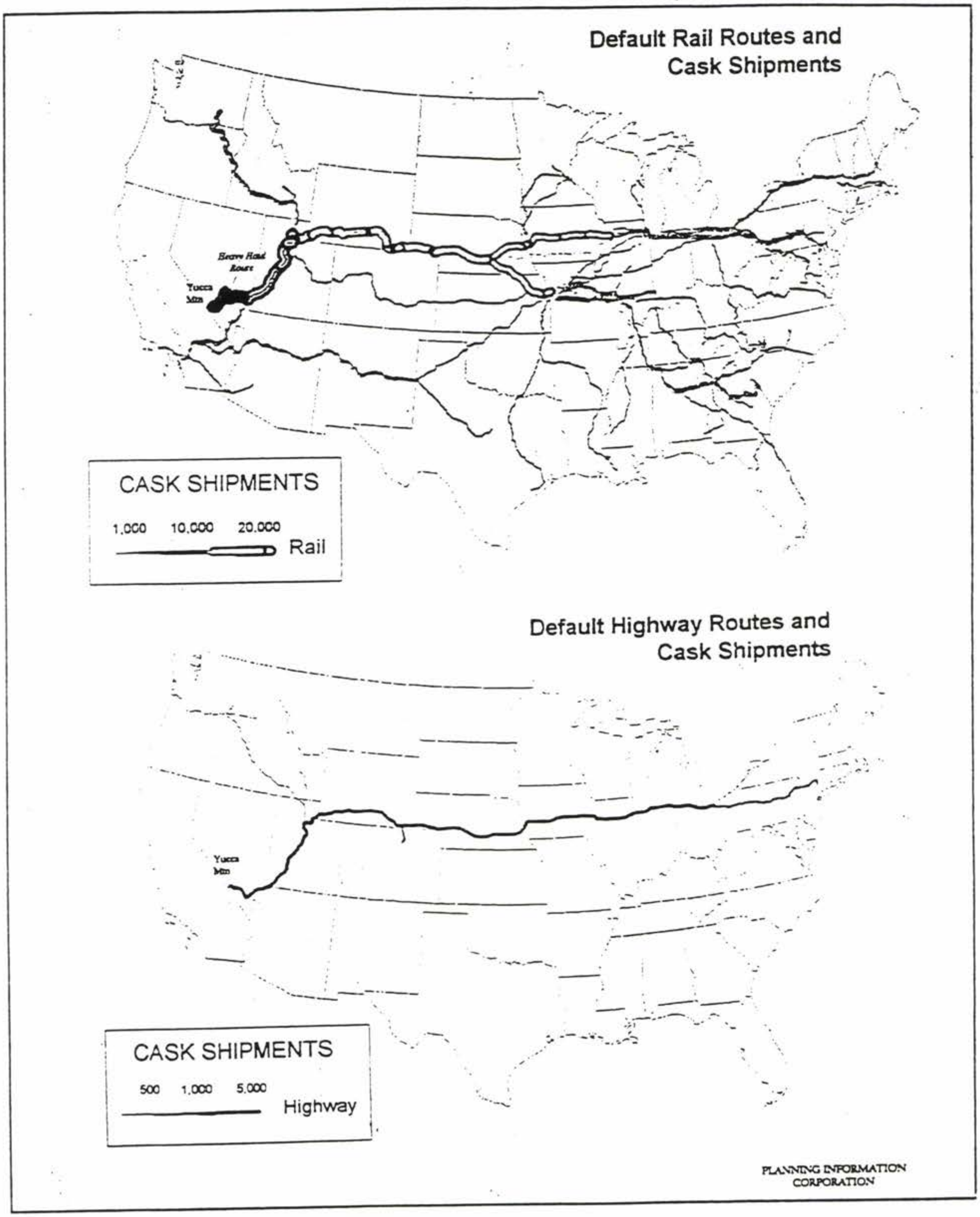


**Figure 16-3. Life of Operations Rail and Highway Cask Shipments Maximum Rail Transportation/Default Routing**



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# 17. NEVADA IMPLICATIONS: THE END OF THE FUNNEL

The end of the funnel for the prospective national shipment campaign is Nevada, where rail and truck shipments from 80 sites in 35 states would converge. Under default routing, rail shipments would move on the Union Pacific rail line north from California or south from Utah to an intermodal transfer facility at the Lincoln County community of Caliente. From Caliente, shipments would continue by heavy-haul truck along U.S. highways and state roads, accessing NTS Area 25 via a newly constructed road across a corner of the Nellis Air Force Range, or continuing on public highways along a circuitous route north and west of the Nellis Air Force Range. Truck shipments would move on Interstate 15 north from California or south from Utah and Arizona to a major interchange with US-95/93 in the heart of Las Vegas, locally known as "the Spaghetti Bowl." From the Spaghetti Bowl, truck shipments would continue northwest on US-95, entering the Nevada Test Site at Lathrop Wells in the Nye County community of Amargosa Valley.

Figure 17-1 shows the rail and highway routes affected by default routing under the current capabilities scenario of transportation choices, scaling the routes according to the number of projected shipments on each segment over the 30-year shipment campaign. Figures 17-2 and 17-3 present similar information for the "MPC base case" and "maximum rail" scenarios of transportation choices.

Table 17-1 presents total cask shipments over the 30-year shipment campaign, under the current capabilities, MPC base case and maximum rail scenarios. Under the current capabilities scenario assuming default routing, Nevada would receive about 12,600 rail cask shipments, of which about 9.2 percent would move north from California through Las Vegas. The state would also receive about 79,300 truck shipments (31,300 using the high-capacity T-4/9 cask) of uncanistered fuel, of which about 8.3 percent would move north from California to the Spaghetti Bowl.

Under the MPC base case scenario of transportation choices, rail cask shipments into the state would increase from 12,600 to about 13,900 while truck cask shipments would decrease from 79,300 to 26,100 (from 31,300 to 6,300 using the high-capacity T-4/9 cask). Assuming default routing, the portion of rail and truck shipments moving north into the state from California or south from Utah would change only slightly.

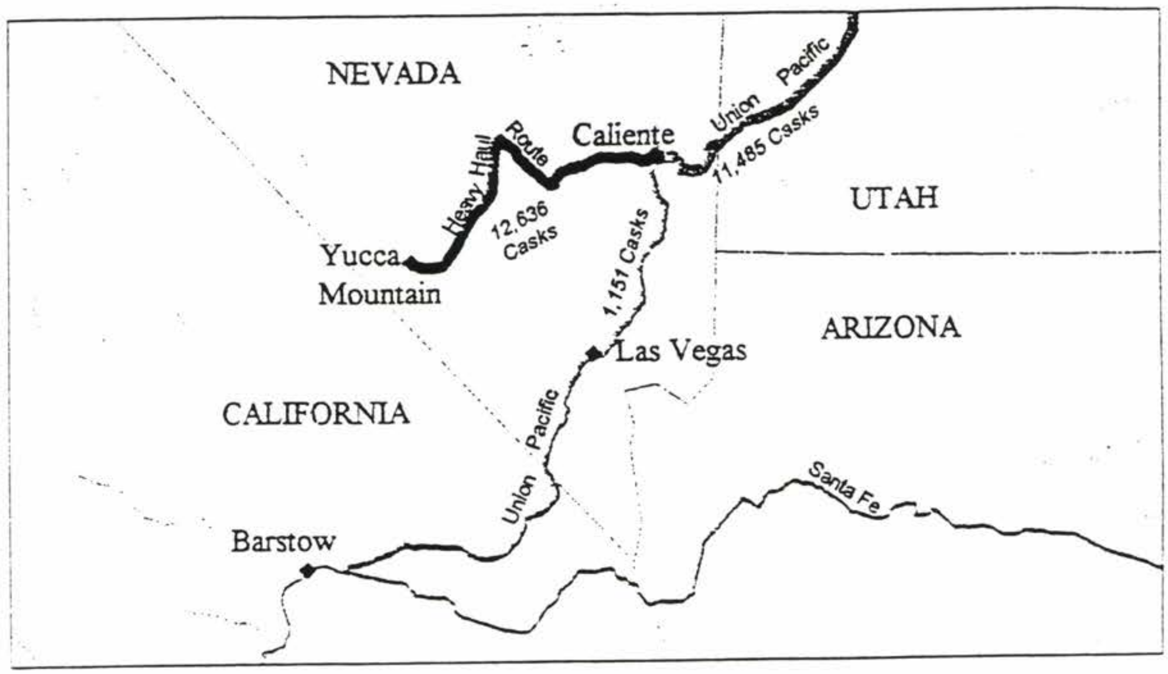
Under the maximum rail scenario of transportation choices, rail cask shipments would increase to 16,800 while truck cask shipments would decrease to 4,700 (to 1,200 using the high-capacity T-4/9 cask). Again, assuming default routing, the portion of rail and truck shipments moving north into the state from California or south from Utah would change only slightly.

Part of a strategy to limit the impacts of transportation shipments in Nevada could involve efforts to avoid Las Vegas, the major urban center of the state. Such a strategy would emphasize rail shipment from the north (where shipments can be intercepted at Caliente) rather than rail shipment from the south or truck shipment on I-15, from the north or south. Among the alternatives considered in this assessment, the maximum rail scenario using default routing (combined with truck shipment using the high-capacity T-4/9 cask) goes the farthest towards this objective. Unfortunately implementation of the maximum rail scenario requires an expensive and not yet devised set of incentives for the choice of rail over truck shipment, and for large rail over small rail shipment. Furthermore, default routing has implications for corridor communities "upstream" in the route system for shipments of SNF and HLW, which we address in the next section. In addition, even if these arrangements and commitments could be made, it is difficult to envision that they could be implemented in time for a shipment campaign beginning in 1998.

**Table 17-1. Life of Operations Rail and Highway Cask Shipments Nevada Rail and Highway Route Segments**

| | CURRENT CAPABIL | MPC BASE CASE | MAXIMUM RAIL |
|---|---|---|---|
| Rail Segments: | ------- | ------- | ------- |
| NV: UP @ UT line | 11485 | 12399 | 15405 |
| NV: UP @ LV Strip | 1151 | 1517 | 1387 |
| Hwy Segments: | ------- | ------- | ------- |
| NV: I-15 @ Moapa | 72768 | 6277 | 1150 |
| NV: I-15 @ Strip | 6577 | 45 | 0 |

**Figure 17-1. Life of Operations Rail & Highway Shipments in Southern NV Region Current Capabilities Transportation Choices/Default Routing**



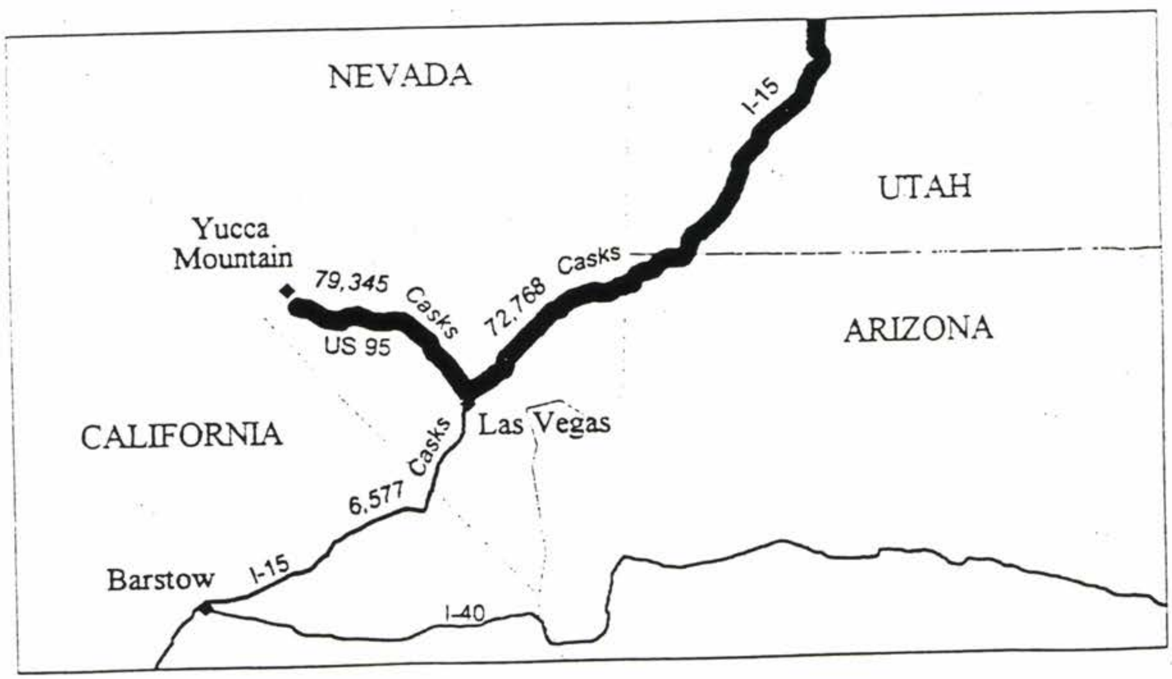
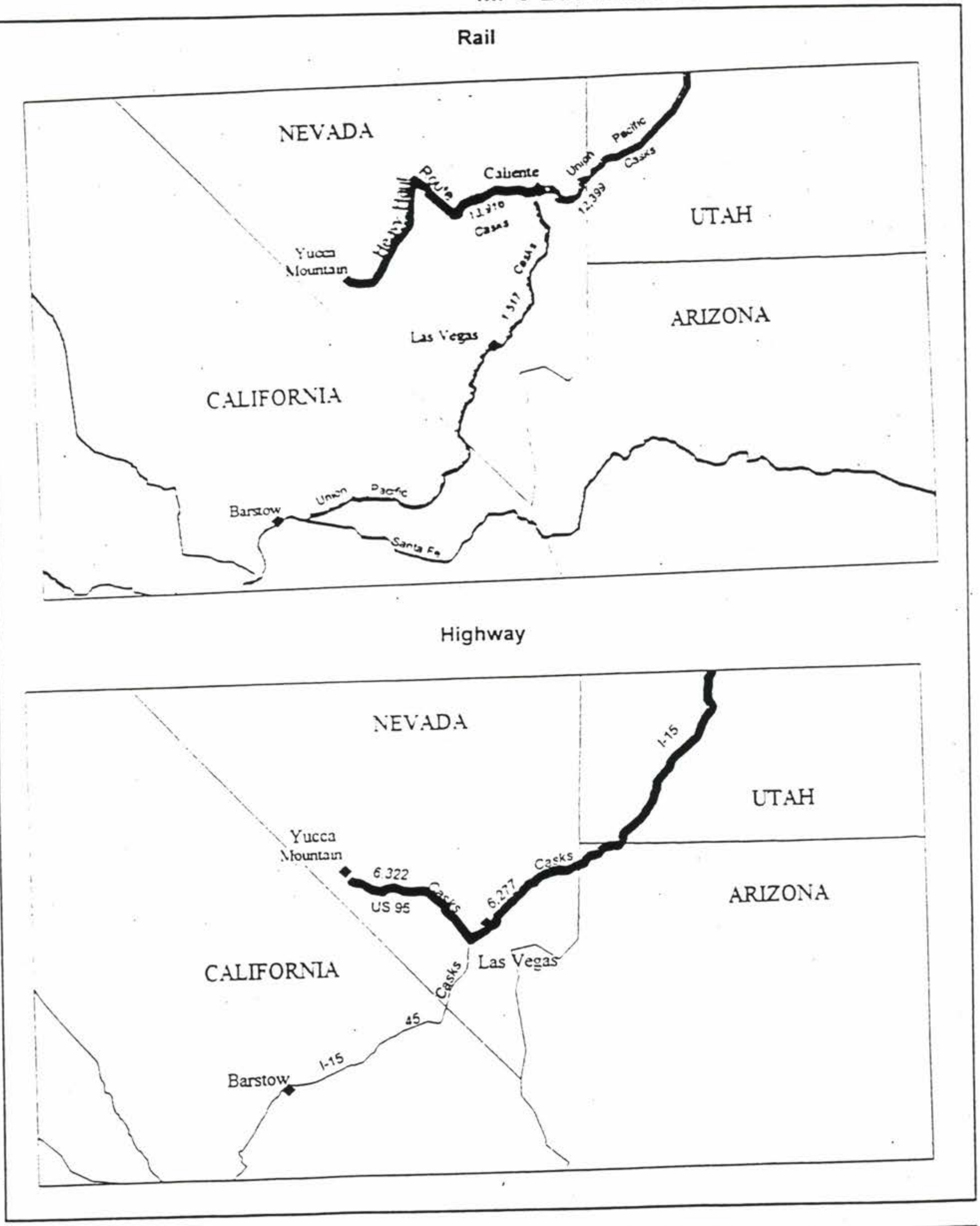
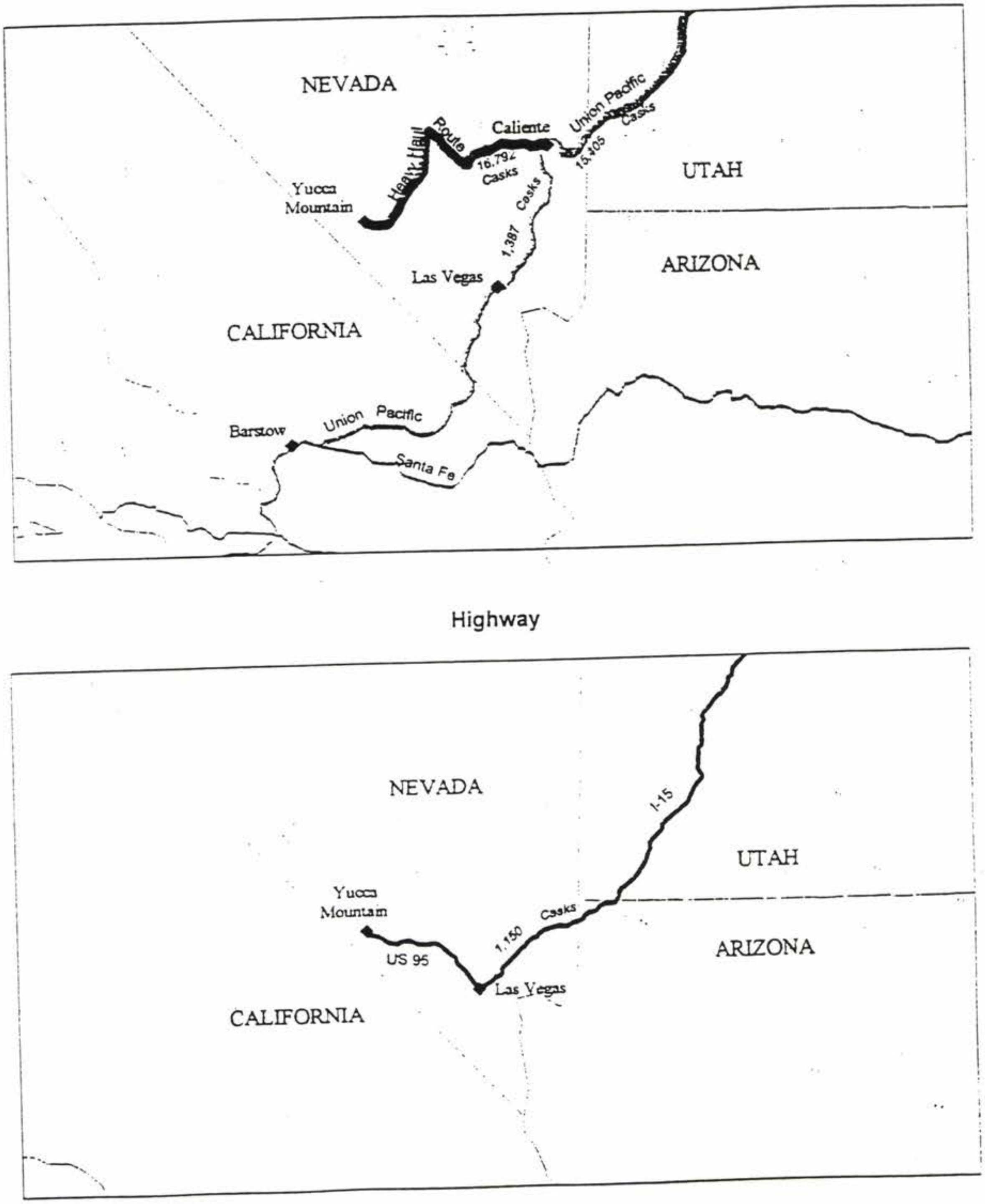



**Figure 17-2. Life of Operations Rail & Highway Shipments in Southern NV Region MPC Base Case Choices/Default Routing**



## Figure 17-3. Life of Operations Rail & Highway Shipments in Southern NV Region Maximum Rail Transportation Choices/Default Routing

Rail




Highway

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# 18. REGIONAL ROUTING ALTERNATIVES

The maps presented in Section 16 can be viewed from many different national, regional, or local perspectives. National perspectives may involve the overall safety or cost efficiency of the national shipment campaign, while regional perspectives may seek to limit impacts on certain centers of population and commerce, and local perspectives may focus on certain facilities (e.g., a hospital or elementary school) or route conditions (e.g., a hazardous interchange) or special events (e.g., the upcoming winter Olympics in Salt Lake City). Under HM164, for example, states may choose to designate alternative routes for shipment of "highway route controlled quantities" of hazardous materials, including SNF and HLW. In a national shipment campaign, such designations have system effects which require coordination with "upstream" and "downstream" states. Rail routes are generally determined by rail carriers, in negotiation with utility shippers and DOE. But the choice to heavy-haul to one railhead rather than another at the origin site, or changes in railroad ownership, can substantially alter a 2,000 mile cross-country route.

The use of Interstate 43, which extends south from Green Bay through Milwaukee and southwest to Beloit, WI provides an example of possible regional perspectives on the routing of SNF shipments. In the current capabilities scenario, I-43 is used to move wastes away from the Kewaunee and Point Beach sites in Wisconsin. In northern Illinois, where the Byron and Zion plants are located, I-43 connects to I-80 via I-39 in Rockford and I-88 in Moline, However, since Byron and Zion ship by rail in the current capabilities scenario, the connecting segments in Illinois are used only by shipments originating in Wisconsin. These circumstances, which are just one example of hundreds involved in a national shipment campaign, could affect the perspective of various state agencies and local communities in Wisconsin and Illinois.

### Consolidated Southern Routing

A major alternative to the default routing criteria reflected in the results presented in Sections 16 and 17, is a "consolidated southern" option which would concentrate cross-country rail shipments on the Santa Fe rail line rather than the Union Pacific and Southern Pacific, and concentrate cross-country highway shipments on I-40 rather than I-80 or I-70. To illustrate the effects of regional routing alternatives, we have compared cask shipment estimates under default and consolidated southern routing options for five rail and five highway route segments in four states—Wyoming, Colorado, New Mexico, and Nevada (see Figures 18-1 through 18-3):

- The Wyoming route segments are along the Union Pacific line near Rawlins in south-central Wyoming, and along a nearby segment of I-80.
- The Colorado segments are along the Southern Pacific rail line near Glenwood Springs in western Colorado, and along a nearby segment of I-70.
- The New Mexico segments are along the Santa Fe rail line near Grants in northwestern New Mexico, and along a nearby segment of I-40.

**Figure 18-1a. Life of Operations Rail and Highway Cask Shipments
Current Capabilities Transportation Choices/Default Routing**

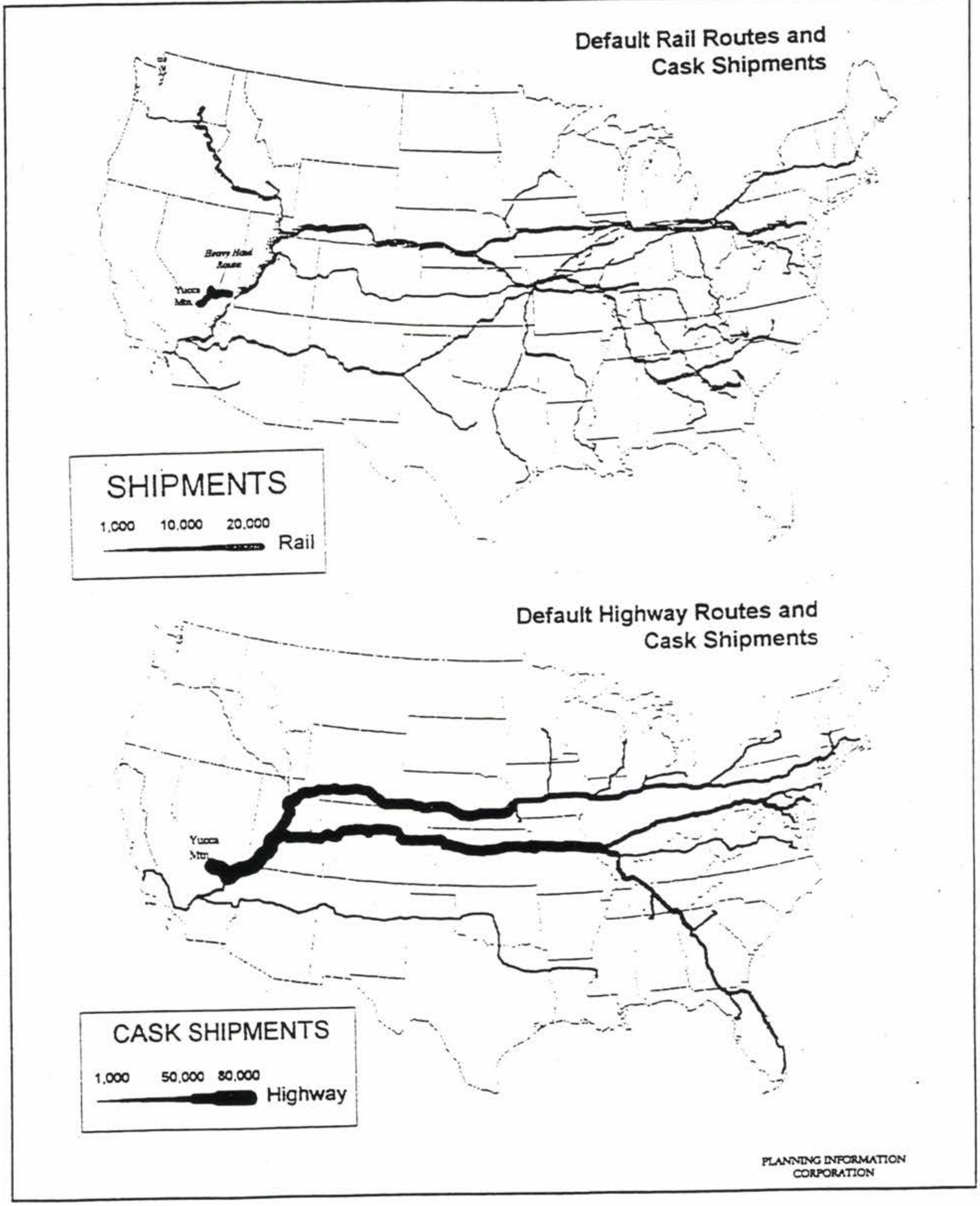


**Figure 18-1b. Life of Operations Rail and Highway Cask Shipments Current Capabilities Transportation Choices/Consolidated Southern Routing**

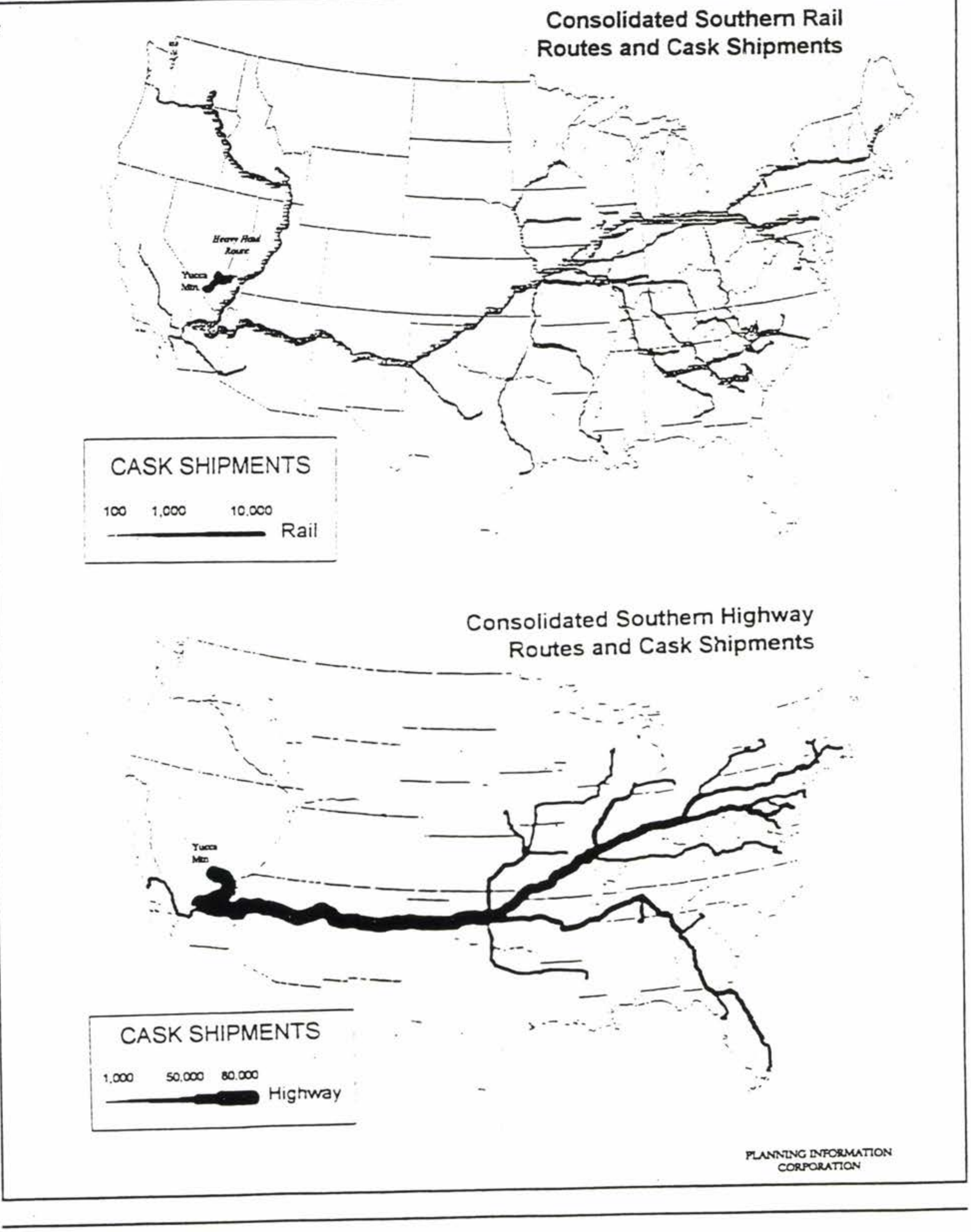


**Figure 18-1a (NV). Life of Operations Rail and Highway Cask Shipments in (NV) Current Capabilities Transportation Choices/Default Routing**

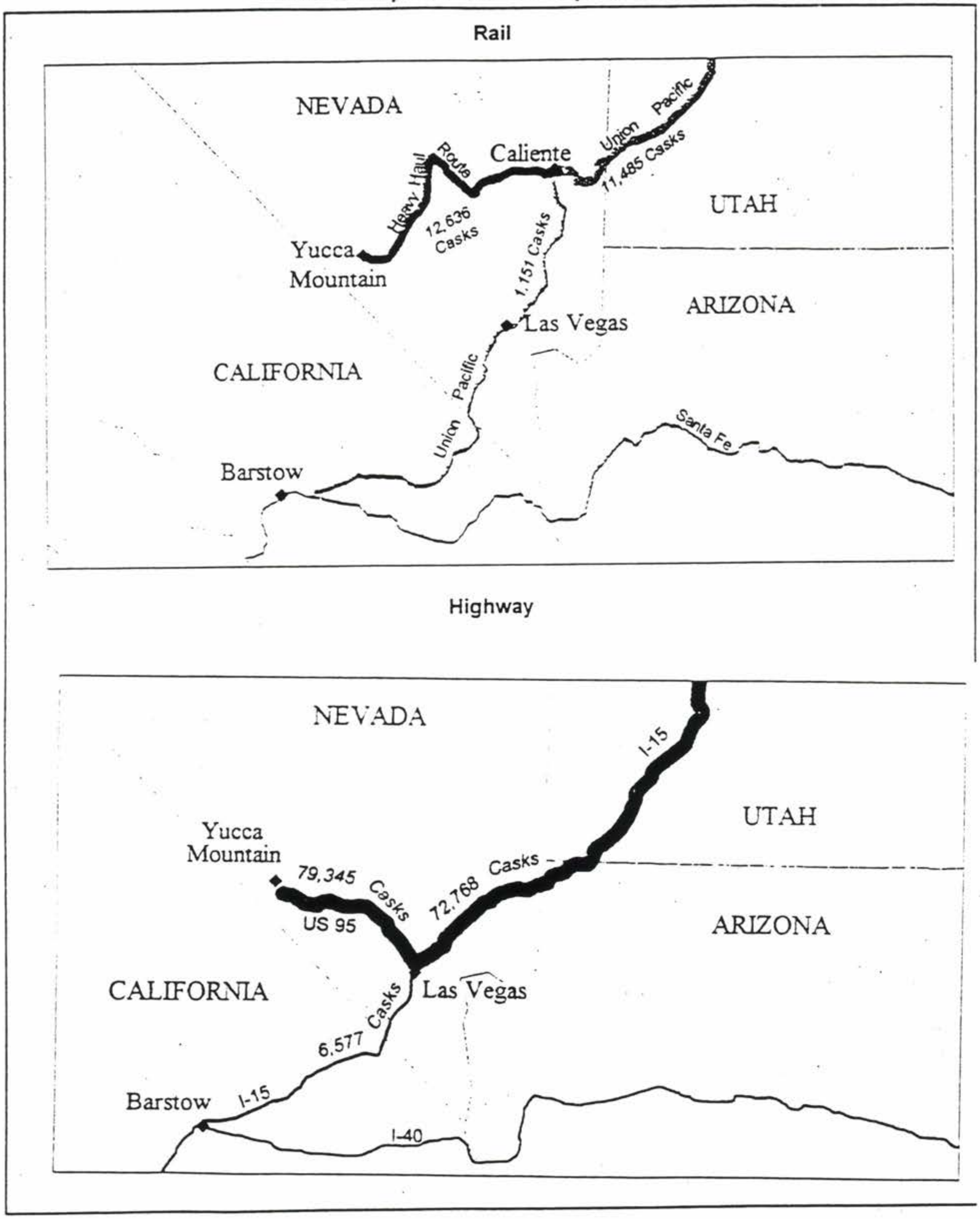


**Figure 18-1b (NV). Life of Operations Rail and Highway Cask Shipments in (NV) Current Capabilities Transportation Choices/Consolidated Southern Routing**

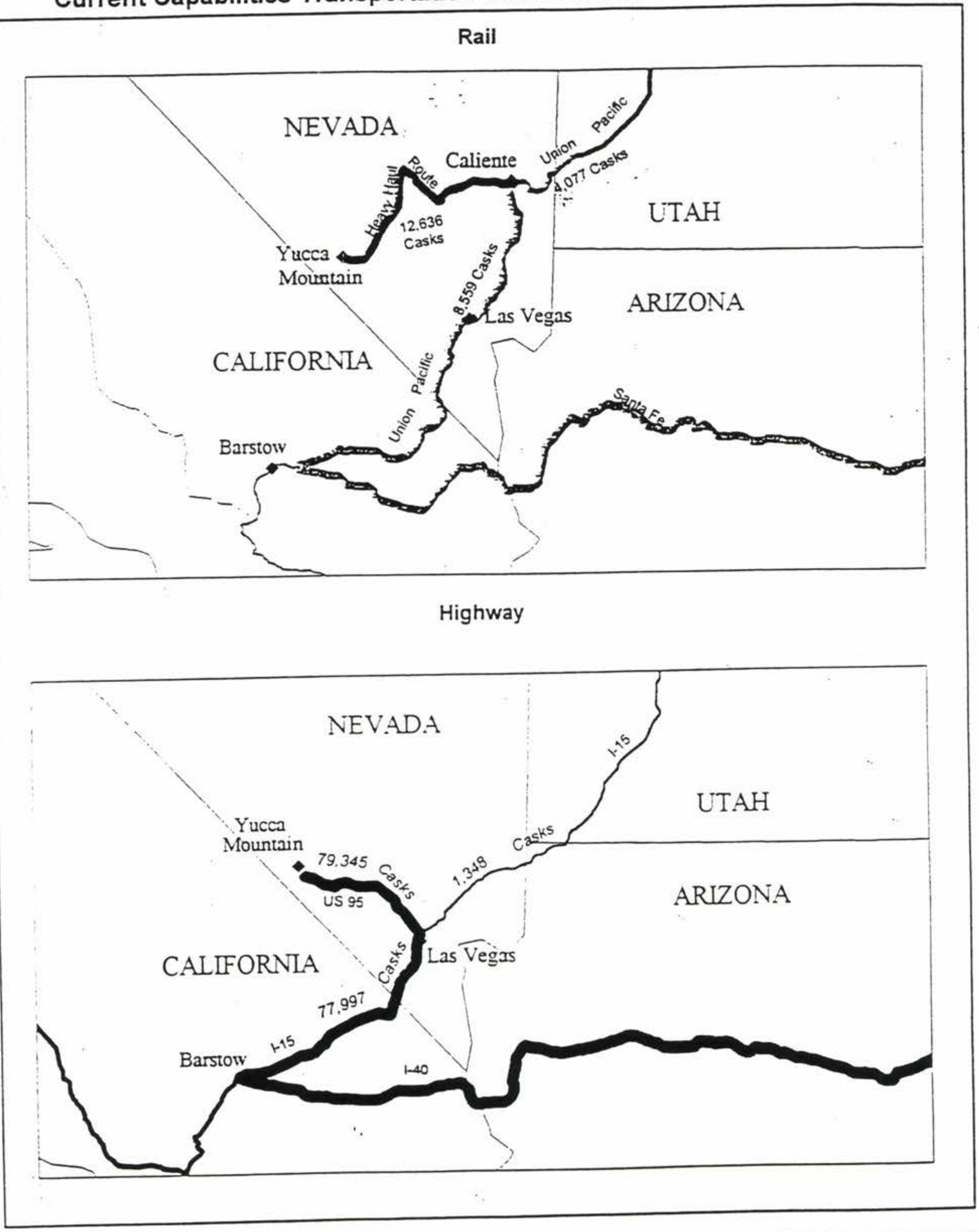


**Figure 18-2a. Life of Operations Rail and Highway Cask Shipments MPC Base Case Transportation Choices/Default Routing**

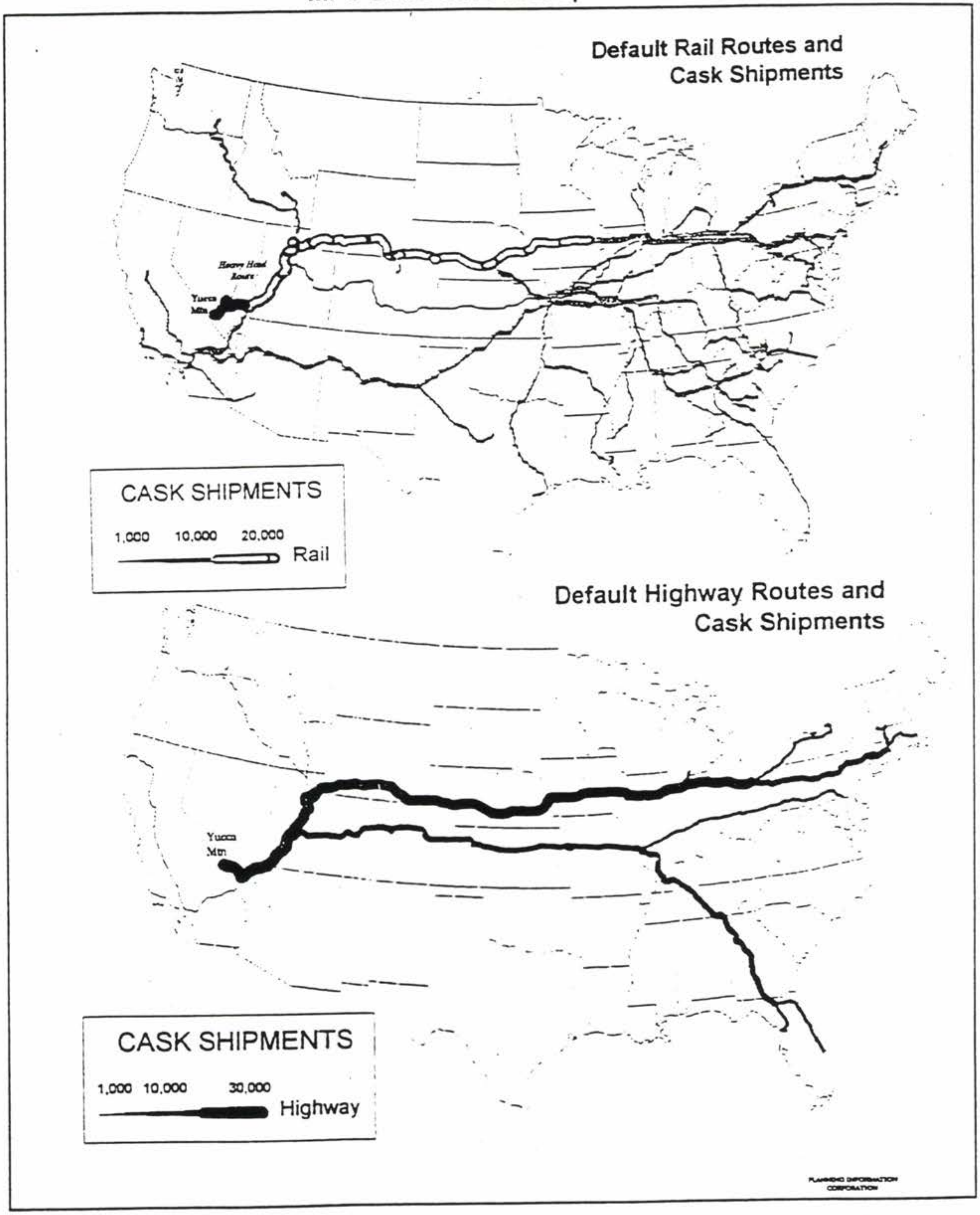


**Figure 18-2b. Life of Operations Rail and Highway Cask Shipments MPC Base Case Transportation Choices/Consolidated Southern Routing**

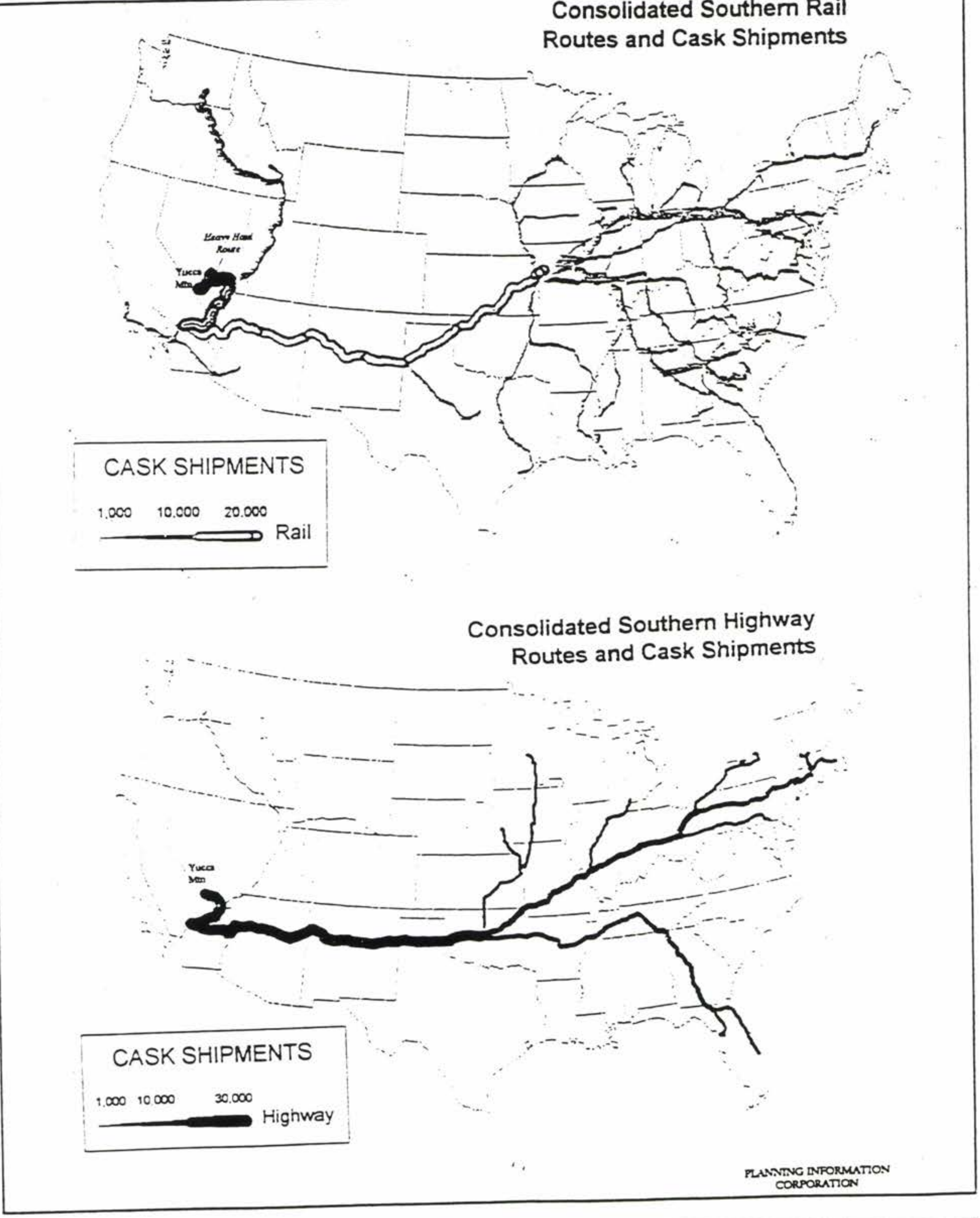


**Figure 18-2a (NV). Life of Operations Rail and Highway Cask Shipments in (NV) MPC Base Case Transportation Choices/Default Routing**

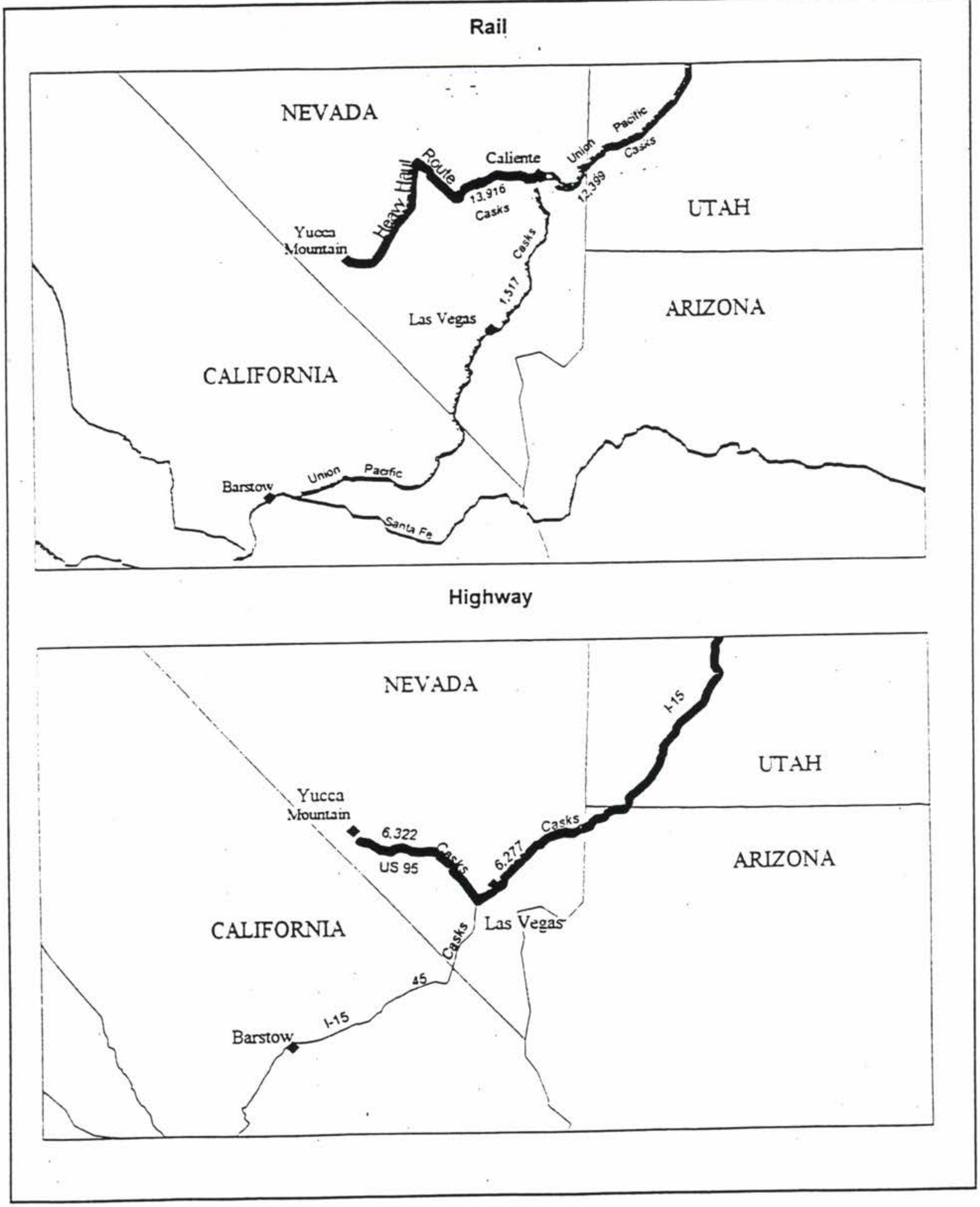


**Figure 18-2b (NV). Life of Operations Rail and Highway Cask Shipments in (NV) MPC Base Case Transportation Choices/Consolidated Southern Routing**

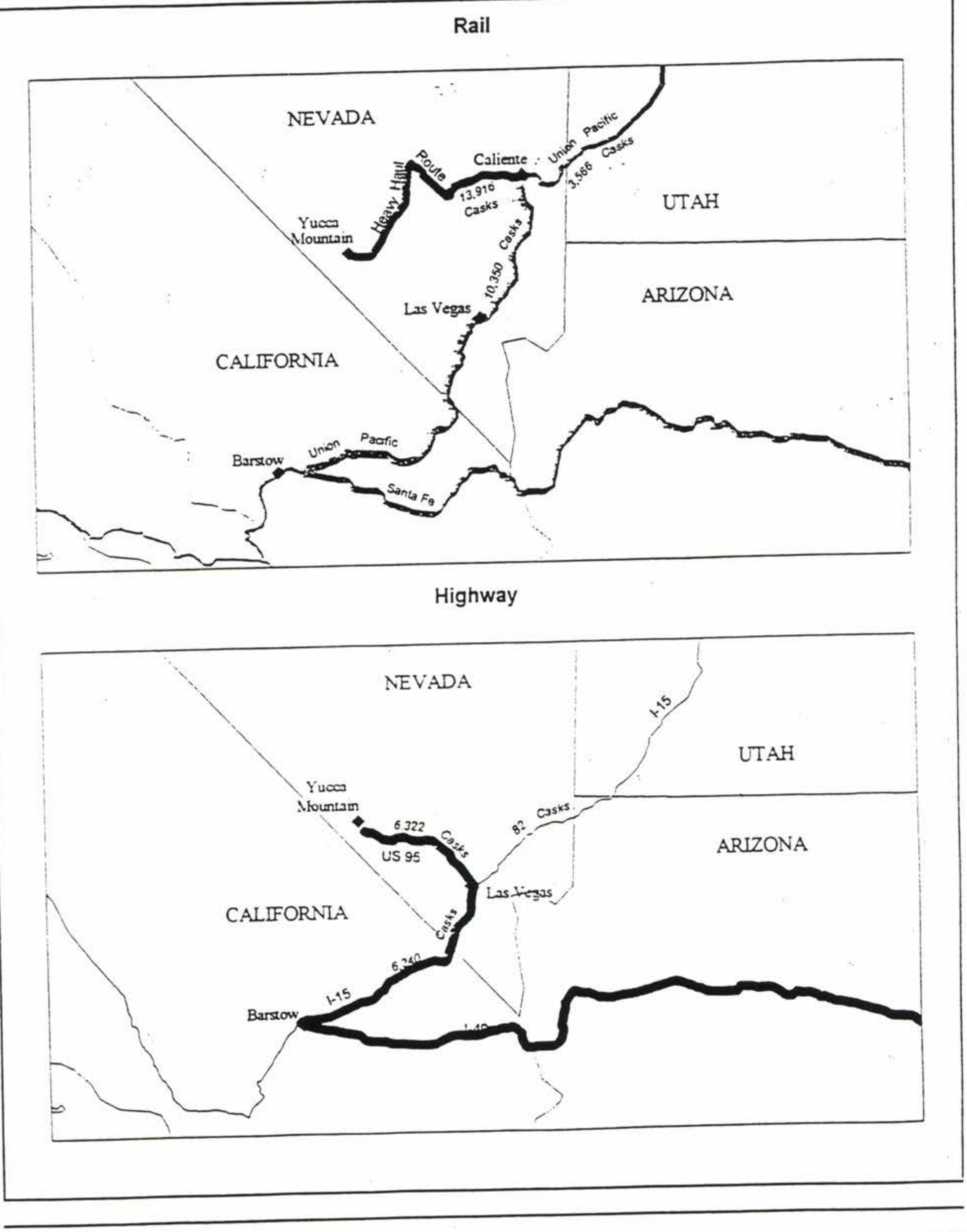
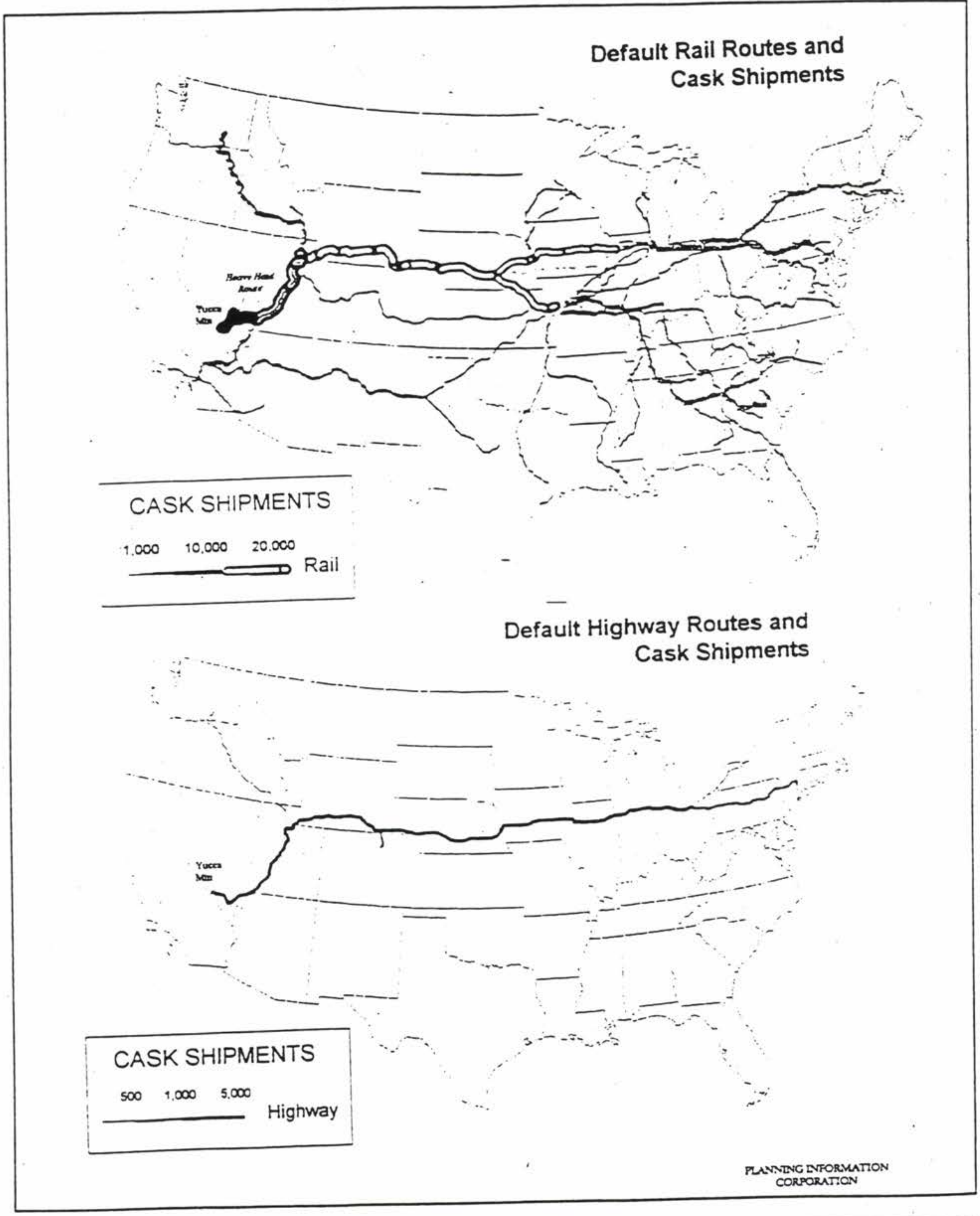


**Figure 18-3a. Life of Operations Rail and Highway Cask Shipments
Maximum Rail Transportation Choices/Default Routing**



## Figure 18-3b. Life of Operations Rail and Highway Cask Shipments Maximum Rail Transportation Choices/Consolidated Southern Routing

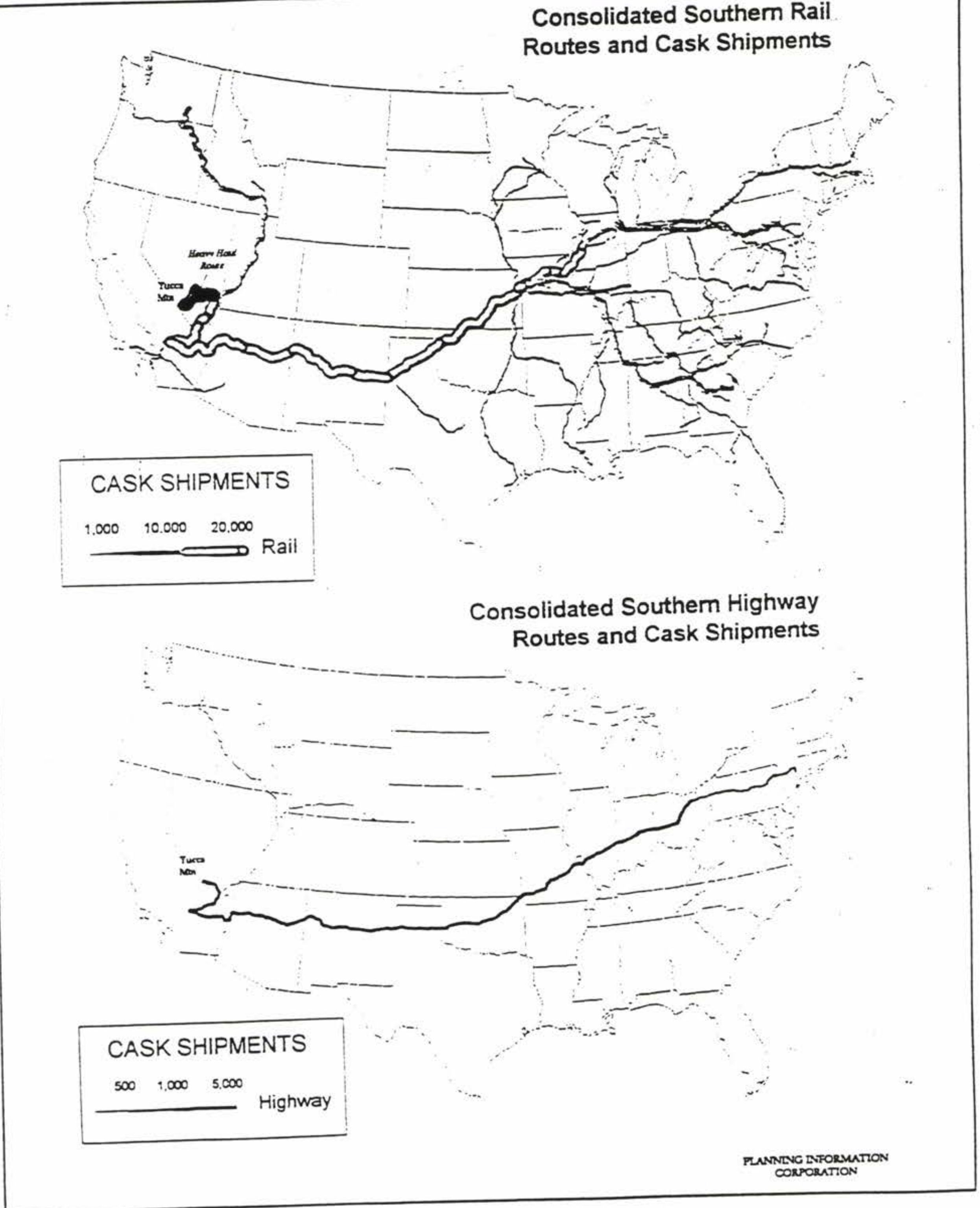
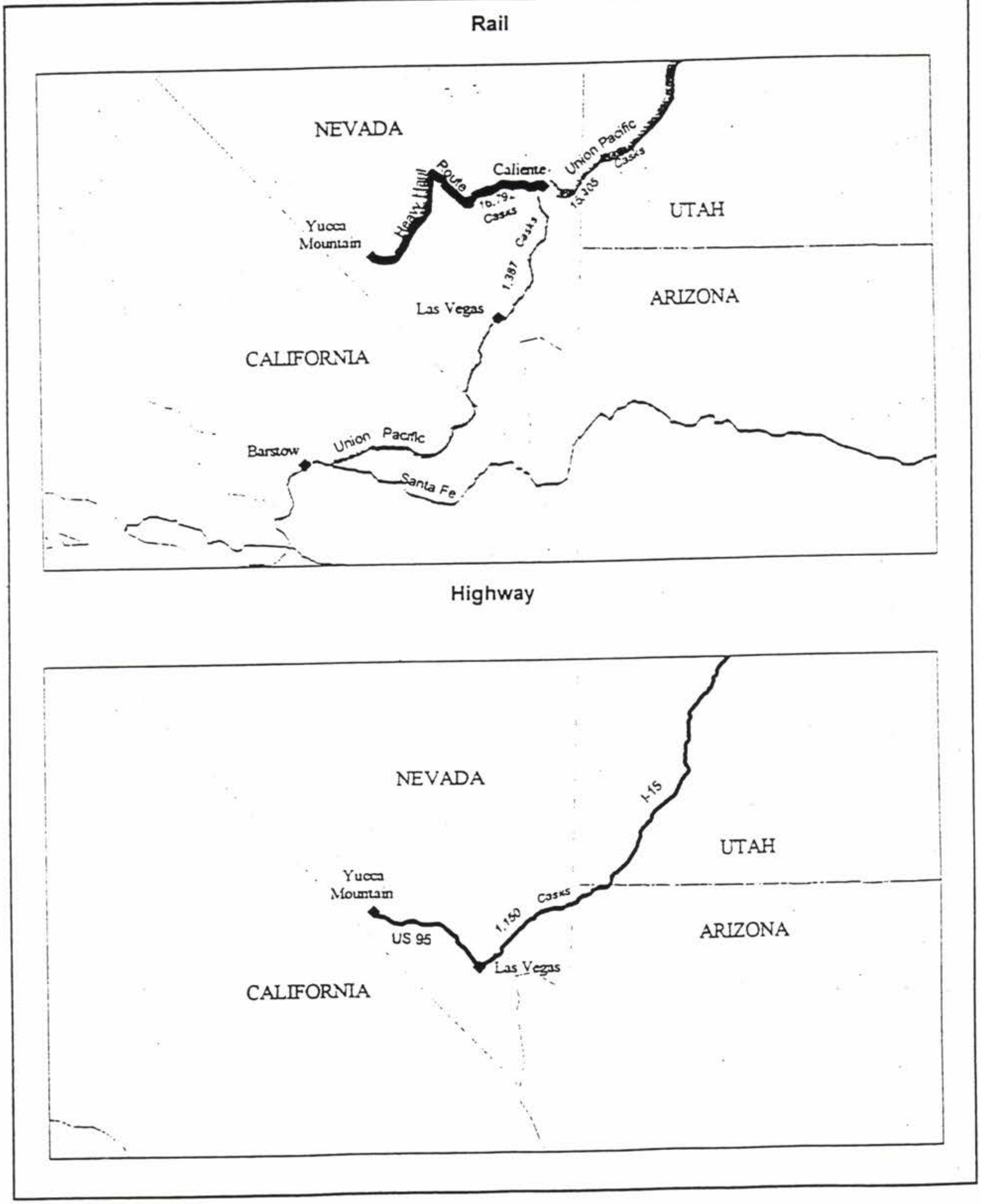
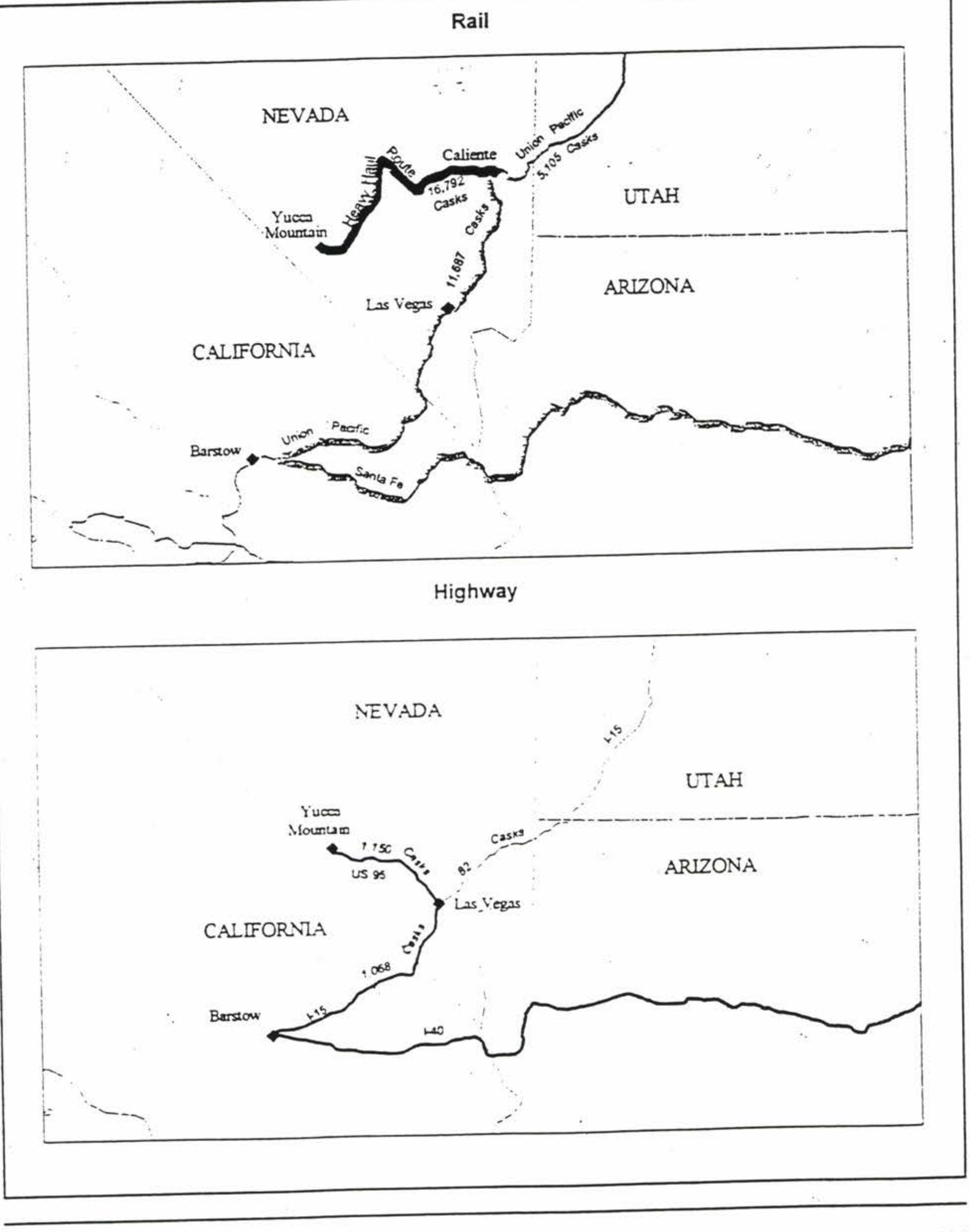


**Figure 18-3a (NV). Life of Operations Rail and Highway Cask Shipments in (NV) Maximum Rail Transportation Choices/Default Routing**



## Figure 18-3b (NV). Life of Operations Rail and Highway Cask Shipments in (NV) Maximum Rail Transportation Choices/Consolidated Southern Routing



- One pair of Nevada segments are the Union Pacific line and a segment of I-15 near the Las Vegas Strip. A second pair of Nevada segments are the Union Pacific rail line near the Utah-Nevada border, and a segment of I-15 as it crosses the Moapa Indian Reservation northeast of Las Vegas.

Under all three scenarios of transportation choices (as indicated in Table 18-1), consolidated southern routing would eliminate rail and highway shipments through Wyoming and Colorado, and substantially reduce rail and highway shipments from Utah into Nevada. At the same time, however, consolidated southern routing would substantially increase rail and highway shipments through New Mexico, through California east of Barstow and into Nevada along the Las Vegas Strip. Though not presented in table 17-1, consolidated southern routing has effects further east in the national routing system for SNF and HLW—e.g., in Chicago, Kansas City, and St. Louis. Other routing options would also have systems effects, increasing rail or highway shipments through certain communities, and reducing shipments through others.

**Table 18-1. Life of Operations Rail and Highway Cask Shipments Default and Consolidated Southern Routing 5 Rail and 5 Highway Cask Segments**

| | CURRENT CAPABILITIES | | | MPC BASE CASE | | | MAXIMUM RAIL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Default Routing | Consol So. Rtg | Change | Default Routing | Consol So. Rtg | Change | Default Routing | Consol So. Rtg | Change |
| Rail Segments: | | | | | | | | | |
| Wyo: UP | 8286 | 0 | -8286 | 9315 | 0 | -9315 | 11114 | 0 | -11114 |
| Col: SP | 362 | 0 | -362 | 79 | 0 | -79 | 214 | 0 | -214 |
| NV: UP @ UT line | 11485 | 4077 | -7408 | 12399 | 3556 | -8833 | 15405 | 5105 | -10300 |
| NM: SF | 770 | 9418 | 8648 | 808 | 10202 | 9394 | 631 | 11959 | 11328 |
| NV: UP @ LV Strip | 1151 | 8559 | 7408 | 1517 | 10360 | 8843 | 1387 | 11687 | 10300 |
| Hwy Segments: | | | | | | | | | |
| Wyo: I-80 | 31109 | 54 | -31055 | 14319 | 10 | -14309 | 1083 | 10 | -1073 |
| Col: I-70 | 39496 | 0 | -39496 | 9877 | 0 | -9877 | 0 | 0 | 0 |
| NV: I-15 @ Moapa | 72768 | 1348 | -71420 | 6277 | 82 | -6195 | 1150 | 82 | -1068 |
| NM: I-40 | 3630 | 74181 | 70551 | 0 | 24186 | 24186 | 0 | 1073 | 1073 |
| NV: I-15 @ Strip | 6577 | 77997 | 71420 | 45 | 6240 | 6195 | 0 | 1068 | 1068 |

# 19. THE NATIONAL SHIPMENT CAMPAIGN: ANNUAL SHIPMENTS

What are the annual impacts of the national shipment campaign for the nation's network of major railroads and highways? Do the impacts vary from year 1 to year 2, or 3, for example, or from year 1 to year 10 to year 20? These questions are relevant to the planning and management of a national shipment campaign. For example, DOE's May 28, 1996 notice regarding the acquisition of transportation services indicates (pg. 1) that "Initially, spent-fuel delivered to the Federal site would be canistered. . .but at some point* . . . the contractor may be required to handle uncanistered spent-fuel." What modifications in the oldest-fuel-first prioritization for spent fuel acceptance and pickup (see Section 5) would be necessary to limit pickup to canistered fuel in the first two acceptance years?

Another concern is the preparedness of state, local, and tribal officials to manage risk and respond to emergencies associated with SNF and HLW shipments. Compounding this concern is the current Congressional intent to accelerate the first shipments of SNF and HLW, perhaps as early as 1998 or 1999. Further complicating the planning process are the initiatives to privatize the transportation process, through a series of contracts with regional servicing agents (RSAs). Finally, many analysts share the belief that the number of shipments should be reduced by using higher-volume rail and truck containers that are yet to be developed or licensed, and by improvements to waste-handling infrastructure that could be expensive to complete.

The scenarios developed for this assessment reveal significant differences between the overall campaign and its initial shipment years. In the current capabilities scenario, for example, about 35 percent of the MTU would be shipped by truck, a percentage which increases to 66 percent in the initial three shipment years. In the MPC base case scenario of transportation choices, about 11 percent of total MTU would be shipped by truck, a percentage which increases to 27 percent in the initial three shipment years—even more if improvements in loading capacity and/or near-site infrastructure were not implemented with casks available for the startup of the shipment campaign.

Figures 18-1, 18-2 and 18-3 present origin sites and affected rail and highway routes (default routing) under the current capabilities scenario of transportation choices in years 1, 2, and 3 of the prospective shipment campaign. While it is possible that the special arrangements and improvements implied by the MPC base case and maximum rail scenarios could be implemented by year 1, it can also be argued that the current capabilities are likely to be operative in the initial years, regardless of the strategy for the overall shipment campaign.

Figures 18-4 and 18-5 present origin sites and affected rail and highway routes (default routing) in year 20 of the prospective shipment campaign—in this case comparing affected routes and cask shipments under the current capabilities and maximum rail scenarios of transportation choices.

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* RSA Phase C contract years 3-5 (see "Timing of RSA Phases": VU-Graph Presentations for July 9, 1996 Presolicitation Conference, ref 2).

### Year 1 Routes and Cask Shipments

Figure 19-1 shows the likely pattern of shipments comprising the 1,200 MTU first-year requirement of S. 1936, assuming the oldest-fuel-first priority acceptance ranking described above. The default routing is essentially unconstrained, as might be developed by an RSA or by DOE contract carriers. Shipments would be made from 8 sites with rail access and 20 sites with truck-only access:

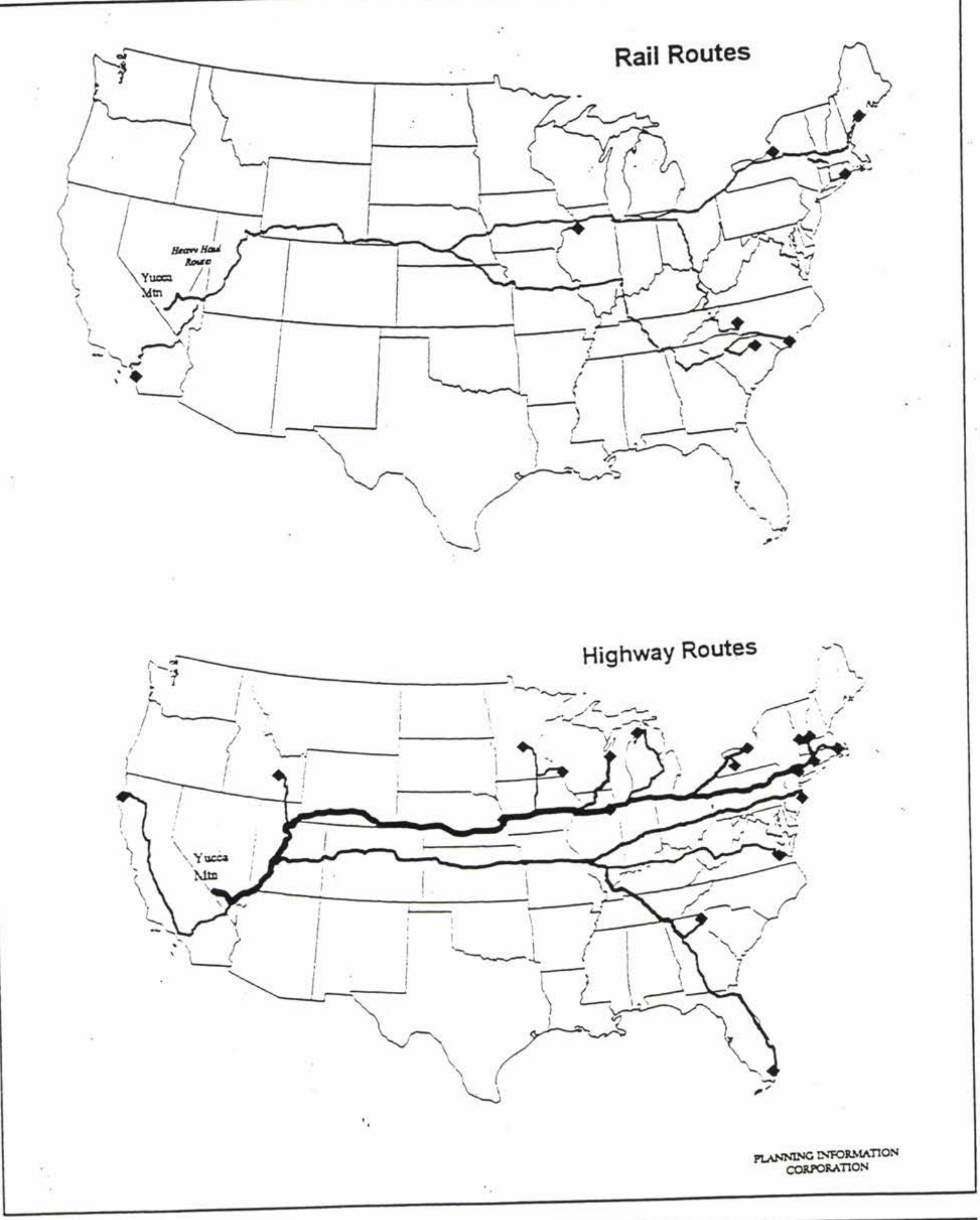
### Rail Shipments

| Origin | Casks |
|---|---|
| CA: San Onofre | 2 |
| CT: Millstone | 12 |
| IL: Quad Cities | 7 |
| NC: Brunswick | 14 |
| NC: McGuire | 2 |
| ME: Maine Yankee | 11 |
| NY: Nine Mile Point | 15 |
| SC: Robinson | 1 |
| TOTAL | 64 |

### Truck Shipments

| Origin | Casks |
|---|---|
| CA: Humboldt Bay | 87 |
| CT: Haddam Neck | 131 |
| FL: Turkey Point | 90 |
| ID: INEL | 6 |
| IL: Braidwood | 9 |
| IL: Dresden | 344 |
| IL: Morris | 755 |
| MA: Pilgrim | 10 |
| MA: Yankee Rowe | 73 |
| MI: Big Rock Point | 9 |
| MN: Monticello | 12 |
| NE: Ft. Calhoun | 25 |
| NJ: Oyster Creek | 246 |
| NY: Ginna | 118 |
| NY: Indian Point | 160 |
| NY: West Valley | 83 |
| SC: Oconee | 35 |
| VA: Surry | 44 |
| VT: Vermont Yankee | 189 |
| WI: LaCrosse | 28 |
| WI: Point Beach | 151 |
| TOTAL | 2,605 |

**Figure 19-1. Year 1 Cask Shipments by Route and Origin Current Capabilities Transportation Choices/Default Routing**



### Year 2 Routes and Cask Shipments

In the second year, the shipment schedule shows an increased number of shipment origin sites (13 railroad, 24 truck), as shown in Figure 19-2. The weight of SNF is the same as in year 2 (at least 1,200 MTU) and the number of casks is somewhat lower than year 1:

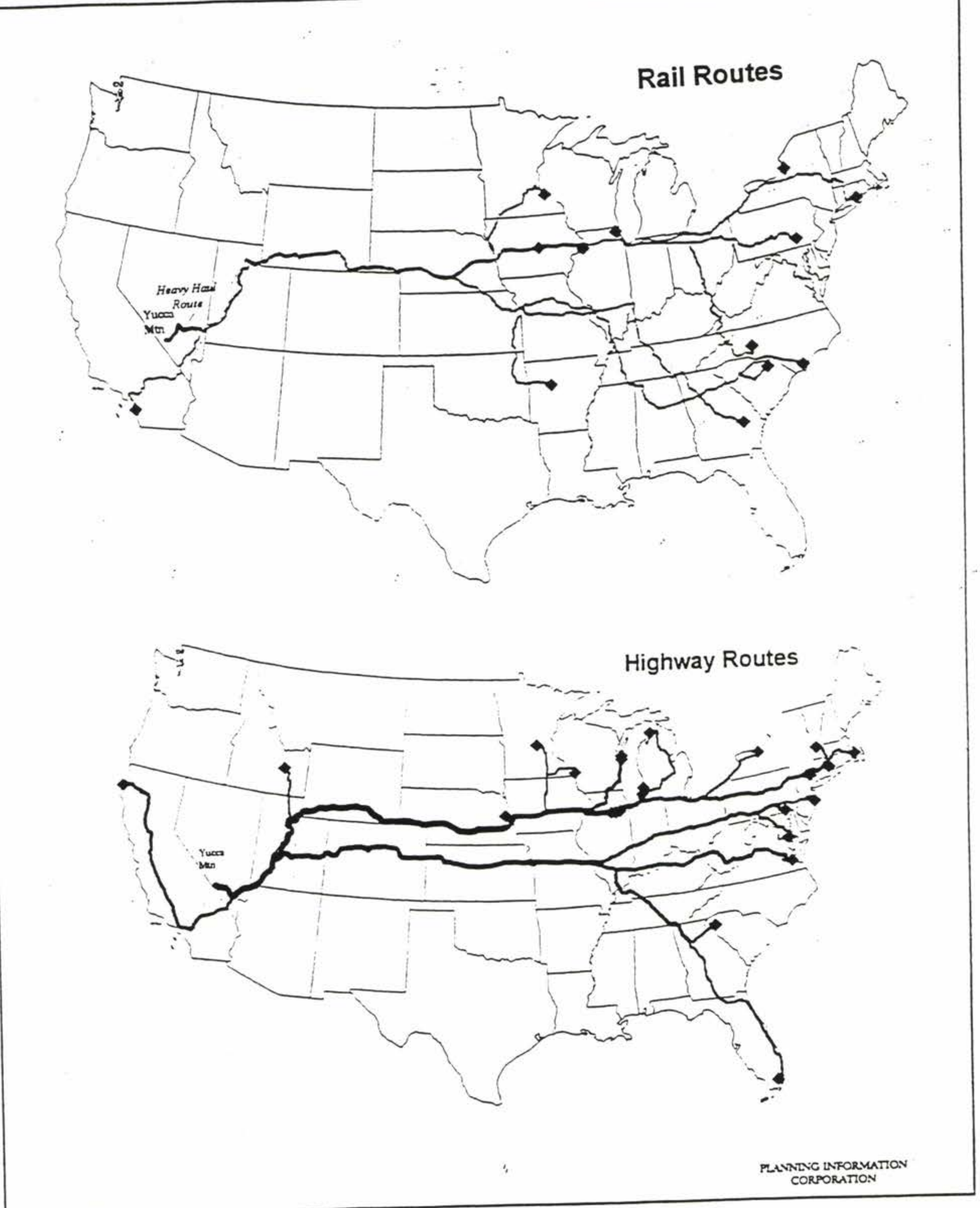
### Rail Shipments

| Origin | Casks |
|---|---|
| AR: Arkansas Nuclear | 5 |
| CA: San Onofre | 2 |
| CT: Millstone | 13 |
| GA: Hatch | 1 |
| IA: Duane Arnold | 8 |
| IL: Quad Cities | 21 |
| IL: Zion | 9 |
| MN: Prairie Island | 6 |
| NC: Brunswick | 10 |
| NC: McGuire | 9 |
| NY: Nine Mile Point | 18 |
| PA: Three Mile Island | 3 |
| SC: Robinson | 1 |
| TOTAL | 106 |

### Truck Shipments

| Origin | Casks |
|---|---|
| CA: Humboldt Bay | 109 |
| CT: Haddam Neck | 101 |
| FL: Turkey Point | 95 |
| ID: INEL | 17 |
| IL: Braidwood | 11 |
| IL: Dresden | 184 |
| IL: Morris | 235 |
| MA: Pilgrim | 66 |
| MA: Yankee Rowe | 40 |
| MD: Calvert Cliffs | 32 |
| MI: Big Rock Point | 11 |
| MI: Cook | 63 |
| MI: Palisades | 205 |
| MN: Monticello | 13 |
| NE: Ft. Calhoun | 36 |
| NJ: Oyster Creek | 28 |
| NY: Ginna | 37 |
| NY: Indian Point | 72 |
| PA: Peach Bottom | 187 |
| SC: Oconee | 26 |
| VA: Surry | 226 |
| WI: Kewaunee | 56 |
| WI: LaCrosse | 13 |
| WI: Point Beach | 119 |
| TOTAL | 1,982 |

**Figure 19-2. Year 2 Cask Shipments by Route and Origin**
**Current Capabilities Transportation Choices/Default Routing**



## Year 3 Routes and Cask Shipments

In year three, the volume of shipment increases from 1,200 to 2,000 MTU, increasing both the number of casks and the number of shipment sites (18 rail and 27 truck), as shown in Figure 19-3. However, we still assume the current capabilities scenario and unconstrained routing.

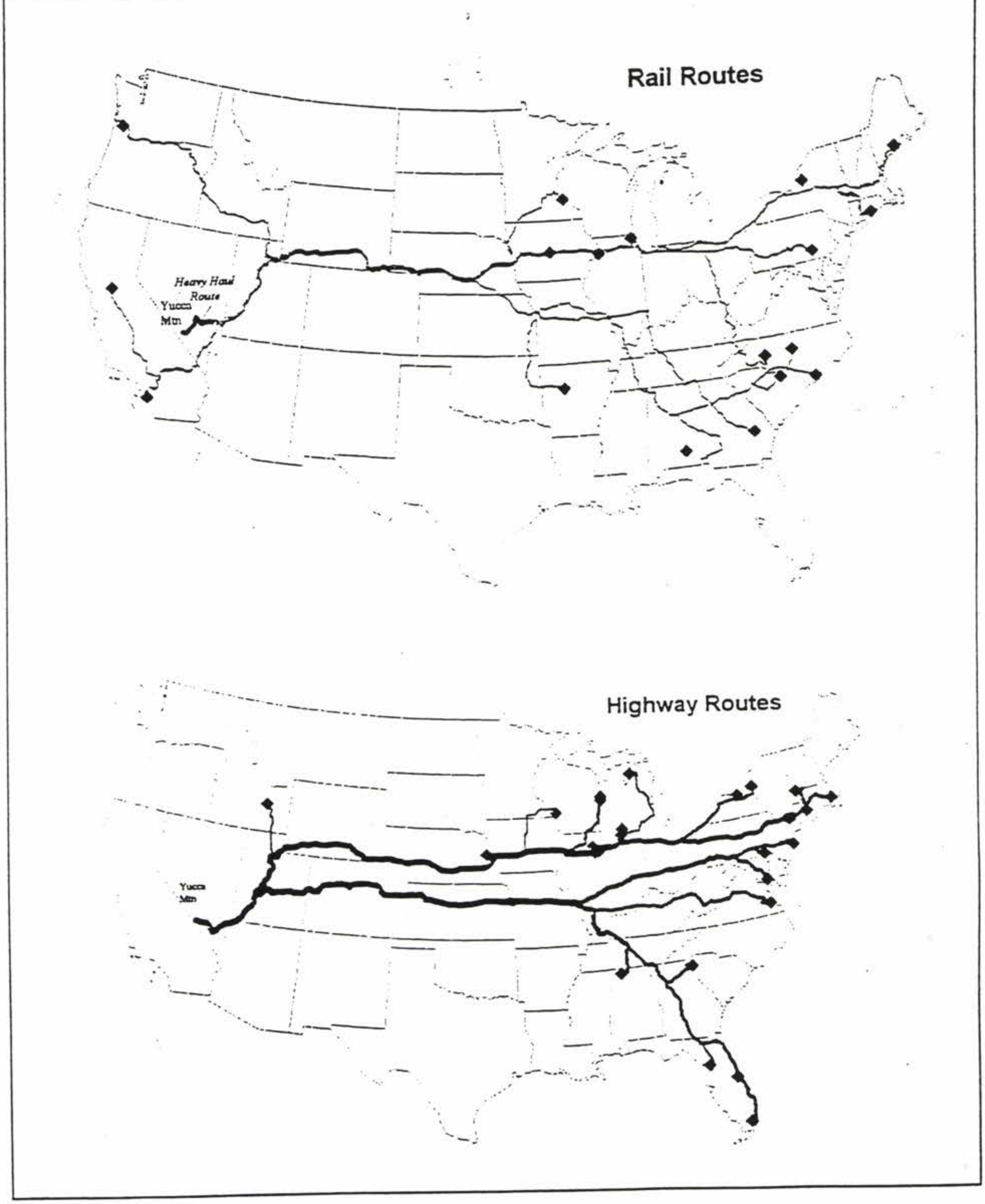
### Rail Shipments

| Origin | Casks |
|---|---|
| AL: Farley | 3 |
| AR: Arkansas Nuclear | 6 |
| CA: Rancho Seco | 7 |
| CA: San Onofre | 2 |
| CT: Millstone | 22 |
| GA: Hatch | 1 |
| IA: Duane Arnold | 6 |
| IL: Quad Cities | 27 |
| IL: Zion | 17 |
| ME: Maine Yankee | 10 |
| MN: Prairie Island | 6 |
| NC: Brunswick | 17 |
| NC: Harris | 6 |
| NC: McGuire | 16 |
| NY: Nine Mile Point | 8 |
| OR: Trojan | 1 |
| PA: Three Mile Island | 15 |
| SC: Robinson | 1 |
| TOTAL | 171 |

### Truck Shipments

| Origin | Casks |
|---|---|
| AL: Browns Ferry | 165 |
| CT: Haddam Neck | 100 |
| FL: Crystal River | 2 |
| FL: St. Lucie | 52 |
| FL: Turkey Point | 151 |
| ID: INEL | 31 |
| IL: Braidwood | 23 |
| IL: Dresden | 451 |
| IL: Morris | 68 |
| MA: Pilgrim | 214 |
| MA: Yankee Rowe | 76 |
| MD: Calvert Cliffs | 184 |
| MI: Big Rock Point | 23 |
| MI: Cook | 64 |
| MI: Palisades | 68 |
| NE: Ft. Calhoun | 96 |
| NJ: Oyster Creek | 148 |
| NY: FitzPatrick | 134 |
| NY: Ginna | 122 |
| NY: Indian Point | 124 |
| PA: Peach Bottom | 342 |
| SC: Oconee | 215 |
| VA: Surry | 165 |
| VT: Vermont Yankee | 109 |
| WI: Kewaunee | 41 |
| WI: LaCrosse | 16 |
| WI: Point Beach | 125 |
| TOTAL | 3,309 |

**Figure 19-3. Year 3 Cask Shipments by Route and Origin Current Capabilities Transportation Choices/Default Routing**



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### Year 20 Routes and Cask Shipments

After several years, it is possible that the utilities and RSAs (or DOE) would implement changes in containers and transportation infrastructure to improve the efficiency and cost-effectiveness of shipments. Figures 19-4 and 19-5 compare the current capabilities (CCP) and the maximum rail (MXR) scenarios in year 20 of the transportation program postulated in this analysis. Under the CCP scenario, rail shipments would be made from 37 sites and truck shipments from 27 sites; under the MXR scenario, 62 of 64 sites would be rail-capable. Modes are indicated as T1 and T2 for legal weight one- or two-assembly containers, or R75 and R125 for the small and large rail containers.

| Origin | CCP Scenario Mode | CCP Scenario Casks | MXR Scenario Mode | MXR Scenario Casks |
|---|---|---|---|---|
| AL: Browns Ferry | T2 | 112 | R125 | 6 |
| AL: Farley | R125 | 6 | R125 | 6 |
| AR: Arkansas Nuc. | R75 | 11 | R125 | 7 |
| AZ: Palo Verde | R125 | 10 | R125 | 10 |
| CA: Diablo Canyon | T1 | 213 | R125 | 11 |
| CA: San Onofre | R125 | 5 | R125 | 5 |
| CT: Haddam Neck | T1 | 41 | R75 | 4 |
| FL: Crystal River | T1 | 66 | R75 | 6 |
| FL: St. Lucie | T1 | 139 | R125 | 8 |
| FL: Turkey Point | T1 | 88 | R125 | 5 |
| GA: Hatch | R125 | 10 | R125 | 10 |
| GA: Vogtle | R75 | 14 | R75 | 14 |
| IA: Duane Arnold | R75 | 6 | R125 | 3 |
| IL: Braidwood | R75 | 15 | R125 | 9 |
| IL: Byron | R75 | 20 | R125 | 12 |
| IL: Dresden | T2 | 439 | R75 | 43 |
| IL: La Salle | R75 | 19 | R125 | 10 |
| IL: Quad Cities | R75 | 15 | R75 | 15 |
| IL: Zion | R75 | 6 | R125 | 4 |
| KS: Wolf Creek | R125 | 4 | R125 | 4 |
| LA: River Bend | R125 | 5 | R125 | 5 |
| LA: Waterford | R125 | 5 | R125 | 5 |
| MA: Pilgrim | T2 | 74 | R75 | 8 |
| MD: Calvert Cliffs | T1 | 81 | R125 | 4 |
| ME: Maine Yankee | R125 | 3 | R125 | 3 |
| MI: Cook | T1 | 148 | R125 | 8 |
| MI: Fermi | T2 | 97 | R125 | 5 |
| MI: Palisades | T1 | 56 | R125 | 3 |
| MN: Monticello | T2 | 68 | R75 | 7 |
| MN: Prairie Island | R125 | 3 | R125 | 3 |
| MS: Grand Gulf | T2 | 140 | R125 | 7 |

| Origin | CCP Scenario Mode | CCP Scenario Casks | MXR Scenario Mode | MXR Scenario Casks |
|---|---|---|---|---|
| NC: Brunswick | R125 | 15 | R125 | 15 |
| NC: Harris | R75 | 4 | R125 | 3 |
| NC: McGuire | R75 | 20 | R125 | 7 |
| NE: Ft. Calhoun | T1 | 43 | R75 | 4 |
| NH: Seabrook | R125 | 4 | R125 | 4 |
| NJ: Hope Creek | T2 | 15 | R125 | 7 |
| NJ: Oyster Creek | T2 | 89 | R125 | 5 |
| NJ: Salem | T1 | 137 | R125 | 8 |
| NY: FitzPatrick | T2 | 100 | R125 | 5 |
| NY: Ginna | T1 | 38 | T4 | 10 |
| NY: Indian Point | T1 | 139 | T4 | 18 |
| OH: Davis-Besse | R125 | 3 | R125 | 3 |
| OH: Perry | R125 | 7 | R125 | 7 |
| PA: Beaver Valley | R75 | 11 | R125 | 7 |
| PA: Peach Bottom | T2 | 119 | R125 | 6 |
| PA: Susquehanna | R125 | 13 | R125 | 13 |
| PA: Three Mile Isld | R75 | 6 | R125 | 4 |
| SC: Catawba | R125 | 9 | R125 | 9 |
| SC: Oconee | T1 | 223 | R125 | 12 |
| SC: Robinson | R75 | 4 | R75 | 4 |
| SC: Savannah River | R | 18 | R | 18 |
| SC: Summer | R125 | 4 | R125 | 4 |
| TN: Sequoyah | R75 | 7 | R125 | 5 |
| TN: Watts Bar | R125 | 6 | R125 | 6 |
| TX: Comanche Peak | R125 | 13 | R125 | 13 |
| TX: South Texas | R125 | 7 | R125 | 7 |
| VA: North Anna | R75 | 6 | R125 | 3 |
| VA: Surry | T1 | 107 | R125 | 6 |
| VT: Vermont Yankee | T2 | 64 | R75 | 7 |
| WA: Hanford | R | 143 | R | 143 |
| WA: WNP | R125 | 4 | R125 | 4 |
| WI: Kewaunee | T1 | 37 | R125 | 2 |
| WI: Point Beach | T1 | 52 | R125 | 4 |
| TOTALS | | | | |
| Truck | | 2,925 | | 28 |
| Rail | | 461 | | 595 |

**Figure 19-4. Year 20 Cask Shipments by Route and Origin Current Capabilities Transportation Choices/Default Routing**

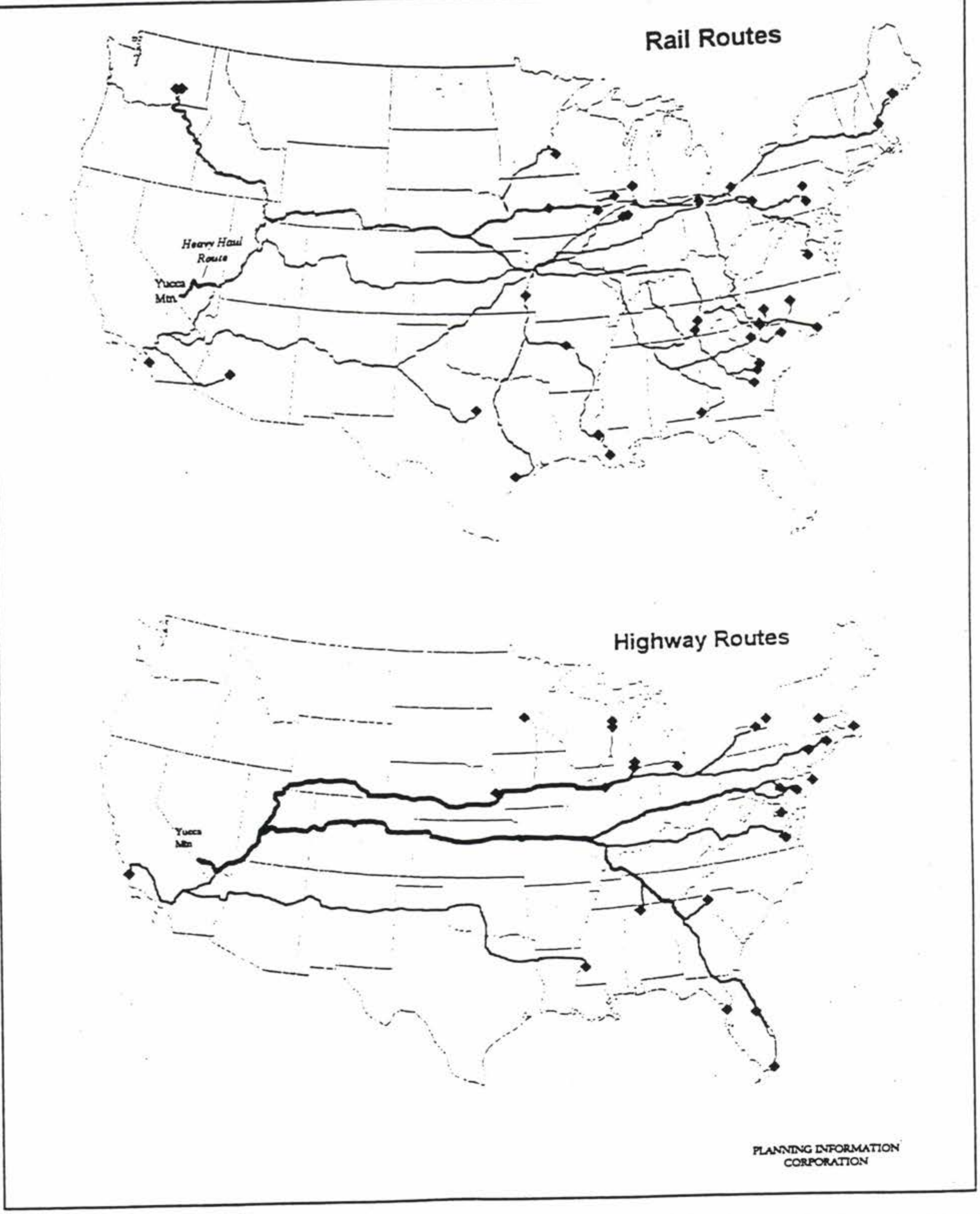
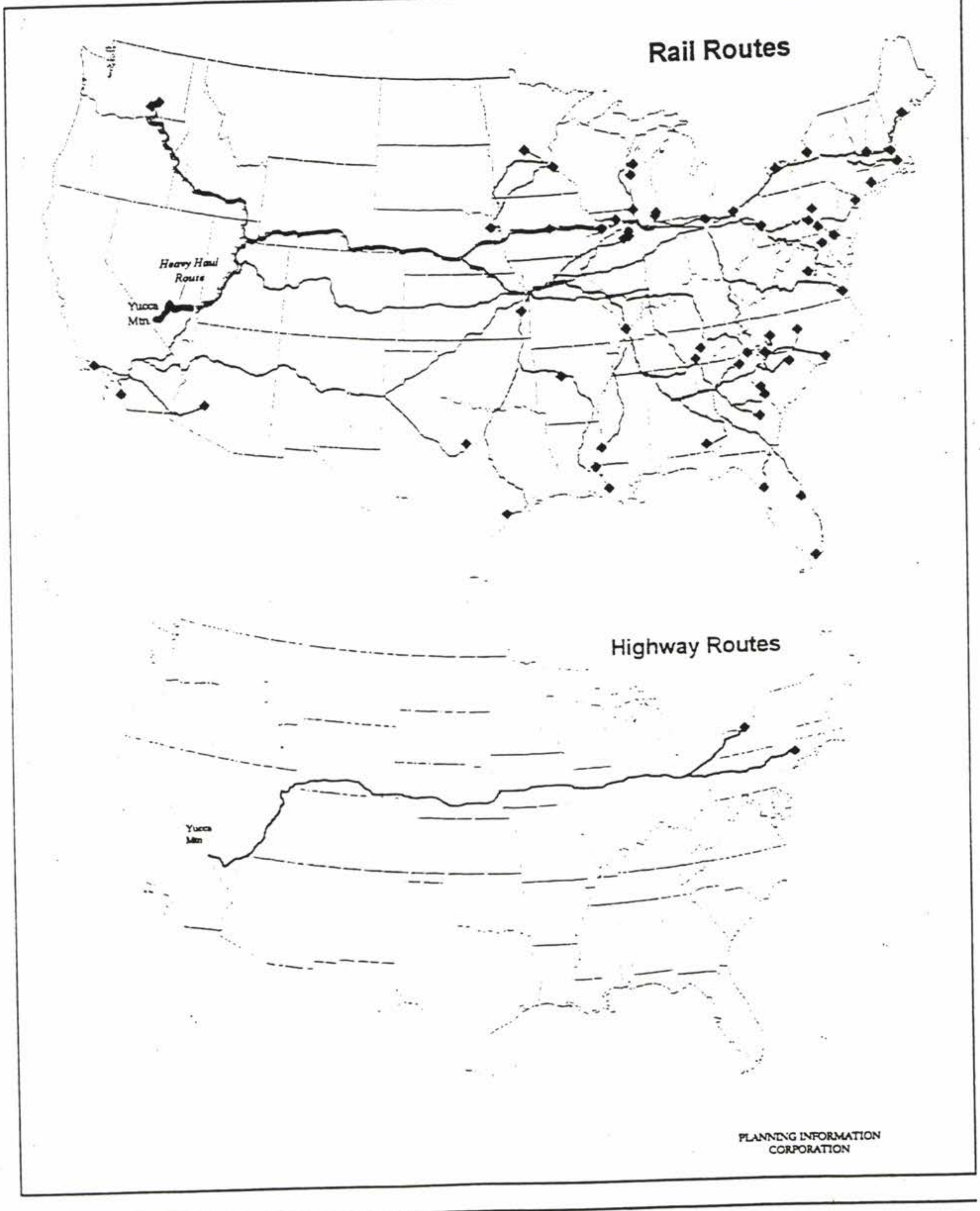


**Figure 19-5. Year 20 Cask Shipments by Route and Origin Maximum Rail Transportation Choices/Default Routing**



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# 20. TRANSPORTATION OPERATIONS REQUIREMENTS

Planning and managing a national shipment campaign requires reliable information on total metric tons shipped, total cask shipments, affected rail and highway route mileage, and total cask shipment miles. These variables yield useful indexes for comparing scenarios for the national shipment campaign: e.g., cask shipments per MTU shipped, cask shipments per affected route mile. Presented on an overall basis in this section, these measures may in other contexts be reviewed on a year-by-year or sub-region basis.

## MTU Shipped

Given the inventory assumptions discussed in Section 2 above, about 86,600 MTU of SNF would be shipped to a centralized storage facility in Nevada. Given the acceptance rate assumptions discussed in Section 3, about 4,440 MTU would be shipped in the first three acceptance years. Given current capabilities transportation choices discussed in Section 11, about 36 percent of total MTU would be shipped via public highways, about 66 percent in the first three acceptance years. (This assumes, of course, that the centralized storage facility would be capable of receiving legal-weight truck shipments and reloading its bare fuel into storage canisters and casks.) Given the MPC base case scenario of transportation choices, about 11 percent of total MTU would be shipped by public highways, about 27 percent in the first three acceptance years. (This assumes the implementation of policies required to persuade utilities and/or regional servicing agents to upgrade loading facilities and near-site infrastructure.)

## Cask Shipments

Given the cask options discussed in Section 6 and the "current capabilities" transportation choices discussed in section 11, about 92,000 cask shipments would be made over the 30-year shipment campaign, of which 86 percent would be on public highways by legal-weight truck. If the high-capacity GA-4/9 legal-weight truck were available and used throughout the shipment campaign, total cask shipments would be reduced to about 31,400, including about 71 percent by legal-weight truck.

During the first three acceptance years, about 8,200 casks shipments should be expected under the current capabilities scenario, almost all (96 percent) by legal-weight truck. Again, the high-capacity GA-4/9 cask, if available and used during the initial years, would reduce cask shipments substantially, from 8,200 to about 2,200. Even so, about 85 percent of the casks shipments would be by legal-weight truck on public highways. The MPC base case scenario of transportation choices, if implemented, would reduce total cask shipments from 92,000 to about 40,000 and the portion involving legal-weight truck shipments on public highways would be reduced from 86 percent to 65 percent. If, in addition, the high-capacity GA-4/9 cask were available and used, total casks shipments could be further reduced to 20,200, and the LWT portion of total cask shipment could be reduced to 31 percent.

**Route Miles Affected**

Given the transportation choices discussed in Section 11, and the default routing criteria discussed in Section 14, about 18,800 miles of railroad* and about 13,700 miles of public highways would receive shipments of SNF and/or HLW during the national shipment campaign. The MPC base case scenario of transportation choices increases the mileage of railroads impacted, from 18,800 to 21,200, and reduces the mileage of public highways impacted—from 13,700 to about 10,200. Total route mileage, however, is similar in the two cases—about 32,500 rail and highway route miles in the current capabilities scenario versus about 31,400 route miles in the MPC base case.

Route mileage impacted is the basic measure by which DOE proposes to allocate the variable amounts to be distributed to states for training local emergency responders and/or rail and highway inspectors.[25] In addition to a base amount provided to any affected state for planning and coordination, the variable amount would be allocated to response areas of an 80-mile radius, with no double counting of rail or highway routes within a response area (pg. 14). Wyoming, for example, with over 400 I-80 route miles and another 400 miles of UP railroad impacted under default routing, might receive variable funds for 2½ response areas. Nevada, where cask shipments could impact I-15, US-95, and the UP railroad, might receive variable funds for two response areas. The route mileage measure does not reflect the number of casks shipments along particular segments, or the amount of radioactive material in those shipments.

**Cask Shipment Miles**

Cask shipment miles, the product of cask shipments and distance from each origin site, is a measure which adjusts route mileage for the number of cask shipments expected along each segment. Given the cask options discussed in Section 6 and the current capabilities scenario of transportation choices discussed in Section 11, the national campaign would involve about 76 million cask shipment miles, 5 million in the first three acceptance years. Of these, 82 percent would be legal-weight truck shipments on public highways, 95 percent in the first three acceptance years.

The high-capacity GA-4/9 cask, if available and used, would substantially reduce total cask shipment miles, from 76 to 29 million, and from 5.1 million to 1.4 million over the first three acceptance years. The legal-weight truck portion of total cask shipment miles would be reduced (from 82 to 51 percent, from 95 to 82 percent in the first three acceptance years), but would still comprise a substantial majority of total cask shipment miles.

The MPC base case scenario of transportation choices, if implemented, would further reduce cask shipment miles, from 29 to 21 million and from 1.4 million to 1.0 million over the first three acceptance years. In the process, the legal-weight truck portion of total cask shipment miles would be reduced from 51 percent to about 27 percent, and from 82 percent to 66 percent in the first three acceptance years.

Identified by route segment, information on cask shipment miles would assist state and local officials to estimate route-specific accident and incident rates, allocate shipment monitoring and escorting efforts, estimate radiation exposure for corridor populations, etc.

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* Excluding the 162-mile heavy-haul route from Caliente to Yucca Mountain.

## Cask Shipment Miles Per MTU Shipped

Cask shipment miles per MTU shipped is a measure of the amount of radioactive material in shipments expected along particular routes, or along all affected routes. It is one measure of the efficiency of the overall shipment campaign, or of its effects in particular corridor segments.

Given the current capabilities scenario of transportation choices, the average cask shipment mileage per MTU shipped is about 2,400 miles, about 4,300 over the first three acceptance years. On average, each MTU shipped by legal-weight truck requires 5,900 cask shipment miles, compared with about 430 cask shipment miles when shipped by rail.

The high-capacity GA-4/9 cask, if available and used, would substantially reduce cask shipment miles per MTU shipped, from 2,400 to about 820. The reduction reflects the reduction in cask shipment miles required to ship an MTU on public highways by legal-weight truck.

The MPC base case scenario of transportation choices, if implemented, would also effect a substantial reduction in cask shipment miles per MTU shipped. This reduction reflects the mix of rail and truck shipment in the MPC base case scenario. Cask shipment miles per MTU shipped by legal-weight truck is actually higher in the MPC base case than in the current capabilities scenario. Sites which are more difficult to upgrade for rail shipment are among those most distant from the Yucca Mountain destination.

## Cask Shipments Per Route Mile Affected

How many cask shipments are expected over each route mile affected by the national shipment campaign? How many cask shipments are expected over particular route segments?

Given the current capabilities scenario of transportation choices (Section 11) and default routing criteria (Section 13) each affected rail route mile should expect about 1,500 rail cask shipments over the 30-year shipment campaign, and each affected highway route mile should expect about 13,400 LWT cask shipments.

The high-capacity GA-4/9 legal-weight truck cask, if available and used, would reduce cask shipments along each affected highway route mile from 13,400 to about 3,200.

The MPC base case scenario of transportation choices would reduce cask shipments along each affected highway route mile from about 13,400 to about 6,500, and shipments along each affected rail route mile (more rail route mileage is affected in the MPC base case) from 1,500 to about 1,460 rail casks.

## Table 20-1. MTU Shipped, Cask Shipments, Route Miles Affected Cask Shipment Miles Life of Operations and Shipment Years 1 through 3 . . . Default Routing

| | LIFE OF OPERATIONS (YR 1-31)...... | | | | | SHIPMENT YEARS 1-3...... | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RAIL | HWY:T1/2 | TOT:T1/2 | HWY:T4/9 | TOT:T4/9 | RAIL | HWY:T1/2 | TOT:T1/2 | HWY:T4/9 | TOT:T4/9 |
| MTU SHIPPED: | | | | | | | | | | |
| Current Capabilities | 55593 | 31045 | 86638 | 31045 | 86638 | 1495 | 2944 | 4439 | 2944 | 4439 |
| MPC Base Case | 76844 | 9855 | 86699 | 9855 | 86699 | 3240 | 1200 | 4440 | 1200 | 4440 |
| Maximum Rail | 84704 | 1995 | 86699 | 1995 | 86699 | 4185 | 255 | 4440 | 255 | 4440 |
| CASK SHIPMENTS: | | | | | | | | | | |
| Current Capabilities | 12636 | 79345 | 91981 | 31370 | 44006 | 327 | 7856 | 8183 | 1855 | 2182 |
| MPC Base Case | 13916 | 26093 | 40009 | 6322 | 20238 | 574 | 3352 | 3926 | 791 | 1365 |
| Maximum Rail | 16792 | 4722 | 21514 | 1150 | 17942 | 781 | 692 | 1473 | 181 | 962 |
| ROUTE MILES AFFECTED: | | | | | | | | | | |
| Current Capabilities | 18805 | 13695 | 32500 | 13695 | 32500 | 18805 | 13695 | 32500 | 13695 | 32500 |
| MPC Base Case | 21210 | 10224 | 31434 | 10224 | 31434 | 21210 | 10224 | 31434 | 10224 | 31434 |
| Maximum Rail | 23507 | 4178 | 27685 | 4178 | 27685 | 23507 | 4178 | 27685 | 4178 | 27685 |
| CASK SHIPMENT MILES:MIL | | | | | | | | | | |
| Current Capabilities | 14.0 | 62.3 | 76.3 | 14.7 | 28.7 | 0.8 | 18.2 | 19.1 | 4.3 | 5.1 |
| MPC Base Case | 15.3 | 24.1 | 39.4 | 5.7 | 21.0 | 1.4 | 8.2 | 9.6 | 1.9 | 3.3 |
| Maximum Rail | 16.8 | 4.0 | 20.8 | 1.0 | 17.8 | 1.9 | 1.7 | 3.6 | 0.4 | 2.4 |
| CASK SHIP MI PER MTU: | | | | | | | | | | |
| Current Capabilities | 425 | 5892 | 2384 | 1391 | 823 | 2491 | 2322 | 2328 | 2322 | 2347 |
| MPC Base Case | 345 | 6749 | 1073 | 1593 | 539 | 2442 | 2458 | 2455 | 2458 | 2451 |
| Maximum Rail | 362 | 5790 | 487 | 1472 | 439 | 2471 | 2476 | 2473 | 2416 | 2461 |
| CASK SHIP PER RT-MILE: | | | | | | | | | | |
| Current Capabilities | 1496 | 13356 | 6493 | 3154 | 2194 | 43 | 1332 | 586 | 314 | 153 |
| MPC Base Case | 1463 | 6505 | 3103 | 1536 | 1487 | 75 | 438 | 513 | 103 | 178 |
| Maximum Rail | 1494 | 2764 | 1686 | 703 | 1375 | 103 | 91 | 194 | 23 | 126 |

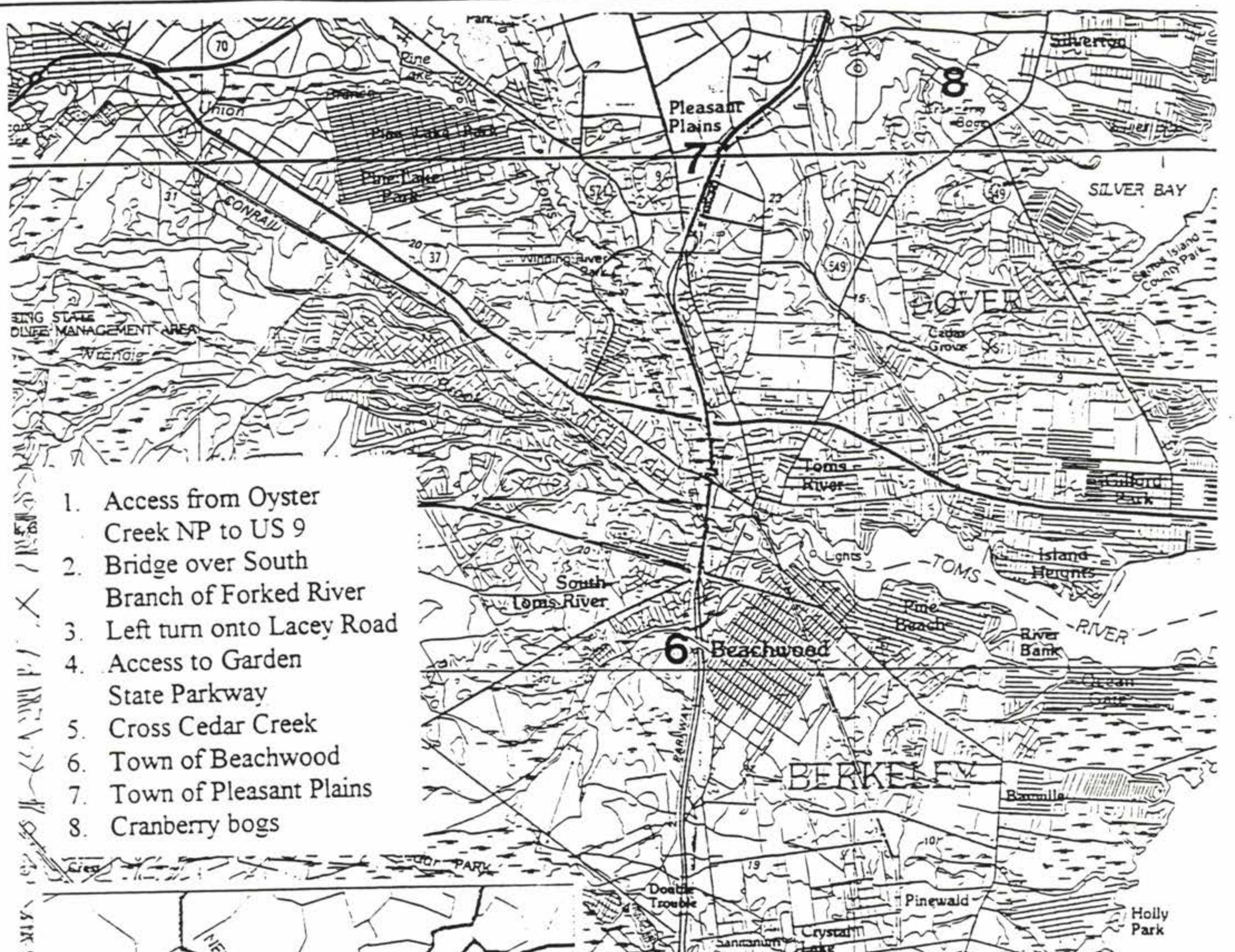
# 21. ROUTE FEATURES

The routing and cask shipment results presented in Sections 16 through 20 are in a sense only the first part of the information base required in planning and managing a national campaign for shipment of spent fuel and high-level waste. The second part is information regarding key features on or along the routes identified. The "key features" may include:

- Features of the route itself—e.g., bridges, intersections, grades, road geometry.
- Route conditions—e.g., pavement and bridge conditions, average daily and peak traffic flows, traffic service levels, accident rates.
- Route segments particularly affected by seasonal traffic, special event traffic, scheduled construction projects, or seasonal weather conditions.
- Facilities along routes which may require consideration in transportation options—e.g., schools, hospitals, sports stadiums, weighing stations, rest areas.
- Administrative boundaries—e.g., state, county, and city boundaries, state patrol and highway maintenance zones.
- Socioeconomic conditions—e.g., resident population, per capita income, workplace employment.
- Route-segment specific transportation management policies—e.g., state-designated routes, rush hour avoidance zones, designated rest or staging areas, safe havens.

Much of the relevant route-specific information must be assembled from various state and local sources. Other elements may be generated in process, as shippers coordinate with federal, state and local agencies in planning and managing a national shipment campaign. A geographically-referenced information base could help organize information on a complex and evolving array of topics and alternatives in origin and corridor communities, as well as provide a record of segment-specific policies and agreements among relevant stakeholders. The following figure[26] suggests how geographically-referenced information regarding route features might be developed, maintained and shared (in hard-copy or electronic form) among stakeholders in a national shipment campaign.

**Figure 21-1. Oyster Creek Highway Route Features**



# APPENDIX A: TRANSPORTATION CHOICE SCENARIOS: DOE ASSUMPTIONS

While DOE has not estimated annual shipments by route segment, several DOE studies consider transportation choices on a site-by-site basis: a 1996 "preliminary transportation strategy study for a potential Nevada repository",[21] and a 1993 evaluation of the use of MPCs in DOE's high-level waste management system.[22] This appendix reviews the transportation choice assumptions in the two DOE studies, comparing them with those in the scenarios developed for this report.

### Transportation Strategy Study 2

This study,[21] prepared as a basis for evaluating transportation options to a potential repository in Nevada, includes in Table F3 an estimate of the number of casks and MTU shipped from each commercial site and the four defense sites over the life of the program. The estimates are not annualized or keyed to proposed acceptance schedules or prioritization policies. Also, while the number of cask shipments is presented, the type of casks shipped is not.

To provide a basis for comparison, we have estimated the types of casks implied by Table F3 of DOE's Transportation Strategy Study 2 (see Table A-2): Data on the number of assemblies and MTU at each reactor was assembled (Ref #13, Table B6), aggregated for shipment sites, and used to calculate the average MTU per assembly at each site. The number of assemblies implied by the MTU in Table F3 was estimated by dividing MTU by the average MTU per assembly. The implied assemblies per cask was estimated by dividing assemblies by the number of casks identified in Table F3. The type of casks implied by Table F3 was identified by comparing estimated assemblies per cask with the capacity (in PWR or BWR assemblies) of small and large MPCs.

DOE's Transportation Strategy Study 2 implies that 11 sites which ship by truck in Nevada's MPC Base Case would instead ship by rail: Sites in columns 1 and 2 below would ship by small MPC, while those in column 3 would ship by large MPC.

| | | |
|---|---|---|
| Big Rock | LaCrosse | Palisades |
| Crystal River | Pilgrim | Peachbottom |
| Fort Calhoun | Vermont Yankee | St. Lucie |
| Humboldt Bay | Yankee Rowe | |

Also, DOE's Transportation Strategy 2 implies that Three Mile Island would ship by large MPC, rather than by small MPC, as assumed in Nevada's MPC base case.

The transportation choices implied by DOE's study are, with the exception of a single site (Haddam Neck, assumed to ship by truck in the DOE study), identical to the "maximum rail scenario" discussed in Section 11 above, and could be implemented only through a set of incentives such as those discussed in the maximum rail scenario. Compared to Nevada's MPC base case, the transportation choices implied by DOE's study would significantly reduce highway impacts and total cask shipments, in the process increasing reliance on rail shipment. However, the necessary investments to improve cask loading capabilities and near-site infrastructure could be greater than those required under the MPC base case scenario of transportation choices, and substantially greater than under the current capabilities scenario.

**Evaluation of Using MPCs**

This study,[22] prepared as part of DOE's MPC initiative, includes in Appendix D a set of shipment projections "based on the assumption that individual utilities will request the largest cask they can effectively handle" (page D-1). The study did not include shipments of HLW or spent fuel from defense sites. Nor did it explain the basis for its judgement that 83 storage locations could effectively handle a large MPC, while 19 could effectively handle a small MPC, and only 14 require canistered truck shipments. Perhaps it refers to locations that, with incentives, could be upgraded to effectively handle the cask types specified. The study did consider storage locations, reaching different judgements for storage locations at the same site (e.g., Millstone 1 versus Millstone 2 and 3, San Onofre 1 versus San Onofre 2 and 3, St. Lucie 1 versus St. Lucie 2).

The MPC evaluation assumes ten storage locations would ship by truck (or require special handling: heavy-haul, cask-to-cask transfer, barge) which the transportation strategy study assumes will be shipped by rail:

| | | |
|---|---|---|
| Big Rock | Humboldt Bay | Callaway |
| Dresden 1 | LaCrosse | Oconee |
| Fort Calhoun | Yankee Rowe | Point Beach |
| | | San Onofre 1 |

The transportation strategy study assumes that the locations in columns 1 and 2 above would ship by small MPC, while those in column 3 would ship by large MPC.

The 1993 MPC evaluation and the 1996 transportation strategy study reach differing rail cask conclusions at thirteen sites:

| | | |
|---|---|---|
| Arkansas Nuclear | Rancho Seco | Brunswick |
| Duane Arnold | Salem | Dresden 2 and 3 |
| Oyster Creek | Three Mile Island 1 | Quad Cities |
| Palisades | Turkey Point | Robinson |
| | | Vogtle |

The transportation strategy study assumes that the locations in columns 1 and 2 would ship by large rail; the MPC evaluation assumes these locations would ship by small rail. The transportation strategy study assumes that the locations in column 3 would ship by small rail; the MPC evaluation assumes these locations would ship by large rail.

## Table A-1. Utility Transportation Choice Scenarios: by Storage Location

| | FUEL STRG LOCATION: | TRANSP CHOICE: TS2 | TRANSP CHOICE: APD |
|---|---|---|---|
| 1 | ARKANSAS NUCLEAR 1 | R125 | R75 |
| 2 | ARKANSAS NUCLEAR 2 | R125 | R75 |
| 3 | ARKANSAS NUCLEAR DRY STRG | R125 | R75 |
| 4 | BEAVER VALLEY 1 | R125 | R125 |
| 5 | BEAVER VALLEY 2 | R125 | R125 |
| 6 | BELLEFONTE 1 | R125 | R125 |
| 7 | BELLEFONTE 2 | R125 | R125 |
| 8 | BIG ROCK 1 | R75 | LWT |
| 9 | BRAIDWOOD 1 | R125 | R125 |
| 10 | BROWNS FERRY 1-2 | R125 | R125 |
| 11 | BROWNS FERRY 3 | R125 | R125 |
| 12 | BRUNSWICK 1 | R75 | R125 |
| 13 | BRUNSWICK 1 PWR POOL | R75 | R125 |
| 14 | BRUNSWICK 2 | R75 | R125 |
| 15 | BRUNSWICK 2 PWR POOL | R75 | R125 |
| 16 | BYRON 1 | R125 | R125 |
| 17 | CALLAWAY 1 | R125 | LWT |
| 18 | CALVERT CLIFFS 1-2 | R125 | R125 |
| 19 | CALVERT DRY STORAGE | R125 | R125 |
| 20 | CATAWBA 1 | R125 | R125 |
| 21 | CATAWBA 2 | R125 | R125 |
| 22 | CLINTON 1 | R125 | R125 |
| 23 | COMANCHE PEAK 1 | R125 | R125 |
| 24 | COOK 1 | R125 | R125 |
| 25 | COOPER STATION | R75 | R75 |
| 26 | CRYSTAL RIVER 3 | R75 | R75 |
| 27 | DAVIS-BESSE 1 | R125 | R125 |
| 28 | DAVIS-BESSE DRY STRG | R125 | R125 |
| 29 | DIABLO CANYON 1 | R125 | R125 |
| 30 | DIABLO CANYON 2 | R125 | R125 |
| 31 | DRESDEN 1 | R75 | LWT |
| 32 | DRESDEN 2 | R75 | R125 |
| 33 | DRESDEN 3 | R75 | R125 |
| 34 | DUANE ARNOLD | R125 | R75 |
| 35 | ENRICO FERMI 2 | R125 | R125 |
| 36 | FARLEY 1 | R125 | R125 |
| 37 | FARLEY 2 | R125 | R125 |
| 38 | FITZPATRICK | R125 | R125 |
| 39 | FORT CALHOUN | R75 | LWT |
| 40 | FORT ST VRAIN | LWT | LWT |
| 41 | FORT ST VRAIN DRY STRG | LWT | LWT |
| 42 | GINNA | LWT | LWT |
| 43 | GRAND GULF 1 | R125 | R125 |
| 44 | HADDAM NECK | LWT | LWT |
| 45 | HARRIS 1 | R125 | R125 |
| 46 | HARRIS 1 BWR POOL | R125 | R125 |
| 47 | HATCH 1-2 | R125 | R125 |
| 48 | HOPE CREEK | R125 | R125 |
| 49 | HUMBOLDT BAY | R75 | LWT |
| 50 | INDIAN POINT 1 | LWT | LWT |
| 51 | INDIAN POINT 2 | LWT | LWT |
| 52 | INDIAN POINT 3 | LWT | LWT |
| 53 | KEWAUNEE | R125 | R125 |
| 54 | LACROSSE | R75 | T |
| 55 | LASALLE 1-2 | R125 | R125 |
| 56 | LIMERICK 1-2 | R125 | R125 |
| 57 | MAINE YANKEE | R125 | R125 |
| 58 | MCGUIRE 1 | R125 | R125 |
| 59 | MCGUIRE 2 | R125 | R125 |
| 60 | MILLSTONE 1 | R75 | R75 |
| 61 | MILLSTONE 2 | R75 | R75 |
| 62 | MILLSTONE 3 | R75 | R125 |
| 63 | MONTICELLO | R75 | R75 |
| 64 | NINE MILE POINT 1 | R125 | R125 |
| 65 | NINE MILE POINT 2 | R125 | R125 |
| 66 | NORTH ANNA 1&2 | R125 | R125 |
| 67 | NORTH ANNA DRY STRG | R125 | R125 |
| 68 | OCONEE 1&2 | R125 | LWT |
| 69 | OCONEE 3 | R125 | LWT |

| | FUEL STRG LOCATION: | TRANSP CHOICE: TS2 | TRANSP CHOICE: APD |
|---|---|---|---|
| 70 | OCONEE DRY STORAGE | R125 | LWT |
| 71 | OYSTER CREEK 1 | R125 | R75 |
| 72 | OYSTER CREEK DRY STRG | R125 | R75 |
| 73 | PALISADES | R125 | R75 |
| 74 | PALISADES DRY STORAGE | R125 | R75 |
| 75 | PALO VERDE 1 | R125 | R125 |
| 76 | PALO VERDE 2 | R125 | R125 |
| 77 | PALO VERDE 3 | R125 | LWT |
| 78 | PEACHBOTTOM 2 | R125 | LWT |
| 79 | PEACHBOTTOM 3 | R125 | LWT |
| 80 | PERRY 1 | R125 | R125 |
| 81 | PILGRIM 1 | R75 | R75 |
| 82 | POINT BEACH 1&2 | R125 | R125 |
| 83 | POINT BEACH DRY STRG | R125 | R125 |
| 84 | PRAIRIE ISLAND 1&2 | R125 | R125 |
| 85 | PRAIRIE ISLAND DRY STRG | R125 | R125 |
| 86 | QUAD CITIES 1 | R75 | R125 |
| 87 | RANCHO SECO 1 | R125 | R75 |
| 88 | RANCHO SECO DRY STRG | R125 | R75 |
| 89 | RIVER BEND 1 | R125 | R125 |
| 90 | ROBINSON 2 | R75 | R125 |
| 91 | ROBINSON DRY STORAGE | R75 | R125 |
| 92 | SALEM 1 | R125 | R75 |
| 93 | SALEM 2 | R125 | R75 |
| 94 | SAN ONOFRE 1 | R125 | LWT |
| 95 | SAN ONOFRE 2 | R125 | R125 |
| 96 | SAN ONOFRE 3 | R125 | R125 |
| 97 | SEABROOK 1 | R125 | R125 |
| 98 | SEQUOYAH 1 | R125 | R125 |
| 99 | SHOREHAM | NA | NA |
| 100 | SOUTH TEXAS 1 | R125 | R125 |
| 101 | SOUTH TEXAS 2 | R125 | R125 |
| 102 | ST LUCIE 1 | R125 | R125 |
| 103 | ST LUCIE 2 | R125 | R125 |
| 104 | SUMMER 1 | R125 | R125 |
| 105 | SURRY 1&2 | R125 | R125 |
| 106 | SURRY DRY STORAGE | R125 | R125 |
| 107 | SUSQUEHANNA 1-2 | R125 | R125 |
| 108 | SUSQUEHANNA DRY STRG | R125 | R125 |
| 109 | THREE MILE ISLAND 1 | R125 | R75 |
| 110 | TROJAN | R125 | R125 |
| 111 | TURKEY POINT 3 | R125 | R75 |
| 112 | TURKEY POINT 4 | R125 | R75 |
| 113 | VERMONT YANKEE 1 | R75 | R75 |
| 114 | VOGTLE 1-2 | R75 | R125 |
| 115 | WASH NUCLEAR 2 | R125 | R125 |
| 116 | WATTS BAR 1&2 | R125 | R125 |
| 117 | WATERFORD 3 | R125 | R125 |
| 118 | WOLF CREEK 1 | R125 | R125 |
| 119 | YANKEE-ROWE 1 | R75 | LWT |
| 120 | ZION 1&2 | R125 | R125 |
| 121 | HANFORD SNF STRG | LWT | LWT |
| 122 | HANFORD SNF STRG | LWT | LWT |
| 123 | INEL SNF STRG | LWT | LWT |
| 124 | INEL SNF STRG | LWT | LWT |
| 125 | INEL SNF STRG | LWT | LWT |
| 126 | SAVANNAH RV SNF STRG | LWT | LWT |
| 127 | SAVANNAH RV SNF STRG | LWT | LWT |
| 128 | WEST VALLEY SNF STRG | R125 | LWT |
| 129 | WEST VALLEY SNF STRG | R125 | LWT |
| 130 | MORRIS | R125 | R125 |
| 131 | MORRIS | R125 | R125 |
| 132 | GENERAL ATOMICS | LWT | LWT |

Shipment Cask Options:
R125: Large MPC for up to 21 PWR or 40 BWR
R75: Small MPC for up to 12 PWR or 24 BWR
LWT: Legal-weight truck casks.... GA-4/9 if a NLI-1/2 or NAC LWT otherwise

Transp Choice: TR2: NV Transp Strategy, Study 2 (DOE: Feb'96, Tbl F-3), PIC
APD: MPC Prelim Evaluation (DOE: Mar 1993, Appendix D)

## Table A-2. Cask Types Implied by DOE's Transportation Strategy Study 2

| SITE# | NUCLEAR REACTOR SITES: | DOE TR2:TBL F3 CASKS | DOE TR2:TBL F3 MTU | PIC EVALUATION: REAC TYPE | PIC EVALUATION: MTU/A | PIC EVALUATION: A/CASK | PIC EVALUATION: EST C-TYPE |
|---|---|---|---|---|---|---|---|
| 1 | ARKANSAS NUCLEAR 1,2 | 128 | 1151 | PWR | 0.44 | 20 | R125 |
| 2 | BEAVER VALLEY 1,2 | 106 | 1015 | PWR | 0.46 | 21 | R125 |
| 3 | BELLEFONTE 1,2 | 0 | 0 | PWR | NA | NA | ??? |
| 4 | BIG ROCK | 40 | 63 | BWR | 0.13 | 12 | R75 |
| 5 | BRAIDWOOD 1,2 | 119 | 1049 | PWR | 0.42 | 21 | R125 |
| 6 | BROWNS FERRY 1,2,3 | 210 | 1537 | BWR | 0.19 | 39 | R125 |
| 7 | BRUNSWICK 1,2 | 207 | 915 | BWR | 0.18 | 24 | R75 |
| 8 | BYRON 1,2 | 130 | 1147 | PWR | 0.42 | 21 | R125 |
| 9 | CALLAWAY 1 | 75 | 640 | PWR | 0.44 | 19 | R125 |
| 10 | CALVERT CLIFFS 1,2 | 145 | 1143 | PWR | 0.38 | 21 | R125 |
| 11 | CATAWBA 1,2 | 128 | 1193 | PWR | 0.43 | 22 | R125 |
| 12 | CLINTON 1 | 65 | 453 | BWR | 0.18 | 38 | R125 |
| 13 | COMANCHE PEAK 1,2 | 105 | 918 | PWR | 0.45 | 19 | R125 |
| 14 | COOK 1,2 | 146 | 1350 | PWR | 0.44 | 21 | R125 |
| 15 | COOPER STATION | 106 | 458 | BWR | 0.19 | 23 | R75 |
| 16 | CRYSTAL RIVER 3 | 89 | 491 | PWR | 0.46 | 12 | R75 |
| 17 | DAVIS-BESSE 1 | 58 | 509 | PWR | 0.47 | 19 | R125 |
| 18 | DIABLO CANYON 1,2 | 133 | 1191 | PWR | 0.45 | 20 | R125 |
| 19 | DRESDEN 1,2,3 | 355 | 1424 | BWR | 0.17 | 23 | R75 |
| 20 | DUANE ARNOLD | 64 | 457 | BWR | 0.18 | 39 | R125 |
| 21 | ENRICO FERMI 2 | 77 | 501 | BWR | 0.18 | 36 | R125 |
| 22 | FARLEY 1,2 | 123 | 1140 | PWR | 0.46 | 20 | R125 |
| 23 | FITZPATRICK | 73 | 519 | BWR | 0.18 | 39 | R125 |
| 34 | FORT CALHOUN | 89 | 381 | PWR | 0.36 | 12 | R75 |
| 25 | FORT ST VRAIN | ??? | ??? | HTG | 0.01 | NA | LWT |
| 26 | GINNA | ??? | ??? | PWR | 0.38 | NA | LWT |
| 27 | GRAND GULF 1 | 121 | 852 | BWR | 0.18 | 39 | R125 |
| 28 | HADDAM NECK | ??? | ??? | PWR | 0.41 | NA | LWT |
| 29 | HARRIS 1 | 69 | 598 | PWR | 0.45 | 19 | R125 |
| 29 | HARRIS 1 BWR POOL | ??? | ??? | BWR | 0.19 | NA | R125 |
| 30 | HATCH 1,2 | 184 | 1332 | BWR | 0.18 | 39 | R125 |
| 31 | HOPE CREEK | 101 | 717 | BWR | 0.19 | 38 | R125 |
| 32 | HUMBOLDT BAY | 17 | 29 | BWR | 0.07 | 23 | R75 |
| 33 | INDIAN POINT 1,2,3 | ??? | ??? | PWR | 0.43 | NA | LWT |
| 34 | KEWAUNEE | 59 | 466 | PWR | 0.39 | 21 | R125 |
| 35 | LACROSSE | 14 | 38 | BWR | 0.11 | 24 | R75 |
| 36 | LASALLE 1,2 | 176 | 1262 | BWR | 0.18 | 39 | R125 |
| 37 | LIMERICK 1,2 | 165 | 1129 | BWR | 0.18 | 37 | R125 |
| 38 | MAINE YANKEE | 91 | 717 | PWR | 0.38 | 21 | R125 |
| 39 | MCGUIRE 1,2 | 151 | 1419 | PWR | 0.44 | 22 | R125 |
| 40 | MILLSTONE 1,2,3 | 347 | 1734 | BWR | 0.26 | 19 | R75 |
| 41 | MONTICELLO | 95 | 394 | BWR | 0.18 | 23 | R75 |
| 42 | NINE MILE POINT 1,2 | 148 | 1030 | BWR | 0.19 | 38 | R125 |
| 43 | NORTH ANNA 1,2 | 131 | 1149 | PWR | 0.46 | 19 | R125 |
| 44 | OCONEE 1,2,3 | 204 | 1897 | PWR | 0.46 | 20 | R125 |
| 45 | OYSTER CREEK 1 | 92 | 651 | BWR | 0.18 | 39 | R125 |
| 46 | PALISADES | 69 | 575 | PWR | 0.40 | 21 | R125 |
| 47 | PALO VERDE 1,2,3 | 204 | 1687 | PWR | 0.41 | 20 | R125 |
| 48 | PEACHBOTTOM 2,3 | 225 | 1602 | BWR | 0.18 | 38 | R125 |
| 49 | PERRY 1 | 86 | 605 | BWR | 0.18 | 38 | R125 |
| 50 | PILGRIM 1 | 117 | 506 | BWR | 0.19 | 23 | R75 |
| 51 | POINT BEACH 1,2 | 107 | 837 | PWR | 0.39 | 20 | R125 |
| 52 | PRAIRIE ISLAND 1,2 | 106 | 807 | PWR | 0.38 | 20 | R125 |
| 53 | QUAD CITIES 1,2 | 314 | 1347 | BWR | 0.18 | 23 | R75 |
| 54 | RANCHO SECO 1 | 24 | 228 | PWR | 0.46 | 21 | R125 |
| 55 | RIVER BEND 1 | 69 | 488 | BWR | 0.18 | 38 | R125 |
| 56 | ROBINSON 2 | 70 | 345 | PWR | 0.44 | 11 | R75 |
| 57 | SALEM 1,2 | 123 | 1136 | PWR | 0.46 | 20 | R125 |
| 58 | SAN ONOFRE 1,2,3 | 175 | 1469 | PWR | 0.40 | 21 | R125 |
| 59 | SEABROOK 1 | 47 | 439 | PWR | 0.46 | 20 | R125 |
| 60 | SEQUOYAH 1,2 | 103 | 979 | PWR | 0.46 | 21 | R125 |
| 61 | SHOREHAM | 0 | 0 | BWR | NA | NA | NA |
| 62 | SOUTH TEXAS 1,2 | 76 | 808 | PWR | 0.54 | 20 | R125 |
| 63 | ST. LUCIE 1,2 | 147 | 1151 | PWR | 0.38 | 21 | R125 |
| 64 | SUMMER 1 | 59 | 525 | PWR | 0.45 | 20 | R125 |
| 65 | SURRY 1,2 | 120 | 1085 | PWR | 0.46 | 20 | R125 |
| 66 | SUSQUEHANNA 1,2 | 211 | 1470 | BWR | 0.18 | 39 | R125 |
| 67 | THREE MILE ISLAND 1 | 56 | 523 | PWR | 0.46 | 20 | R125 |
| 68 | TROJAN | 38 | 359 | PWR | 0.46 | 21 | R125 |
| 69 | TURKEY POINT 3,4 | 107 | 1011 | PWR | 0.46 | 21 | R125 |
| 70 | VERMONT YANKEE 1 | 138 | 602 | BWR | 0.18 | 24 | R75 |
| 71 | VOGTLE 1,2 | 218 | 1024 | PWR | 0.46 | 10 | R75 |
| 72 | WASHINGTON NUCLEAR 2,3 | 81 | 555 | BWR | 0.18 | 38 | R125 |
| 73 | WATERFORD 3 | 75 | 597 | PWR | 0.41 | 19 | R125 |
| 74 | WATTS BAR 1,2 | 32 | 300 | PWR | 0.46 | 20 | R125 |
| 75 | WOLF CREEK 1 | 63 | 575 | PWR | 0.46 | 20 | R125 |
| 76 | YANKEE-ROWE 1 | 45 | 127 | PWR | 0.24 | 12 | R75 |
| 77 | ZION 1,2 | 144 | 1375 | PWR | 0.46 | 21 | R125 |
| | Sub-Total | 8385 | 60195 | | 0.28 | 25 | |

# REFERENCES

1. DOE/OCRWM Notice of Proposed Policy and Procedures (May 10, 1996)
Safe Transportation and Emergency Response Training: Technical Assistance and Funding.

2. DOE/OCRWM Waste Acceptance, Storage and Transportation
Notice and request for expression of interest and comments (May 28, 1996)
Draft Concept of Operations: Waste Acceptance, Storage and Transportation (June 1996).
Draft Statement of Work: Waste Acceptance and Transportation Services (June 1996).

3. 1992 Acceptance Priority Ranking: Revision 1 (May 1993)
DOE/RW-0419 (through December 31, 1991)

1994 Acceptance Priority Ranking: (March 1995)
DOE/RW-0457 (through December 31, 1993)

1995 Acceptance Priority Ranking: (May 1996)
Unpublished (through November 28, 1994)

4. Spent Fuel Storage Requirements: 1994-2042 (June 1995)
DOE/RW-0432-Revision 1

5. Integrated Data Base - 1994 (September 1995)
DOE/RW, Revision 11 (Table 2.7)

6. Aging Nuclear Power Plants: Managing plant Life and Decommissioning U.S. Office of Technology Assessment (September 1993) OTA-E-575.

7. Draft Waste Management Programmatic EIS for Managing, Treatment, Storage, and Disposal of Radioactive and Hazardous Waste.
DOE/EIS-0200-D (August 1995, Vol I, pp. 9-12).

8. DOE Programmatic Spent Nuclear Fuel Management FEIS (April 1995)
DOE/EIS-0203-F Volume 1 (Tables 1-1 and 1-2).

9. DOE Final Interpretation of Nuclear Waste Acceptance Issues
DOE/OCRWM April 28, 1995.

10. Petition for Declaratory Judgement and Review of Final Decision of USDOE: Reply Brief of State Petitioners and Intervenors (December, 1995)
State of Michigan and the Michigan Public Service Commission et al. (U.S. Court of Appeals in the District of Columbia Circuit)
Decision in favor of petitioners: Indiana Michigan Power Co. et al. v. Department of Energy, NO. 95-1279 (U.S. Court of Appeals, July 23, 1996).

11. 1994 Acceptance Priority Ranking and Annual Capacity Report (March 1995)
DOE/RW-0457 (Appendix B).

12. Multi-Purpose Canister System Evaluation:
A Systems Engineering Approach (September 1994)
DOE/RW-0445 (Table 2.2-1)

13. Spent Nuclear Fuel Discharges from U.S. Reactors: 1994
DOE/EIA SR/CNEAF/96-01 (February 1996).

14. Report on High-Level Nuclear Waste:
Prepared Pursuant to Assembly Concurrent Resolution No. 8 of the 1987 Nevada Legislature (December 1988, pg 26). Nevada Nuclear Waste Project Office.

15. Multi-Purpose Canisters in the Civilian Waste Management System
Jeff Williams DOE/OCRWM (October 27, 1994)

16. NRC Information Digest: 1995 (March 1995)
NUREG-1350 (Tables 16 and 17).

17. Facility Interface Capability Assessment (FICA) Project Report (September 1995)
Prepared by J.M. Vielbrock and N. Mote (Nuclear Assurance Corporation) for Oak Ridge National Laboratory and DOE/OCRWM. ORNL/SUB/86-97393/6

18. Near-Site Transportation Infrastructure Project: Final Report (February 1992)
Prepared by J.M. Vielbrock and N. Mote (Nuclear Assurance Corporation) for DOE/Chicago Operations Office (DOE/CH/1044-1).

19. Rail Transportability of the Large MPC Study Report (March 1995)
TRW Environmental Safety Systems for DOE/OCRWM.

20. High-Level Nuclear Waste Shipping Route Maps to Yucca Mountain, and Shipment Number Estimates:
Multi-Purpose Canister Base Case (January 1995).
Nevada Nuclear Waste Project Office

21. Nevada Potential Repository:
Preliminary Transportation Strategy Study 2 (February 1996)
By TRW for DOE/OCRWM

22. Preliminary Evaluation of Using Multi-Purpose Canisters Within the Civilian Radioactive Waste Management System (March 24, 1993; Revision 0).
By TRW for DOE/OCRWM.

23. HIGHWAY 3.1—An Enhanced Highway Routing Model: Program Description, Methodology, and Revised User's Manual. Prepared by P.E. Johnson, D.S. Joy, D.B. Clarke, and J.M. Jacobi (March 1993).

24. INTERLINE 5.0—An Expanded Railroad Routing Model: Program Description, Methodology, and Revised User's Manual. Prepared by P.E. Johnson, D.S. Joy, D.B. Clarke, and J.M. Jacobi (March 1993).

25. DOE/OCRWM: May 10, 1996
Notice of Proposed Policies and Procedures for Safe Transportation and Emergency Response Training Technical Assistance and Funding under NWPA section 180(c).

26. Pilot Study: SNF Shipments, Routing, Transportation Issues:
Oyster Creek, NJ to Yucca Mountain, NV (March 1996)
Planning Information Corporation for Council of State Governments/Northeast

Pilot Study: SNF Shipments, Routing, Transportation Issues:
Brunswick, NC to Yucca Mountain, NV (March 1996)
Planning Information Corporation for Southern States Energy Board

**ATTACHMENT W**

| TABLE 1 | | |
|---|---|---|
| YMDEIS TRANSPORTATION IMPACTS | | |
| TRUCK SHIPMENTS OF CIVILIAN SNF | | |
| NEVADA CURRENT CAPABILITIES SCENARIO (PIC, 9/96) | | |
| DOE BASE CASE ROUTING (TRW1999uData,Ch.4, file bt.map.prn | | |
| DOE TRUCK SHIPMENT NUMBERS (DEIS, Table J-5) | | |
| Reactor/Storage Site (State) | Proposed Action (2010-2033) | Modules 1 or 2 (2010-2048) |
| Browns Ferry (AL) | 1,175 | 2,067 |
| Diablo Canyon (CA) | 632 | 1,308 |
| Humboldt Bay (CA) | 44 | 44 |
| Haddam Neck (CT) | 255 | 255 |
| Crystal River (FL) | 283 | 442 |
| St. Lucie (FL) | 681 | 1,086 |
| Turkey Point (FL) | 582 | 871 |
| Dresden/Morris (IL) | 1,386 | 1,569 |
| Pilgrim (MA) | 316 | 476 |
| Yankee-Rowe (MA) | 134 | 134 |
| Calvert Cliffs (MD) | 757 | 1,140 |
| Big Rock Pt (MI) | 131 | 131 |
| DC COOK (MI) | 824 | 1,235 |
| E Fermi (MI) | 312 | 764 |
| Palisades (MI) | 367 | 454 |
| Monticello (MN) | 267 | 342 |
| Callaway (MO) | 392 | 735 |
| Grand Gulf (MS) | 516 | 1,016 |
| Cooper (NE) | 274 | 454 |
| Fort Calhoun (NE) | 258 | 362 |
| Oyster Creek (NJ) | 424 | 519 |
| Salem/Hope Creek (NJ) | 1,027 | 1,992 |
| Fitzpatrick/Nine Mile Pt (NY) | 1,094 | 1,971 |
| Ginna (NY) | 309 | 379 |
| Indian Pt (NY) | 701 | 1,155 |
| Peach Bottom (PA) | 924 | 1,408 |
| Oconee (SC) | 1,007 | 1,500 |
| Surry (VA) | 647 | 902 |
| Vermont Yankee (VT) | 369 | 484 |
| Kewaunee (WI) | 288 | 401 |
| Lacrosse (WI) | 37 | 37 |
| Pt Beach (WI) | 575 | 742 |
| Total | 16,988 | 26,375 |

| TABLE 2 | | |
|---|---|---|
| YMDEIS TRANSPORTATION IMPACTS | | |
| RAIL SHIPMENTS OF CIVILIAN SNF | | |
| NEVADA CURRENT CAPABILITIES SCENARIO (PIC, 9/96) | | |
| DOE BASE CASE ROUTING (TRW1999uData,Ch.4, file ca.rail.prn) | | |
| DOE RAIL SHIPMENT NUMBERS (DEIS, Table J-6) | | |
| | | |
| Reactor/Storage Site (State) | Proposed Action | Modules 1&2 |
| | (2010-2033) | (2010-2048) |
| Farley(AL) | 103 | 157 |
| Arkansas(AR) | 170 | 252 |
| Palo Verde(AZ) | 156 | 350 |
| Rancho Seco(CA) | 21 | 21 |
| San Onofre(CA) | 143 | 207 |
| Millstone(CT) | 367 | 524 |
| Hatch(GA) | 128 | 197 |
| Vogtle(GA) | 195 | 431 |
| Arnold(IA) | 105 | 158 |
| Braidwood(IL) | 95 | 215 |
| Byron(IL) | 136 | 244 |
| Clinton(IL) | 103 | 200 |
| LaSalle(IL) | 89 | 172 |
| Quad Cities(IL) | 299 | 419 |
| Zion(IL) | 147 | 250 |
| Wolf Creek(KS) | 52 | 106 |
| River Bend(LA) | 48 | 101 |
| Waterford(LA) | 49 | 91 |
| Maine Yankee(ME) | 60 | 60 |
| Prairie Island(MN) | 151 | 221 |
| Brunswick(NC) | 201 | 321 |
| Harris(NC) | 150 | 258 |
| McGuire(NC) | 253 | 427 |
| Seabrook(NH) | 37 | 83 |
| Davis-Besse(OH) | 44 | 71 |
| Perry(OH) | 42 | 82 |
| Trojan(OR) | 33 | 33 |
| Beaver Valley(PA) | 86 | 160 |
| Limerick(PA) | 262 | 497 |
| Susquehanna(PA) | 119 | 219 |
| Three Mile Island(PA) | 71 | 113 |
| Catawba(SC) | 148 | 253 |
| Robinson(SC) | 75 | 97 |
| Summer(SC) | 46 | 82 |
| Sequoyah(TN) | 90 | 161 |
| Watts Bar(TN) | 21 | 121 |
| Comanche Peak(TX) | 90 | 246 |
| South Texas(TX) | 151 | 358 |
| North Anna(VA) | 101 | 167 |
| WPPSS(WA) | 53 | 107 |

TABLE 3
YMDEIS TRANSPORTATION IMPACTS
TRUCK SHIPMENT MILES OF CIVILIAN SNF
NEVADA CURRENT CAPABILITIES SCENARIO (PIC, 9/96)
DOE BASE CASE ROUTING (TRW1999uData,Ch.4, file bt.map.prn)
DOE HIGHWAY DISTANCES (DEIS, Table J-11)

| Reactor/Storage Site (State) | kms | Miles | Shipments Prop. Action (2010-2033) | Shipment-Miles | Shipments Mod. 1 or 2 (2010-2048) | Shipment-Miles |
|---|---|---|---|---|---|---|
| Browns Ferry (AL) | 3442 | 2139 | 1,175 | 2,513,038 | 2,067 | 4,420,808 |
| Diablo Canyon (CA) | 1016 | 631 | 632 | 398,989 | 1,308 | 825,756 |
| Humboldt Bay (CA) | 1749 | 1087 | 44 | 47,818 | 44 | 47,818 |
| Haddam Neck (CT) | 4519 | 2808 | 255 | 716,033 | 255 | 716,033 |
| Crystal River (FL) | 4319 | 2684 | 283 | 759,486 | 442 | 1,186,194 |
| St. Lucie (FL) | 4588 | 2851 | 681 | 1,941,426 | 1,086 | 3,096,018 |
| Turkey Point (FL) | 4842 | 3009 | 582 | 1,751,048 | 871 | 2,620,555 |
| Dresden/Morris (IL) | 3059 | 1901 | 1,386 | 2,634,468 | 1,569 | 2,982,309 |
| Pilgrim (MA) | 4722 | 2934 | 316 | 927,178 | 476 | 1,396,636 |
| Yankee-Rowe (MA) | 4616 | 2868 | 134 | 384,345 | 134 | 384,345 |
| Calvert Cliffs (MD) | 4278 | 2658 | 757 | 2,012,273 | 1,140 | 3,030,372 |
| Big Rock Pt (MI) | 3866 | 2402 | 131 | 314,690 | 131 | 314,690 |
| DC COOK (MI) | 3196 | 1986 | 824 | 1,636,380 | 1,235 | 2,452,585 |
| E. Fermi (MI) | 3524 | 2190 | 312 | 683,189 | 764 | 1,672,937 |
| Palisades (MI) | 3244 | 2016 | 367 | 739,771 | 454 | 915,139 |
| Monticello (MN) | 3003 | 1866 | 267 | 498,215 | 342 | 638,163 |
| Callaway (MO) | 2633 | 1636 | 392 | 641,338 | 735 | 1,202,509 |
| Grand Gulf (MS) | 3354 | 2084 | 516 | 1,075,383 | 1,016 | 2,117,420 |
| Cooper (NE) | 2523 | 1568 | 274 | 429,554 | 454 | 711,743 |
| Fort Calhoun (NE) | 2348 | 1459 | 258 | 376,416 | 362 | 528,150 |
| Oyster Creek (NJ) | 4424 | 2749 | 424 | 1,165,551 | 519 | 1,426,700 |
| Salem/Hope Creek (NJ) | 4350 | 2703 | 1,027 | 2,775,939 | 1,992 | 5,384,295 |
| Fitzpatrick/Nine Mile Pt (NY) | 4234 | 2631 | 1,094 | 2,878,183 | 1,971 | 5,185,466 |
| Ginna (NY) | 4089 | 2541 | 309 | 785,102 | 379 | 962,956 |
| Indian Pt (NY) | 4382 | 2723 | 701 | 1,908,713 | 1,155 | 3,144,884 |
| Peach Bottom (PA) | 4205 | 2613 | 924 | 2,414,283 | 1,408 | 3,678,908 |
| Oconee (SC) | 3853 | 2394 | 1,007 | 2,410,898 | 1,500 | 3,591,208 |
| Surry (VA) | 4255 | 2644 | 647 | 1,710,622 | 902 | 2,384,824 |
| Vermont Yankee (VT) | 4616 | 2868 | 369 | 1,058,382 | 484 | 1,388,230 |
| Kewaunee (WI) | 3347 | 2080 | 288 | 598,961 | 401 | 833,970 |
| Lacrosse (WI) | 3014 | 1873 | 37 | 69,294 | 37 | 69,294 |
| Pt Beach (WI) | 3341 | 2076 | 575 | 1,193,698 | 742 | 1,540,390 |
| Total | | | 16,988 | 39,450,666 | 26,375 | 60,851,305 |

| | | |
|---|---|---|
| | 4690 | 8232 |

| | | | | | | |
|---|---|---|---|---|---|---|
| TABLE 4 | | | | | | |
| YMDEIS TRANSPORTATION IMPACTS | | | | | | |
| RAIL SHIPMENT MILES OF CIVILIAN SNF | | | | | | |
| NEVADA CURRENT CAPABILITIES SCENARIO (PIC, 9/96) | | | | | | |
| DOE BASE CASE ROUTING (TRW1999uData,Ch.4, file ca.rail.prn) | | | | | | |
| DOE RAIL DISTANCES (DEIS, Table J-11) | | | | | | |
| Reactor/Storage Site (State) | kms | Miles | Shipments Prop. Action (2010-2033) | Shipment-Miles | Shipments Mod. 1 or 2 (2010-2048) | Shipment-Miles |
| Farley(AL) | 4322 | 2686 | 103 | 276,613 | 157 | 421,633 |
| Arkansas(AR) | 2996 | 1862 | 170 | 316,476 | 252 | 469,129 |
| Palo Verde(AZ) | 1149 | 714 | 156 | 111,377 | 350 | 249,884 |
| Rancho Seco(CA) | 1159 | 720 | 21 | 15,124 | 21 | 15,124 |
| San Onofre(CA) | 750 | 466 | 143 | 66,642 | 207 | 96,468 |
| Millstone(CT) | 4555 | 2830 | 367 | 1,038,735 | 524 | 1,483,098 |
| Hatch(GA) | 4229 | 2628 | 128 | 336,355 | 197 | 517,671 |
| Vogtle(GA) | 4286 | 2663 | 195 | 519,322 | 431 | 1,147,836 |
| Arnold(IA) | 2572 | 1598 | 105 | 167,807 | 158 | 252,510 |
| Braidwood(IL) | 2993 | 1860 | 95 | 176,677 | 215 | 399,848 |
| Byron(IL) | 2806 | 1744 | 136 | 237,125 | 244 | 425,430 |
| Clinton(IL) | 2998 | 1863 | 103 | 191,875 | 200 | 372,573 |
| LaSalle(IL) | 2887 | 1794 | 89 | 159,657 | 172 | 308,550 |
| Quad Cities(IL) | 2829 | 1758 | 299 | 525,599 | 419 | 736,542 |
| Zion(IL) | 2946 | 1831 | 147 | 269,092 | 250 | 457,639 |
| Wolf Creek(KS) | 2512 | 1561 | 52 | 81,166 | 106 | 165,453 |
| River Bend(LA) | 3380 | 2100 | 48 | 100,811 | 101 | 212,123 |
| Waterford(LA) | 3423 | 2127 | 49 | 104,221 | 91 | 193,552 |
| Maine Yankee(ME) | 4734 | 2942 | 60 | 176,494 | 60 | 176,494 |
| Prairie Island(MN) | 2807 | 1744 | 151 | 263,372 | 221 | 385,465 |
| Brunswick(NC) | 4594 | 2855 | 201 | 573,769 | 321 | 916,318 |
| Harris(NC) | 4495 | 2793 | 150 | 418,959 | 258 | 720,609 |
| McGuire(NC) | 4366 | 2713 | 253 | 686,364 | 427 | 1,158,409 |
| Seabrook(NH) | 4582 | 2847 | 37 | 105,343 | 83 | 236,311 |
| Davis-Besse(OH) | 3416 | 2123 | 44 | 93,394 | 71 | 150,705 |
| Perry(OH) | 3519 | 2187 | 42 | 91,837 | 82 | 179,301 |
| Trojan(OR) | 2031 | 1262 | 33 | 41,646 | 33 | 41,646 |
| Beaver Valley(PA) | 3645 | 2265 | 86 | 194,781 | 160 | 362,383 |
| Limerick(PA) | 4216 | 2620 | 262 | 686,360 | 497 | 1,301,989 |
| Susquehanna(PA) | 4232 | 2630 | 119 | 312,927 | 219 | 575,891 |
| Three Mile Island(PA) | 4110 | 2554 | 71 | 181,322 | 113 | 288,583 |
| Catawba(SC) | 4363 | 2711 | 148 | 401,234 | 253 | 685,892 |
| Robinson(SC) | 4339 | 2696 | 75 | 202,209 | 97 | 261,524 |
| Summer(SC) | 4299 | 2671 | 46 | 122,878 | 82 | 219,044 |
| Sequoyah(TN) | 3716 | 2309 | 90 | 207,811 | 161 | 371,751 |
| Watts Bar(TN) | 3714 | 2308 | 21 | 48,463 | 121 | 279,240 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Comanche Peak(TX) | 2716 | 1688 | 90 | 151,888 | 246 | 415,160 |
| South Texas(TX) | 3228 | 2006 | 151 | 302,873 | 358 | 718,070 |
| North Anna(VA) | 4347 | 2701 | 101 | 272,811 | 167 | 451,083 |
| WPPSS(WA) | 1772 | 1101 | 53 | 58,357 | 107 | 117,814 |
| Total | | | 4690 | 10,289,765 | 8232 | 17,938,746 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| Caliente to Yucca Mountain | 513 | 319 | 4690 | 1,494,998 | 8232 | 2,624,055 |

TABLE 5
YMDEIS TRANSPORTATION IMPACTS
MTHMs CIVILIAN SNF SHIPPED BY TRUCK
NEVADA CURRENT CAPABILITIES SCENARIO (PIC, 9/96)
DOE BASE CASE ROUTING (TRW1999uData,Ch.4, file bt.map.prn)
DOE CIVILIAN SNF INVENTORY (DEIS, Tables A-6 & A-7)

| Reactor/Storage Site (State) | Proposed Action (2010-2033) | Modules 1 or 2 (2010-2048) |
|---|---|---|
| Browns Ferry (AL) | 1,932 | 3,348 |
| Diablo Canyon (CA) | 1126 | 2,187 |
| Humboldt Bay (CA) | 29 | 29 |
| Haddam Neck (CT) | 420 | 420 |
| Crystal River (FL) | 512 | 805 |
| St. Lucie (FL) | 1020 | 1,611 |
| Turkey Point (FL) | 1074 | 1520 |
| Dresden/Morris (IL) | 2,146 | 2,541 |
| Pilgrim (MA) | 527 | 770 |
| Yankee-Rowe (MA) | 127 | 127 |
| Calvert Cliffs (MD) | 1142 | 1,710 |
| Big Rock Pt (MI) | 58 | 58 |
| DC COOK (MI) | 1433 | 2,155 |
| E Fermi (MI) | 523 | 1160 |
| Palisades (MI) | 585 | 733 |
| Monticello (MN) | 426 | 537 |
| Callaway (MO) | 702 | 1288 |
| Grand Gulf (MS) | 856 | 1,610 |
| Cooper (NE) | 452 | 762 |
| Fort Calhoun (NE) | 379 | 534 |
| Oyster Creek (NJ) | 699 | 844 |
| Salem/Hope Creek (NJ) | 1,659 | 3,245 |
| Fitzpatrick/Nine Mile Pt (NY) | 1,812 | 2,900 |
| Ginna (NY) | 463 | 565 |
| Indian Pt (NY) | 1164 | 1,683 |
| Peach Bottom (PA) | 1554 | 2,312 |
| Oconee (SC) | 1,865 | 2,674 |
| Surry (VA) | 1194 | 1689 |
| Vermont Yankee (VT) | 609 | 822 |
| Kewaunee (WI) | 451 | 612 |
| Lacrosse (WI) | 38 | 38 |
| Pt Beach (WI) | 876 | 1143 |
| Total | 27,853 | 42,432 |

TABLE 6
YMDEIS TRANSPORTATION IMPACTS
MTHMs SNF SHIPPED BY RAIL (DEIS, Tables A-6 & A-7)
NEVADA CURRENT CAPABILITIES SCENARIO (PIC, 9/96)
DOE BASE CASE ROUTING (TRW1999uData,Ch.4, file ca.rail.prn)
DOE CIVILIAN SNF INVENTORY (DEIS, Tables A-6 & A-7)

| Reactor/Storage Site (State) | Proposed Action (2010-2033) | Modules 1 or 2 (2010-2048) |
|---|---|---|
| Farley(AL) | 1174 | 1869 |
| Arkansas(AR) | 1109 | 1650 |
| Palo Verde(AZ) | 1674 | 3573 |
| Rancho Seco(CA) | 228 | 228 |
| San Onofre(CA) | 1423 | 2043 |
| Millstone(CT) | 1709 | 2655 |
| Hatch(GA) | 1446 | 2272 |
| Vogtle(GA) | 1080 | 2458 |
| Arnold(IA) | 467 | 692 |
| Braidwood(IL) | 1029 | 2287 |
| Byron(IL) | 1068 | 2181 |
| Clinton(IL) | 477 | 1084 |
| LaSalle(IL) | 952 | 1863 |
| Quad Cities(IL) | 1277 | 1834 |
| Zion(IL) | 1052 | 1052 |
| Wolf Creek(KS) | 630 | 1278 |
| River Bend(LA) | 531 | 1132 |
| Waterford(LA) | 500 | 938 |
| Maine Yankee(ME) | 536 | 536 |
| Prairie Island(MN) | 866 | 1210 |
| Brunswick(NC) | 896 | 1440 |
| Harris(NC) | 750 | 1205 |
| McGuire(NC) | 1439 | 2527 |
| Seabrook(NH) | 425 | 964 |
| Davis-Besse(OH) | 505 | 825 |
| Perry(OH) | 452 | 910 |
| Trojan(OR) | 359 | 359 |
| Beaver Valley(PA) | 1018 | 1832 |
| Limerick(PA) | 1143 | 2390 |
| Susquehanna(PA) | 1276 | 2373 |
| Three Mile Island(PA) | 548 | 825 |
| Catawba(SC) | 1148 | 2217 |
| Robinson(SC) | 384 | 509 |
| Summer(SC) | 526 | 958 |
| Sequoyah(TN) | 1023 | 1845 |
| Watts Bar(TN) | 251 | 893 |
| Comanche Peak(TX) | 998 | 2635 |

| | | |
|---|---|---|
| South Texas(TX) | 1012 | 2319 |
| North Anna(VA) | 1184 | 1955 |
| WPPSS(WA) | 581 | 1167 |
| | 35146 | 62983 |

**ATTACHMENT X**

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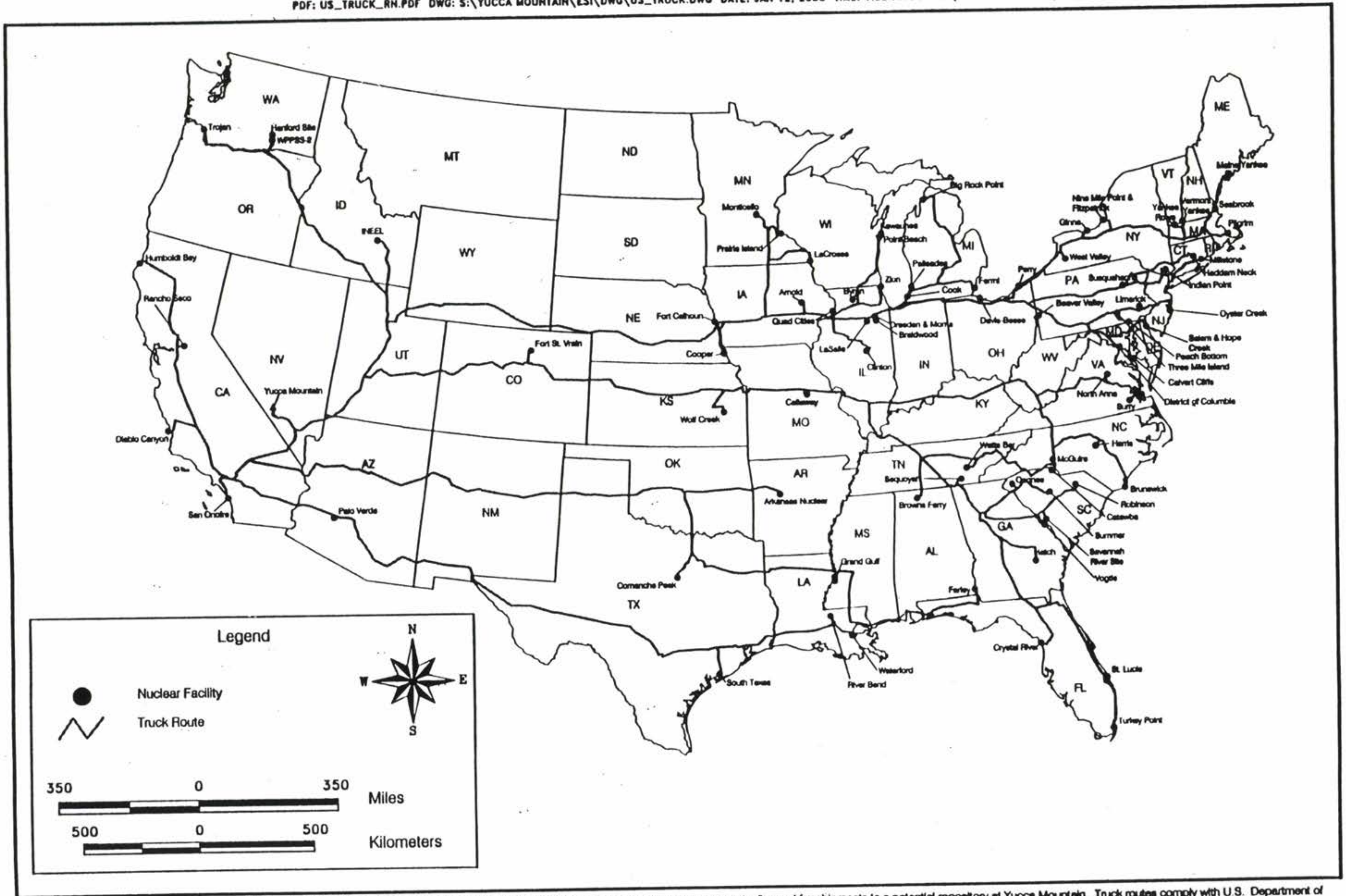


These routes represent the routes analyzed in Chapter 6 of the Draft Repository Environmental Impact Statement and may not be the routes actually used for shipments to a potential repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads. Direction arrow is approximate.

**ATTACHMENT Y**

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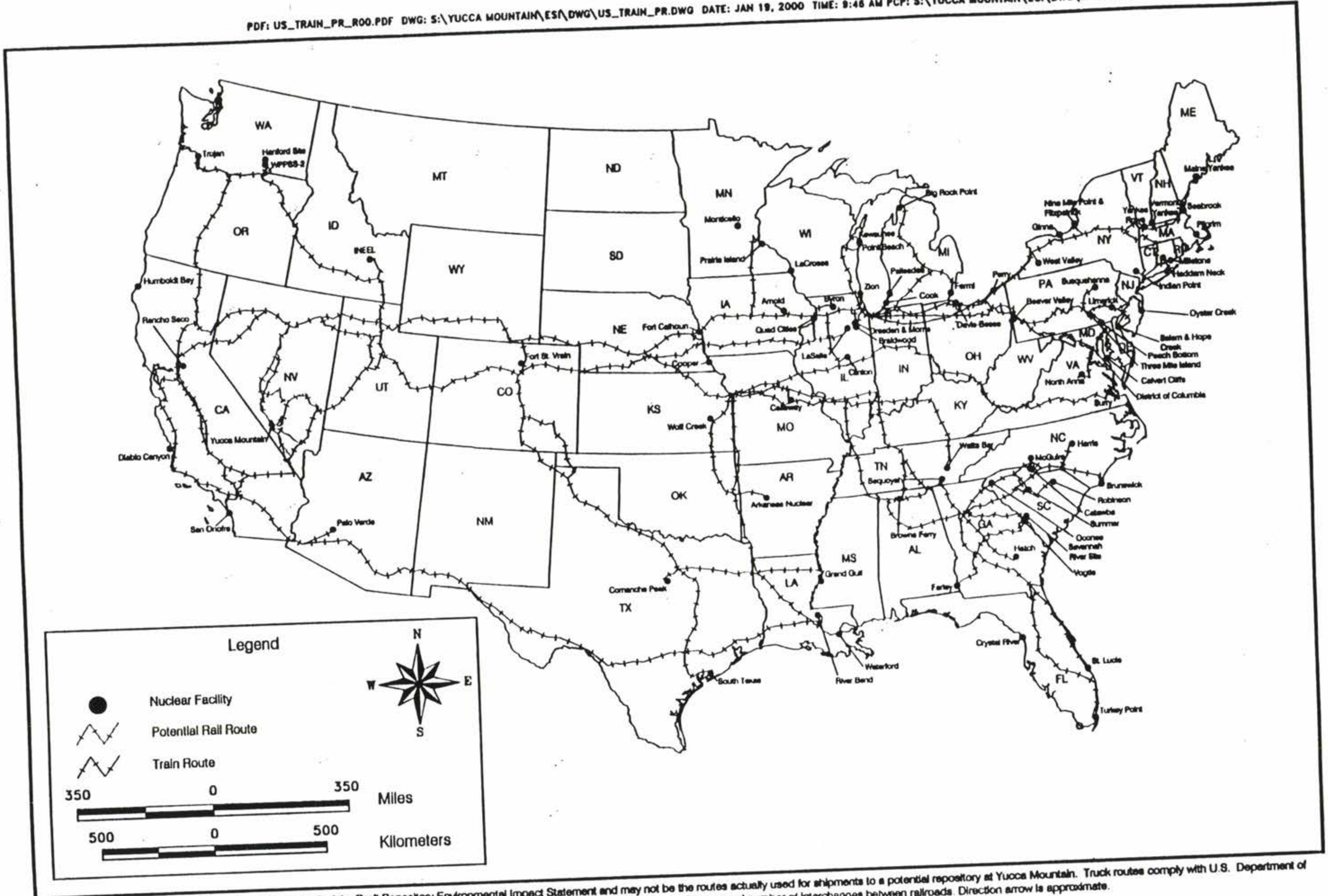


These routes represent the routes analyzed in Chapter 6 of the Draft Repository Environmental Impact Statement and may not be the routes actually used for shipments to a potential repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads. Direction arrow is approximate.

**ATTACHMENT Z**

# COMMENTS OF ROBERT J. HALSTEAD ON BEHALF OF THE STATE OF NEVADA AGENCY FOR NUCLEAR PROJECTS REGARDING THE U.S. NUCLEAR REGULATORY COMMISSION STUDY ASSESSING RISKS OF SPENT NUCLEAR FUEL TRANSPORTATION ACCIDENTS (MODAL STUDY UPDATE)

PRESENTED AT THE PUBLIC MEETING IN
HENDERSON, NEVADA
DECEMBER 8, 1999

## PHYSICAL TESTING AND COMPUTER SIMULATION

1. Nevada will continue to pursue full-scale regulatory physical testing of new shipping casks as a requirement for NRC certification and/or DOE procurement

2. Nevada believes issue of full scale physical testing of casks should be addressed in a venue separate from the Modal Study Update

3. Modal Study Update should include physical testing of critical cask components
a. Truck Cask - GA 4: closure bolts and seals (impact and fire, full scale), depleted uranium gamma shield fittings and welds (impact, fire, puncture, full scale or ½ scale), and cask tie-down systems (impact, full scale or ½ scale)
b. Large Rail Cask - TBD (e.g., MPC, NAC/ST, HiStar): closure bolts and seals (impact and fire, full scale), gamma shield (lead, lead/DU, cast iron) interface, fittings and welds (impact, fire, puncture, full scale or ½ scale), and cask tie-down systems (impact, full scale or ½ scale)

4. Modal Study Update should include computer simulations to determine GA-4 truck cask performance under extremely severe accident conditions and to determine failure thresholds for severe fire and impacts

5. Modal Study Update should include computer simulations to determine large rail cask performance under extremely severe accident conditions and to determine failure thresholds for severe fire and impacts

## HIGHWAY AND RAILWAY ACCIDENTS

1. Modal Study Update should evaluate historical accidents which created conditions that challenge the NRC cask performance standards:

a. Catastrophic highway infrastructure accidents, including:
June 29, 1983, Greenwich, CT, I-95: Collapse of Mianus River Bridge
March 5, 1985, Waynesville, NC, I-40: Massive rock slide onto highway and tunnel
April 5, 1987, Amsterdam, NY, I-90: Collapse of Schoharie Creek Bridge
July 14, 1988, Burley, ID, I-84:Support impact and overpass collapse
Oct. 17, 1989, Oakland, CA, Nimitz Freeway: Elevated Highway Collapse (earthquake)

b. Truck and rail accidents involving military explosives, including:
April 28, 1973, Roseville, CA, Southern Pacific: Explosion of 18 boxcars
May 24, 1973, Benson, AZ, Southern Pacific: Explosion of 12 boxcars
Aug. 4, 1985, Checotah, OK, I-40: Truck explosion
Nov. 21, 1990, Goldfield, NV, US 95:Truck explosion

c. Highway accidents involving impact and fire/explosion, including:
Dec. 23, 1988, Memphis, TN, I-240: Collision and explosion, propane tanker
May 20, 1991, Bronx, NY: Collision and explosion, gasoline tanker
July 24, 1998, Valdese, NC, I-40: Bridge support impact and fire, gasoline tanker

d. Railway accidents involving high speed impact and/or fire, including:
July 8, 1986, Miamisburg, OH, CSXT: Derailment and fire, multiple chemicals
Feb. 2, 1989, Helena, MT, MT Rail: Derailment and explosion, multiple chemicals
Feb. 26-28, 1989, Akron, OH, CSXT: Derailment and fire, butane tankers
May 12-25, 1989, San Bernardino, CA, Southern Pacific: Derailment, pipeline explosion
July 22-24, 1989, Freeland, MI, CSXT: Derailment and fire, multiple chemicals
Dec. 14, 1994, Cajon Pass, CA, Santa Fe: Collision
Feb. 1, 1996, Cajon Pass, CA, BNSF: Derailment and fire
Feb. 21, 1996, Leadville, CO, Southern Pacific: Derailment and spill, sulfuric acid
Mar. 4-22, 1996, Weyauwega, WI, Wisconsin Central: Derailment and fire, propane tankers

2. Modal Study Update should develop a bounding approach to accident probability which considers:
a. State specific data for most heavily impacted states
b. Route specific data for most likely national routes: I-80, Buffalo - Sacramento; I-70, Baltimore - Cove Fort; I-40, Asheville - Barstow; I-15, SLC - Barstow, US 95, Las Vegas - Tonopah; UP/SP, Chicago-Gibbon-Oakland; UP/SP, St. Louis-Gibbon-SLC-Los Angeles; BNSF, Kansas City-San Bernardino
c. Range of statistical measures to reflect year-to-year variations
d. Actual accident/incident rates for historical U.S. SNF shipments (Truck - 0.7/10.5 per million shipment-miles, Rail - 9.7/19.4 per million shipment-miles, 1970-1990, SAIC,1991)

3. Nevada is currently evaluating historical severe accidents to determine maximum credible events as part of review of DOE YM DEIS. DOE contractor report suggests 1939

Harney, NV rail sabotage incident which caused train to derail at full-speed into deep canyon. DOE YM EA (1986) acknowledged potential for military aircraft carrying live munitions bombing or crashing into rail or truck shipment. Given inherent large uncertainties in PRA, Modal Study Update should analyze accidents with probabilities at least as low as 1 in 10 million per year.

4. Probability of undetected defects and improper loading must be evaluated both as accident-initiating and as consequence-exacerbating factors.

5. Nevada advocates use of dedicated trains and special safety protocols to reduce rail accident probability and consequence. However, Modal Study Update should not consider dedicated trains and administrative controls because:
a. DOE and nuclear industry oppose mandatory use of dedicated trains;
b. DOE YM DEIS assumes use of general rail freight service;
c. Eastern and Western railroads have different opinions regarding maximum speeds (35 mph versus 55 mph); and
d. Dedicated trains can have accidents (TMI shipment in St. Louis)

CONTAINER PERFORMANCE DURING COLLISIONS AND FIRES

1. Modal Study Update must select appropriate casks for analysis: Truck, GA-4 and NAC LWT; Rail - Large MPC, NAC S/T, Hi-Star, although IF-300 will probably see continued use. Several rail casks must be evaluated to address different gamma shield materials and configurations (lead, lead/DU, cast iron).

2. Modal Study Update must develop method of translating maximum credible real world impacts in comparison to regulatory drop onto unyielding surface. Examples: Rail cask 90 mph impact with rock face, bridge support column, oncoming locomotive, or another large rail cask; Truck cask 75 mph impact with rock face, bridge support column, another tractor, etc.

3. Modal Study Update must analyze cask performance in engulfing fire conditions for longer durations and higher temperatures than NRC standards require, to address potential for maximum credible real world fires. Truck cask should analyzed for 1475 degree fire for 8 hours, and 2000 degree fire for 4 hours. Rail cask should be analyzed for 1475 degree fire for 24 hours, and 2000 degree fire for 12 hours.

4. Modal Study Update must consider heat generated by SNF during fire as factor in SNF oxidation. SNF heat is probably an important factor in performance of 5-year to 10-year cooled fuel, and may be factor in seal performance for truck cask carrying 5-year cooled fuel.

## SPENT NUCLEAR FUEL ASSEMBLY BEHAVIOR IN ACCIDENT

**1. Modal Study Update must select appropriate SNF types for bounding analysis of radiological consequences of both loss of shielding and loss of containment accidents. Greatest radiological risk involves shipment of 5-year cooled, high-burnup PWR fuel (5.0 percent U-235 initial enrichment, 62,000 MWd/MTU burnup, as allowed under NRC Final Rule in 10CFR51). Moderate radiological risk would result from shipment of 26-year cooled, medium-burnup PWR fuel (3.7 percent U-235 initial enrichment, 39,600 Mwd/MTHM, as assumed by DOE in YM DEIS).**

**2. Modal Study Update must assume complete cladding failure and oxidation in most severe loss of containment accident. Both normal SNF and failed/degraded SNF(including core debris) must be considered in all accident scenarios. Failed/degraded fuel (including core debris) should be assumed to be containerized before shipment, and the container should be credited in boundary calculations.**

**3. Nevada is evaluating issue of dual-purpose cask container boundary credit.**

**4. Only way to gain useable knowledge about SNF behavior under extreme conditions is to test real SNF rods and pellets. Actual SNF should be tested to gain understanding of burst/rupture and fracture characteristics. Particle size distribution is a major uncertainty in modeling loss of containment accident release and dispersion.**

## OTHER TRANSPORTATION SAFETY ISSUES

**1. Questionable justification of PRA approach based on historical data, when future shipment numbers and shipment characteristics, based on analysis of DOE YM DEIS and other DOE program documents, are radically different from past shipping campaigns.**

**2. Need for PRA to consider policy and program issues relevant to safety, such as future Congressional funding for infrastructure maintenance, NTSB safety analysis and USDOT safety inspections; DOE proposal for privatization of transportation services under fixed-cost contracts; and utility interpretation of standard contracts allowing abandonment of commitment to ship oldest fuel first (OFF).**

**3. Need for comprehensive human factors assessment, including human factors issues relevant to particular cask/transporter systems such as the GA-4. Issues include both driver performance and tractor/trailer performance under anticipated real world conditions, e.g. very long distance hauls cross-country and challenging driving conditions due to Western states road and weather conditions.**

**ATTACHMENT AA**

**Radioactive Waste Management Associates**

# Memo

**To:** Bob Halstead

**From:** RWMA

**Date:** 02/14/00

**Re:** RADTRAN IV Economic Analysis

---

This memo discusses the inputs, methodology, and results of a RADTRAN IV economic analysis of a severe accident involving a rail cask of spent nuclear fuel in an urban area. It is divided into two rough sections. The first section discusses the equations used by RADTRAN to estimate economic impacts. The second section discusses our results obtained from running the RADTRAN IV economic code.

## I. RADTRAN equations used in the economic analysis of spent fuel accidents

We will only be discussing urban costs, as these are the relevant inputs needed for our analysis.

RADTRAN II and RADTRAN III User's Guides assume the following land use distribution for an urban area:

**RADTRAN Default Land use Assumptions: Urban Environment**

| Description | % of land |
|---|---|
| High-density residences ≤ 6 floors | 10 |
| High-density residences ≥ 6 floors | 10 |
| Single family residences | 20 |
| Public Land | 20 |
| Commercial Land | 20 |
| Parks, Cemeteries | 10 |
| Undeveloped/Vacant Land | 10 |

The parameter which controls the choice of equations for determining the economic impact of transportation accidents is the Decontamination Factor, or DECON $_n$. DECON$_n$ is described as follows:

$$DECON_n = \frac{n \cdot PPS \cdot RF \cdot AER \cdot \bar{x}_n \cdot V_d}{CULVL}$$

n = number of curies per package
PPS = packages per shipment (1)
RF = release fraction of spent fuel inventory for each family of radionuclides
AER = fraction of released fuel in aerosol form
$\bar{X}_n$ = atmospheric dilution factor in area n
$V_d$ = deposition velocity
CULVL = Cleanup Level following an accident

In the RADTRAN IV User's Guide, chapter 3, the following discussion on the CULVL value is given:

> Clean-Up Level (CULVL). This factor describes the required level to which contaminated surfaces must be cleaned up (EPA, 1977). The default value is set to the proposed guideline of 0.2 $\mu Ci/m^2$. Note that this value applies to the sum of deposited activity over all isotopes of a multi-isotope material and that the default cleanup value is not widely accepted.

In our analysis of economic costs, the default CULVL was retained. For a sensitivity analysis, a RADTRAN IV run was also performed using a CULVL value of 1 $\mu Ci/m^2$, the maximum value allowed as input.

The Decontamination factor (DECON) is the ration of the contamination level before cleanup to the eventual cleanup level. In determining equations for cleanup costs, the DECON values are grouped into clusters based on the following divisions. Note that the variable names DECON and DF are the same, and are used interchangeably in the RADTRAN User's Guides.

$DF_1$ = 0.1 = minimum level of detectability.
$DF_2$ = 1.0 = criteria level for cleanup. This value corresponds tc a contamination level equal to CULVL.
$DF_3$ = 20 = maximum contamination level for low to moderate range
$DF_4$ = 40 = max level for which cleanup criterion level is feasible

RADTRAN IV uses the CULVL value and the other data for the radionuclide inventory to assign a decontamination factor for a given area of contamination. The atmospheric dilution factor, deposition velocity, and release fraction are radionuclide-specific. Then, RADTRAN assigns economic consequence equations for the following divisions:

**$DECON<DF_2$:**

For areas in which the Decontamination Factor is less than the criteria level for cleanup, there is no cleanup cost outside of the initial fixed costs.

**$DF_2<DECON<DF_3$:**

For areas in which the Decontamination Factor is greater than the criteria level for cleanup, but less than twenty times this level, the RADTRAN II and RADTRAN III User's Guides specify values and equations for economic consequences. These values are derived from per-capita values, then multiplied by the percentage of land occupied by each division. Thus, for example, it is assumed that cleanup of High-Density Residences having $\geq$ 6 floors is \$40 per capita. Since it is assumed that 10% of a city is covered by these buildings, the cost of cleanup is \$40 *.1 or \$4 per person.

| Description | Cleanup Costs ($) |
|---|---|
| Survey Costs (fixed) | 200,000 * Area |
| Evacuation Costs (fixed) | 180 * Pop. Density * Area |
| Income Loss | 230 * Pop. Density * Area |
| Cleanup Costs: | |
| High-Density Residences ≥ 6 floors | 2 * Pop. Density * Area |
| High-Density Residences ≤ 6 floors | 4 * Pop. Density * Area |
| Single-family Homes | 73.1 * Pop. Density * Area |
| Public Land | 10.6 * Pop. Density * Area |
| Commercial Land | 5.6 * Pop. Density * Area |
| Parks, Cemeteries | 3.9 * Pop. Density * Area |
| Undeveloped/Vacant Land | 22,000 * Area |

The above criteria is then combined into a single equation, given below:

Cost of Cleanup ($DF_2$<DECON<$DF_3$)
= [2.2e5 + (509.2*Pop. Density)]*Area

**DF$_3$<DECON<DF$_4$:**

Similarly, for areas in which the Decontamination Factor is greater than twenty times the criteria level for cleanup, but less than forty times this level, the RADTRAN II and RADTRAN III User's Guides specify values and equations for economic consequences. These values are derived from per-capita values, then multiplied by the percentage of land occupied by each division. Thus, for example, it is assumed that cleanup of High-Density Residences having ≥ 6 floors is $40 per capita. Since it is assumed that 10% of a city is covered by these buildings, the cost of cleanup is $40 *.1 or $4 per person.

| Description | Cleanup Costs ($) |
|---|---|
| Survey Costs (fixed) | 200,000 * Area |
| Evacuation Costs (fixed) | 180 * Pop. Density * Area |
| Income Loss | 230 * Pop. Density * Area |
| Cleanup Costs: | |
| High-Density Residences ≥ 6 floors | 18.7 * Pop. Density * Area |
| High-Density Residences ≤ 6 floors | 37.4* Pop. Density * Area |
| Single-family Homes | 235 * Pop. Density * Area |
| Public Land | 112 * Pop. Density * Area |
| Commercial Land | 284 * Pop. Density * Area |
| Parks, Cemeteries | 5.1 * Pop. Density * Area |
| Undeveloped/Vacant Land | 22,000 * Area |

The above criteria is then combined into a single equation, given below:

Cost of Cleanup ($DF_3$<DECON<$DF_4$)
= [2.2e5 + (1102*Pop. Density)]*Area

**DECON>DF$_4$:**

For areas where the contamination level is greater than 40 times the criterion cleanup level, it is assumed that the land will be permanently interdicted, and economic costs stem from relocation and opportunity costs.

| Description | Cleanup Costs ($) |
|---|---|
| Survey Costs (fixed) | 100,000 * Area |
| Evacuation Costs (fixed) | 180 * Pop. Density * Area |
| Personal Income Loss | 5880 * Pop. Density * Area |
| Corporate Income Loss | 2470 * Pop. Density * Area |
| Land Value Loss | 23,000 * Pop. Density * Area |
| Permanent Relocation Cost | 3874 * Pop. Density * Area |
| Relocation of Government Operations | 67 * Pop. Density * Area |
| Security Cost | 1,200,000 * Area |

The above criteria is then combined into a single equation, given below:

Cost of Cleanup (DECON > $DF_4$)
= [1.3e6 + (35470*Pop. Density)]*Area

## II. RWMA Economic Analysis using RADTRAN IV

This section highlights the inputs needed for the economic analysis in addition to the CULVL value discussed in the previous section.

**Keywords used in Economic Analysis:**

**ECONF:**

This parameter is the discount factor used to account for inflation. Since the RADTRAN 4 economic model gives results in 1980 dollars, this has to be updated to present value using an interest rate. One way to approximate this is to use the Consumer Price Index:

**Cost (2000) = Cost (1980) * (CPI (2000)/CPI (1980))**

According to the Federal Reserve Bank of Minneapolis, the CPI in 1980 was 82.4, and the CPI in 2000 is projected to be 171, based on the change from $4^{th}$ quarter 1998 to $4^{th}$ quarter 1999. Thus, the ECONF factor used as input for RADTRAN will be the ratio of the two consumer price indexes, or 2.08.

**ONSCST:**

This parameter specifies the estimated on-scene costs for cleanup of a spent fuel accident of a given severity. The severity of the accident is determined by the release fraction for the fuel. There are four values inputted into the ONSCST array. The first value is a basic cost for determining that there was no release. This cost corresponds to a release fraction (RF) of 0.0. the second value is a cost estimate for accidents with overall release fractions $0<RF\leq .01$; the third for $.01<RF\leq .10$; and the fourth for $RF>.10$. Each species category (eg, NOBLE, PARTICULATE, VOLATILE, RUTHENIUM) has a release fraction for each accident severity category. The overall release fraction is determined from the fraction of the total inventory released.

In the RADTRAN 4 User's Manual, example output file 3 includes economic impacts of transportation by rail in rural areas. This analysis uses the following values for ONSCST:

ONSCST 250 2400 2400 5000

These numbers correspond to the values given in the RADTRAN III User's Manual for spent fuel particulate releases. As an initial estimate, our analysis of a severe train accident in an urban area used these values.

**EMRCST:**

This parameter estimates the immediate cost for a given severity category for emergency response. Since we are only concerned with one accident severity category here (the maximum reasonably foreseeable accident scenario), there will be one estimate here.

In the RADTRAN 4 User's Manual, example output file 3 includes economic impacts of transportation by rail in rural areas. This analysis uses the following values for EMRCST:

EMRCST 20 400 500 600 1500 1700 2100 2500

These EMRCST values correspond to values for each of 8 severity categories. Since our analysis is only considering one category, we use the cost estimate for the most severe category. I will also use the EMRCST value for severity category 6, because I am unclear whether the most severe accident considered by the YMEIS falls into category 6 or category 8.

Since the current analysis is for an accident requiring cleanup costs, the cost involved with initial emergency response will be a relatively small component of the overall costs. For this reason, we are using the values suggested in the RADTRAN IV example problem, keeping in mind that this is likely to result in an underestimate of the true cost of an accident.

**Results:**

The first step in using RADTRAN IV is to ensure it calculates similar health consequences to those calculated using RADTRAN 5. This is done to check our inputs as well as to check the program itself. We took the inputs from the RADTRAN 5 calculation of impacts from 10-year cooled, 4 $\mu Ci/cm^2$ CRUD density, spent nuclear fuel transported in a rail cask containing 26 PWR assemblies. We assumed the same population density (4932.5 persons/km$^2$) and release fractions for maximum accidents. The comparison is given below.

**Comparison between RADTRAN 5 and RADTRAN 4**

| Program used | Population Density persons/km$^2$ | Spent Fuel Age years | Crud Density Ci/cm2 | Crud Inventory* Ci | Population Dose person-rem | Expected LCFs |
|---|---|---|---|---|---|---|
| RADTRAN 5 | 4932.5 | 10 | 4 | 4.36 | 915000 | 457.5 |
| RADTRAN 4 | 4932.5 | 10 | 4 | 4.36 | 857000 | 428.5 |

The table shows that RADTRAN 4 computes consequences that are reasonably close to those given by RADTRAN 5. The conservative nature of the calculated consequences using RADTRAN 4 when compared to the consequences calculated using RADTRAN 5 suggest that the economic impacts could be greater than those calculated and reported here.

The following table shows the results of all RADTRAN 4 calculations performed by RWMA. It shows the economic consequences of a severe spent fuel accident to be crippling.

**RADTRAN 4: Calculations of Economic Impacts of Max. Reasonably Foreseeable Rail Accident**

| File Name | Spent Fuel Age | CRUD Inventory* | ECONF | ONSCST | | | | EMRCST | Pop. Dose | Expected LCFs | Economic Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | years | Ci | * | RF = 0 | 0<RF<.01 | .01<RF<1 | RF>1 | $ | person-rem | | $ |
| one.in4 | 10 | 4.36 | 1 | 250 | 2400 | 2400 | 5000 | 2500 | 857000 | 428.5 | 4.53E+09 |
| two.in4 | 10 | 4.36 | 2.08 | 250 | 2400 | 2400 | 5000 | 2500 | 857000 | 428.5 | 9.42E+09 |
| three.in4 | 10 | 56.03 | 1 | 250 | 2400 | 2400 | 5000 | 2500 | 864000 | 432 | 4.53E+09 |
| four.in4 | 10 | 56.03 | 2.08 | 250 | 2400 | 2400 | 5000 | 2500 | 864000 | 432 | 9.42E+09 |
| five.in4 | 10 | 4.36 | 1 | 250 | 2400 | 2400 | 5000 | 1700 | 857000 | 428.5 | 4.53E+09 |
| six.in4 | 10 | 4.36 | 2.08 | 250 | 2400 | 2400 | 5000 | 1700 | 857000 | 428.5 | 9.42E+09 |
| seven.in4 | 25.9 | 0.55 | 1 | 250 | 2400 | 2400 | 5000 | 2500 | 852000 | 426 | 4.53E+09 |
| eight.in4 | 25.9 | 0.55 | 2.08 | 250 | 2400 | 2400 | 5000 | 2500 | 852000 | 426 | 9.42E+09 |
| nine.in4 | 25.9 | 7.09 | 1 | 250 | 2400 | 2400 | 5000 | 2500 | 853000 | 426.5 | 4.53E+09 |
| ten.in4 | 25.9 | 7.09 | 2.08 | 250 | 2400 | 2400 | 5000 | 2500 | 853000 | 426.5 | 9.42E+09 |
| eleven.in4 | 25.9 | 0.55 | 1 | 250 | 2400 | 2400 | 5000 | 1700 | 852000 | 426 | 4.53E+09 |
| twelve.in4 | 25.9 | 0.55 | 2.08 | 250 | 2400 | 2400 | 5000 | 1700 | 852000 | 426 | 9.42E+09 |

One more analysis was done to perform a sensitivity analysis on the impact of the cleanup level on economic costs. For this scenario, we reran file "eight.in4," which corresponds to 25.9-year cooled fuel, corrected to 2000 dollars, this time using a CULVL value of 1.0 $\mu Ci/m^2$, the maximum level allowed by RADTRAN IV. In this case, the calculated economic cleanup cost was $3,180,000,000, about 1/3 the cost of the 0.2$\mu Ci/m^2$ cleanup level case.

It is important to note that the economic figures obtained through the RADTRAN IV code are extremely conservative. Regardless, the estimated consequences are crippling.

RADTRAN 5 appears to give results that are less dependent on CRUD density and spent fuel age than RISKIND results. However, both programs calculate severe fatality consequences resulting from a spent fuel shipping accident.

Some general results can be given. First, the magnitude increase in consequences when considering 10-year fuel vs. 26-year fuel is strongly dependent on the CRUD inventory being considered. Second, it appears as if the DOE YMEIS consequence analysis used dispersion coefficients based on effective release height. The choice of population distribution around the accident site likely causes this discrepancy: more people are assumed to live near the accident, so a ground-level release with no significant buoyancy rise will affect more people in this model. In the case of a severe impact accident with no fire, the Pasquill-Gifford coefficients should be used for a ground-level release, since there will be no buoyancy-induced dispersion from an elevated-temperature event such as a fire.

Further, the economic costs of such an accident would be astounding. In the economic spreadsheet model provided on the RADTRAN website at Sandia National Laboratories, it is estimated that the cleanup costs for a plutonium dispersal accident in an urban area would be ~$400 million *per* $km^2$. A similar study needs to be performed for a spent nuclear fuel shipping accident. However, the economic model component of RADTRAN 4 and 5 appears to be disabled. We attempted to put economic variable into RADTRAN 4, but the program would not run.

# ATTACHMENT BB

**Radioactive Waste Management Associates**

# Memo

**To:** Bob Halstead

**From:** RWMA

**Date:** 02/14/00

**Re:** RISKIND and RADTRAN calculations

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## Riskind Calculations for rail accident: 26 vs. 10 year old fuel

This memo discusses the procedure used to obtain the results listed in the Yucca Mountain EIS for the population dose during the "maximum reasonably foreseeable accident scenario" involving a train shipment of PWR fuel and compares these results to those of the RADTRAN5 output. Because certain dose limits are wired into the RISKIND code, it was necessary to run RADTRAN5 and compare the results. As an introduction to the RISKIND calculations, we'll first discuss the inputs into the program, including any values that are not specifically mentioned in the YM EIS.

### Population Density

On pg. J-62 of the YMEIS, the following statement is made.

> "The analysis used estimated populations in successive 8-kilometer (5-mile)-wide annular rings around the centers of the 21 large urbanized areas (cities and metropolitan areas) in the continental United States (TRW 1999a, page 22). The average population for each ring was used to form a population distribution for use in the analysis. To be conservative in estimating consequences, the analysis assumed that accidents in urbanized areas would occur at the center of the population zone."

The cited reference provides population information on 20 urbanized areas, given in successive 5-mile annular rings. To estimate the average population at the center of an "average" urban area, the average population in each successive annulus was averaged for all cities to come up with a single population distribution as a function of distance away from the center of a population zone. An exponential trendline was then fitted to the data using Microsoft Excel, and the y-intercept determines the population density at the center of the zone. Two approaches were used to estimate the population density at the center: one fitting a trendline to the average population density data provided in the TRW report cited above, and one fitting a trendline to the median data. The densities obtained were 5214 and 4651 persons/km$^2$, respectively. For this analysis, the average of these two values, 4932.5 persons/km$^2$ was used.

The affected population is assumed to extend 80 kilometers from the site of the accident, as is given in the Yucca Mountain EIS.

**Short Term Exposure Time**:

The Yucca Mountain EIS provides no information on what this parameter should be. The default value given in RISKIND is 2 hours, and the maximum allowable value is 100 hours. If everything else is held constant, the calculated difference in population dose does not vary significantly over the range of 2-100 hours exposure time. This is because the major short-term contribution to dose is inhalation from the passing radioactive cloud.

**Long Term Exposure Time:**

On Page J-59 of the Yucca Mountain EIS, the assumption of long-term exposure time is given:

> "Populations would continue to live on contaminated land for 1 year."

This is the assumption we used to replicate the numbers given in the YMEIS for the maximum reasonably foreseeable accident scenario. This significantly affects the calculations of expected latent cancer fatalities due to a severe accident, when compared with a more standard value of 50 years exposure time (about an order of magnitude more lcf's are calculated using a 50 year exposure time compared with the single year time assumed in the YMEIS). Note that RISKIND caps any individual dose to five rems in a lifetime, the EPA-allowable limit. Thus, RISKIND makes an assumption either about clean-up levels or evacuation. If the populations continues to reside in a contaminated area for a 50-year period, the direct gamma doses will dramatically increase compared to a one-year exposure time.

**Fraction of Gamma Radiation:**

There is no information in the Yucca Mountain EIS that estimates this parameter. Therefore, the RISKIND default value of 0.6 is used. Changing this number from 0.6 to 0.8 does not significantly alter the results.

**Cask Dimensions:**

Figure J-4 in the Yucca Mountain EIS is a drawing of a large rail cask. Its length dimension is given as 6-7 meters. For our analysis, a length of 7 meters is used.

There is no information in the Yucca Mountain EIS that estimates the cask radius. The Luna et al sabotage study uses a rail cask having a radius of approximately 1.1m. The default radius given by RISKIND is 1.08m. Since these two values are in agreement, we decided to use RISKIND's default.

**Spent Fuel Inventory Data:**

We assumed a rail cask carrying 26 PWR assemblies in order to determine our fuel inventory. For the 26-year case, we assumed 39560 MWd/MTU burnup, 25.9 year old spent fuel, as was specified in the YMEIS. We assumed there was 0.46 MTU per assembly, or 11.96 MTU in the rail cask.

**CRUD Inventory**

In RISKIND, the amount of Cobalt-60 released to the environment during a postulated accident event is a function of two mechanisms: Co-60 from the structural components of the fuel released as a particulate, and Co-60 in CRUD released as a CRUD release. For a "severity 6" accident like the maximum reasonably foreseeable accident, it is assumed that 100% of the CRUD is spalled from the fuel rods and released into the environment. For the structural components of the fuel rods, RISKIND assumes a release fraction 2.E-5. The two Co-60 contributors are then added to arrive at a release amount.

The determination of health effects resulting from a postulated release is sensitive to the estimate of the CRUD surface activity density, given in $\mu Ci/cm^2$, and the cask cavity surface area, $m^2$. For our analysis, we assume that the cask cavity surface area is $400m^2$. This is given in the RISKIND help menu as the size of large licensed rail casks. No data is available from the Yucca Mountain EIS concerning this parameter.

The surface activity density of the CRUD is extremely variable. The YMEIS has no data concerning the value they used for this important parameter. RISKIND'S default value is 4 $\mu Ci/cm^2$ for a PWR assembly and 350 $\mu Ci/cm^2$ for a BWR reactor. Appendix D of the RISKIND User's Manual, table D.1 lists the maximum observed Co-60 ($\mu Ci/cm^2$) for a PWR as 0.1 to 140. Table D.4 of the same appendix lists CO-60 activity densities for a variety of PWR reactors as: 140, 100,10,2,16,73,and 19 $\mu Ci/cm^2$. It is important to note that, in RISKIND, the value inputted as the surface activity density is adjusted by the decay of Co-60, according to the age of the fuel. For this Co-60 CRUD data, the age of the fuel and testing methodology is not stated.

The variability of data for CRUD densities makes the estimation of this parameter extremely difficult. To correlate the YMEIS results, we chose the RISKIND default value of 4 $\mu Ci$ Co-60/$cm^2$, the Co-60 surface density, measured at discharge. In addition, we varied this parameter to determine its effect on consequence assessments.

**Meteorological Data and Dispersion Models**

The Yucca Mountain EIS specifies that the maximum reasonably foreseeable accident scenario was analyzed as occurring under stable conditions which would not be exceeded 95% of the time. On pg. J-59 (Table J-23), wind speed frequencies are given as functions of stability class. For the two most stable classes (F&G), the average wind speed, using Table J-23, is 1.55m/s. We used this wind speed and stability class F as inputs for the RISKIND problem.

Another decision in RISKIND involves what atmospheric dispersion model coefficients should be used. RISKIND provides three choices for the model: "Based on effective release height," Pasquill-Gifford, and Briggs stability categories. The RISKIND User's Manual states that the Pasquill-Gifford stability categories should be used for ground level or near ground-level releases. The first model determines which coefficients to use based on calculations of effective release heights of a plume of contaminants, serving to decrease calculated consequences using this program. High temperature fires during severe accidents would serve to increase the effective release height through increased buoyancy forces. For our analysis, we sought to determine the effect the choice of dispersion model has on the RISKIND-calculated results, so we ran a "Based on effective release height" and a "Pasquill-Gifford" model for each set of inputs. As is shown on the results table, the choice of atmospheric dispersion model greatly affects the results. This is because RISKIND assumes an accident takes place at the population center; if the effective release height is higher, more radioactive material is dispersed into areas with lower population density, thereby decreasing the total population dose.

**Accident Severity**

The maximum reasonably foreseeable accident scenario is a category 6 accident. The release fractions specified on page J-57 of the YMEIS (Table J-21) were used as inputs to the RISKIND code. In addition, it is assumed that 100% of the fuel rods will fail in a severe accident.

**Results:**

Using the above inputs, RISKIND was run to determine the population dose and expected latent cancer fatalities resulting from a category 6 accident involving a rail cask in an urban areas under slowly-dispersing conditions. The table below compares our RISKIND run with the run reported in the YM EIS, pg. J-63.

**25.9 Year Fuel Scenario: RWMA Correlation Run**

| | Population Dose (person-rem) | Latent Cancer Fatalities |
|---|---|---|
| **DOE Yucca Mountain EIS** | 61,000 | 31 |
| **RWMA** | 61,500 | 30.8 |

Given the large amount of unspecified inputs, the correlation is excellent.

In addition, fuels with different properties were evaluated to determine the effect of CRUD density, age, and the atmospheric model chosen on consequences from the severe rail accident scenario. These are compared in the following table.

**RISKIND calculations for severe rail accident consequences**

| Case | population density | Crud Surface Activity Density | Atmospheric Dispersion Model | Spent Fuel Age | Population Dose | Expected LCFs |
|---|---|---|---|---|---|---|
| | persons/km$^2$ | μCi/cm$^2$ | | years | person-rem | |
| DOE YMEIS | | | | 25.9 | 61000 | 31 |
| RWMA correlation | 4932.5 | 4 | effective release height | 25.9 | 61500 | 30.8 |
| RWMA RISKIND runs, using population density estimate cited in Yucca Mountain EIS | 4932.5 | 4 | Pasquill-Gifford | 25.9 | 219000 | 109 |
| | 4932.5 | 51.4 | effective release height | 25.9 | 61900 | 31 |
| | 4932.5 | 51.4 | Pasquill-Gifford | 25.9 | 220000 | 110 |
| | 4932.5 | 140 | effective release height | 25.9 | 62600 | 31.3 |
| | 4932.5 | 140 | Pasquill-Gifford | 25.9 | 223000 | 111 |
| | 4932.5 | 1250 | effective release height | 25.9 | 71600 | 35.8 |
| | 4932.5 | 1250 | Pasquill-Gifford | 25.9 | 255000 | 127 |
| | 4932.5 | 4 | effective release height | 10 | 80700 | 40.3 |
| | 4932.5 | 4 | Pasquill-Gifford | 10 | 287000 | 144 |
| | 4932.5 | 51.4 | effective release height | 10 | 83700 | 41.8 |
| | 4932.5 | 51.4 | Pasquill-Gifford | 10 | 298000 | 149 |
| | 4932.5 | 140 | effective release height | 10 | 89300 | 44.7 |
| | 4932.5 | 140 | Pasquill-Gifford | 10 | 318000 | 159 |
| | 4932.5 | 1250 | effective release height | 10 | 160000 | 80 |
| | 4932.5 | 1250 | Pasquill-Gifford | 10 | 569000 | 284 |
| | | | | | | |
| Special Runs: New York City | 24000 | 4 | effective release height | 25.9 | 299000 | 150 |
| | 24000 | 4 | Pasquill-Gifford | 25.9 | 1070000 | 533 |
| | 24000 | 1250 | effective release height | 25.9 | 348000 | 174 |
| | 24000 | 1250 | Pasquill-Gifford | 25.9 | 1240000 | 619 |
| | 24000 | 4 | effective release height | 10 | 393000 | 196 |
| | 24000 | 4 | Pasquill-Gifford | 10 | 1400000 | 698 |
| | 24000 | 1250 | effective release height | 10 | 778000 | 389 |
| | 24000 | 1250 | Pasquill-Gifford | 10 | 2770000 | 1380 |

The table shows how sensitive consequence estimates are to CRUD activity and the choice of dispersion model. It also shows how considering 25.9-year fuel instead of 10-year fuel can result in a significant underestimate of the consequences of a severe spent nuclear fuel transportation accident.

Further, we performed consequence estimates for a severe accident in a "hyper-urban" area such as Manhattan. It is important to keep in mind that these results only concentrate on fatalities, not on morbidity or economic consequences. The economic consequences resulting from the cleanup and decontamination of such an accident in an urban area would be astronomical: it is important to understand this in order to fully assess the true consequences of a spent fuel accident. RISKIND does not estimate the economic consequences of an accident.

The YMEIS assumes that, in the event of a severe accident, persons will live on the contaminated land for one year before moving. That is, their long-term exposure duration is 1 year. A more realistic assessment may be to use a 50-year exposure period. This will drastically increase the number of expected latent cancer fatalities due to direct gamma groundshine from Co-60 and Cs-137. For comparison, we ran RISKIND using a 50 year long-term exposure duration for spent fuel with a CRUD activity of 4$\mu$Ci/cm$^2$ aged both 25.9 and 10 years. These are shown below. As seen the number of latent cancer fatalities is 8.5 times greater for a 50-year residence time on contaminated land.

**RISKIND results: sensitivity to long-term exposure**

| Long-term Exposure Time (years) | Spent Fuel Age (years) | Atmospheric Dispersion Model | Population Dose (person-rem) | Expected LCFs |
|---|---|---|---|---|
| 1 | 25.9 | Pasquill-Gifford | 219,000 | 109 |
| 50 | 25.9 | Pasquill-Gifford | 1,870,000 | 933 |
| 1 | 10 | Pasquill-Gifford | 287,000 | 144 |
| 50 | 10 | Pasquill-Gifford | 2,470,000 | 1,370 |
| 1 | 25.9 | Effective release height | 61,500 | 30.8 |
| 50 | 25.9 | Effective release height | 525,000 | 262 |
| 1 | 10 | Effective release height | 80,700 | 40.3 |
| 50 | 10 | Effective release height | 771,000 | 386 |

**RADTRAN 5 Calculations for a Severe Rail Accident**

Because of the wired-in limits in the RISKIND code, it is possible that RADTRAN yields dose estimates that are far higher. In order to address this issue, we ran RADTRAN 5 for conditions similar to those described above. RADTRAN is set up as a "risk" assessment program: it sums the probabilities of each occurrence times its consequences to arrive at an "expected" dose. In order to use RADTRAN to perform a consequence analysis for a severity 6 accident, we needed to make a few adjustments to default values in the program. For example, we considered only one "accident severity category," the most severe accident category given in the Yucca Mountain EIS, and made the probability of this accident 100% in urban areas. We used the same fuel properties as we did in the RISKIND analysis above. The table below shows the results of this analysis.

**RADTRAN 5 calculations for severe rail accident consequences**

| Population Density | Spent Fuel Age | Crud Density | Crud Inventory* | Interdiction Level | Population Dose | Expected LCFs |
|---|---|---|---|---|---|---|
| persons/km$^2$ | years | $\mu$Ci/cm2 | Ci | | person-rem | |
| 4932.5 | 25.9 | 4 | 0.55 | 40 | 846000 | 423 |
| 4932.5 | 25.9 | 4 | 0.55 | 1.00E+08 | 847000 | 423.5 |
| 4932.5 | 25.9 | 51.4 | 7.09 | 40 | 847000 | 423.5 |
| 4932.5 | 25.9 | 51.4 | 7.09 | 1.00E+08 | 848000 | 424 |
| 4932.5 | 25.9 | 1250 | 172.46 | 40 | 870000 | 435 |
| 4932.5 | 25.9 | 1250 | 172.46 | 1.00E+08 | 871000 | 435.5 |
| 4932.5 | 10 | 4 | 4.36 | 40 | 915000 | 457.5 |
| 4932.5 | 10 | 4 | 4.36 | 1.00E+08 | 916000 | 458 |
| 4932.5 | 10 | 51.4 | 56.03 | 40 | 922000 | 461 |
| 4932.5 | 10 | 51.4 | 56.03 | 1.00E+08 | 923000 | 461.5 |
| 4932.5 | 10 | 1250 | 1362.66 | 40 | 1110000 | 555 |
| 4932.5 | 10 | 1250 | 1362.66 | 1.00E+08 | 1110000 | 555 |

*Crud Inventory is decayed to the age of the spent fuel, Crud Density is assumed to be the density at fuel discharge

**ATTACHMENT CC**

**Radioactive Waste Management Associates**

# Memo

**To:** R Halstead

**From:** M Lamb and M Resnikoff

**Date:** 02/22/00

**Re:** Comment Summary – Yucca Mtn Draft EIS

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## Summary

After reviewing DOE/EIS-0250D, *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (July, 1999), with emphasis on the transportation of spent fuel to the proposed repository, a number of questions have been raised which need answer. Below is an outline summarizing some of the key deficiencies of the EIS. Many of the comments listed below follow a central theme: the EIS uses outdated experimental data and improper mathematical models to arrive at unbelievable estimates of health consequences due to incident-free transportation and accident scenarios. No new experiments have been performed to assess shipping cask response to postulated accident conditions or sabotage scenarios, even though the current generation of casks bear little resemblance to the casks used in experiments cited by the current EIS. No new estimation of the frequencies of severe accidents is made, even though rail and highway conditions, such as speed limits, have changed since the cited studies were performed. Computer models estimating release fractions in a terrorist strike are used which cannot properly model the casks involved. When the deficiencies in the EIS's treatment of transportation are assessed, it becomes clear that new experimental studies are necessary to provide a realistic assessment of the costs of transportation. These new experiments must involve an updated Modal Study, new experiments concerning modern cask response to sabotage events, and new traffic surveys estimating the frequency of severe accidents. The outlined points below are just brief summaries, and detailed analyses of each point will be provided at a later date.

# 1. Use of data from the Modal Study to estimate accident severities and probabilities of severe accidents

## 1.1. Use of "mid-lead" temperature as parameter determining accident severity

1.1.1. Lead (MP 621°F) will stabilize the inner core temperature in the event of a fire until it is completely melted. This has the affect of insulating the inner core from temperature increases for an extended period of time. Uranium, with a much higher melting point, will not melt, resulting in an inner core temperature that will rise constantly with heat input; therefore, inner cores of newer casks are expected to have higher temperatures during a fire of a given intensity.

1.1.2. The use of mid-lead temperature results in grouping of all fires with temperature greater than 1050°F into one consequence category, since lead-nickel alloying occurs here, weakening the integrity of the older casks. Since uranium and/or stainless steel will behave differently under temperature duress, new classifications based on its properties must be used for categorizing fire intensities.

## 1.2. Use of "reference cask" containing a water jacket neutron shield

The Modal Study models the dead air space resulting from the evaporation of the water jacket neutron shield to reduce the heat transfer rate from a fire to the cask by over 70%. Modern casks use polypropylene, not water jackets; hence the estimated heat transfer rate in fire events is a significant underestimate of the behavior of modern casks (Audin states this may result in a reduction in the time it takes to melt the lead cask from 1.09 hours to 20 minutes)

## 1.3. "Lead cask bias" used to select most appropriate measurement parameter

The decision to use strain on the inner cask wall as the primary measure of cask response is based on lead's tendency to "slump" when subjected to high loading, resulting in high strains on inner cask wall. However, uranium and/or stainless steel, is strong and rigid and thus will not slump. Rather, the force from impacts will be transferred to the joints and welds of the cask, likely resulting in a greater force being applied to them than those in a lead cask. The choice of strain as the sole measurement parameter for physical duress will likely lead to an underestimation of the damage caused to newer casks through rupture of welds and seals in the event of an accident. Therefore, new experiments must be performed to model this behavior.

## 1.4. Incorrect use of "distribution" and "frequency" of velocities

The EIS states that, even though the average speed limit on national interstates has increased since the Modal Study, the distribution of accidents, and the frequency distribution of accidents, on the highways is not likely to change. However, no evidence is cited to support this statement. The National Highway Safety Traffic Administration (NHTSA 1998), along with numerous other agencies, have provided evidence that increases in speed limit lead to more accidents, more fatalities, and a greater proportion of vehicles traveling at higher speeds. All of these suggest that the DOE is incorrect in claiming that increased speed limits will not affect accident severity distributions. In one study assessing the change in Interstate fatalities in states which raised the speed limit in 1995, the NHSTA discovered that "Interstate fatalities experienced a statistically significant increase in those states that raised their posted speed limits late in 1995 or early in 1996." (NHTSA 1998) Further, the Insurance Institute for Highway Safety reported that distributions of travel velocities do indeed change with increased speed limits. For example, the Institute cited traffic statistics in New Mexico, finding that "the proportion of motorists exceeding 70mph grew from 5 percent shortly after speed limits were raised [from 55 to 65 mph] to 36 percent." (Institute). This shows that the EIS's statement that traffic velocity distributions will not be affected is incorrect, which leads to the conclusion that the probabilities of severe accidents used by the EIS are also incorrect and likely to be underestimates. This provides another reason why the Modal Study is not useful or relevant to current transportation conditions.

## 1.5. Improper assumptions regarding the location of severe accidents

The Modal Study correlated severe accidents with high velocities, concluding that the most severe accidents will take place, both for rail and truck, in rural environments. However, most severe rail accidents take place at downgrades, which are as likely to be located in suburban areas as rural ones. Further, the probability of a severe truck fire is greater in urban and suburban environments then it is in rural ones. Refer to Resnikoff, 1993.

In determining severe accident scenarios, the EIS assumed that severe accidents had an equal probability of occurring anywhere, with the probability in each population zone being determined by the length of time each truck or train passes through it. Since trucks and trains spend less time in urban zones, some of the most severe accident scenarios are considered "not reasonably foreseeable" in urban areas. Accident data does not support the assumption that severe accidents are randomly distributed (Resnikoff, 1993). Therefore, the DOE needs to assess the consequences of these most severe accidents as occurring in urban zones.

## 1.6. Improper Exclusion of most severe accident scenarios

1.6.1. The Modal Study used as its "average highway conditions" a stretch of Interstate 5 in Los Angeles and Orange counties. For example, it tallied the number, height, and geographic conditions of the bridges on this stretch and used these to estimate the number of bridges of a certain height. This was then used to estimate how many tall bridges existed in the entire nation for spent fuel trucks to cross. Using this, it was determined that an accident involving a truck falling off a high bridge was not "reasonably foreseeable" and its consequences were not determined. Since this stretch of highway is dominated by urban areas, the distribution of bridge types is biased in favor of small, short bridges, like the ones that cross over other roads. This is not representative of national conditions and leads to the unnecessary exclusion of a potentially disastrous consequence.

1.6.2. The Modal Study assumes that the probability of train accidents involving the falling off of a bridge is the same as that for the highway scenario, with the geographic conditions also taken from the highway estimations. More clearly, the Study used data taken from Interstate 5 to estimate the geographic conditions of national train routes, including bridge heights. Thus, the same argument given for the highway scenario (point 1.5.1) holds here, but more so since there is no proof that highway and rail conditions are similar.

1.6.3. The method of rejecting accidents having a yearly probability less than one in 10 million is arbitrary and incorrect when performing a probabilistic risk assessment. The product of the probability and the likely consequences are what determine significance in a risk assessment.

1.6.4. DOE consistently offers estimations of health effects due to transportation without giving a range of likely effects in the event of an accident. This is based on the assumption that the effects given are "conservative." However, the points raised here show that the studies are not conservative: unless new studies are performed, a range of possible health effects should be given.

1.6.5. If the DOE insist on using the "reasonably foreseeable" criteria of 1 in 10 million mentioned above, improper accident distribution data, unknown cask response to accident conditions, and improper estimation of accident probabilities (all mentioned above) will make some circumstances not deemed "reasonably foreseeable" in the Modal Study "reasonably foreseeable." These events must be considered in any acceptable consequence analysis.

## 2. Improper Attention to Sabotage and Terrorism Scenarios

### 2.1. Inadequate Selection of "Reference Weapons"

2.1.1. The 1999 Sandia Study (Luna et al) needs to be more specific on the type of device it selected for computer simulation. Although the report claims that the vagueness was necessary to prevent the document from being classified, it is necessary to provide more details so a thorough analysis of its findings can be performed. This is the only way to test the validity of the computer simulations used in the report.

2.1.2. The DOE needs to make clear exactly what range of devices is available for consideration as "reference devices." It is our belief that devices such as the Milan

Anti-Tank Missile and the US TOW 2 Anti- Tank missile, reported to have armor-penetrating capabilities of greater than 1000mm (39.4 inches) and greater than 700 mm (28.5 inches), respectively, must be considered (Norris).

2.1.3. All Sandia reports considering sabotage implicitly assume that a terrorist attack will involve a single strike using a single charge or missile. However, some devices can be fired multiple times in quick succession: the US TOW 2 can be fired up to three times in 90 seconds (Norris, Halstead & Ballard). The DOE needs to address the potential for a multiple-strike terrorist attack, which is likely to cause significantly more damage then the scenario modeled in the Sandoval and Luna reports.

2.2. **Improper extrapolation of previous experiments to current cask designs**

2.2.1. Use of "Swept Volume" as a surrogate for fraction of respirable material released

2.2.1.1. The equation listed in the Luna report which attempts to define a "swept mass" solely in terms of the geometric properties of the hole left by the charge does not balance its units. This will be analyzed in detail in the Review Comments. If this equation turns out to be invalid, the entire analysis performed in the Luna report and cited in the EIS becomes irrelevant, requiring a completely new analysis. Until this is addressed the results correlating swept volume and respirable aerosol production cannot be trusted.

2.2.1.2. The relationship assumes that there is only one hole into the fuel cask (i.e. an entry hole but no exit hole). Multiple holes will significantly increase the amount of respirable material released (Luna estimated it to be by a factor of 10). Due to the possibility that certain weapons can completely penetrate a cask, or that a cask will be penetrated by multiple shots, any relationship relying on a single hole entry into the cask is not credible as a worst-case scenario.

2.2.1.3. The "one hole assumption" results in another underestimation of the fraction of respirable aerosol produced by the oxidation of $UO_2$. Assuming a cask is fully penetrated, this will create a flow of oxygen into the cask, which will result in the oxidation of $UO_2$ to $U_3O_8$, a fine powder of mostly respirable particles. This oxidation rate is increased significantly at temperatures above $250^0C$ (Aronson). Temperatures this high will be likely in the event of a missile strike coupled with a fire. This significant source of respirable aerosols was not accounted for in the Luna correlation exercises.

2.2.1.4. Using a geometric correlation assumes that all casks, and all devices used in an attack, will exhibit the same thermal properties as the cask in the Sandoval experiments. Since the thermal properties of uranium are very different from lead, this will not be the case. Because of this, it is not enough to simply assume a relationship between aerosol released and swept volume, and use this to estimate releases in unrelated casks. This ignores the thermal mechanisms of aerosol generation, such as oxidation of $UO_2$ under elevated temperatures. Further, different attack devices will impart a different amount of heat into the cask, resulting in different aerosol production rates as a function of thermal input. This will be likely to change to relationship between swept volume and aerosol released, making any correlation attempt between different casks or different devices trivial.

2.2.2. Estimation of respirable aerosol produced due to breach of pressurized rods

Luna cited irrelevant data to estimate the amount of surrogate fuel aerosol that could be created within the cask and released in the event of a breach. The cited experiment showed a linear relationship between the energy density in the material from the impact of a calibrated hammer on brittle objects and mass of particulate material having diameter smaller than 10μm. However, the materials chosen were refractory to ensure that melting and vaporization were not observed. In the event of a missile strike, temperature effects are likely to be extremely significant. Therefore, any study that tries to estimate aerosol production as a function of energy density, but does not include temperature effects, is irrelevant and should not be used. Because of this, the estimate of 5% aerosol production due to HEDD impact is not accurate or conservative. It may do better to assume that all of the uranium mass not accounted for in the Sandoval studies (assumed to be inside the cask and deposited on its walls) was of respirable size and able to be expelled in the event of cask compromise. This will significantly alter the consequence analysis, since about 1% of the total $UO_2$ mass, and 37% of the mass released from the pins, was "unaccounted for" in the Sandoval full-scale experiment. A direct measurement of the amount of material deposited inside the cask walls is necessary to estimate how much aerosol is produced due to HEDD action. Therefore, a new study is recommended with more complete sampling procedures in order to obtain an experimental value for the respirable aerosol production due to the HEDD. The 5% value assumed is likely to be low.

2.2.3. Unsubstantiated reduction in the spent fuel-surrogate fuel ratio

Luna attempts to reduce the value used by Sandoval which accounts for the fact that spent fuel will produce more respirable aerosols then the surrogate fuel used in most experiments. Luna quotes the following experimental estimations of this ratio: .53, 5.6, .71, .42, 3, 2.8, 2.5, 3, 12. From this, it is estimated that 3 is the most appropriate ratio, even though the range of experimentally-determined ratios differs over 3 orders of magnitude. Further, after Luna (correctly) dismisses all values less than 1.0 as implausible, it would make sense to use the largest cited value for a conservative approximation. Alternately, the geometric mean of a large distribution of numbers is often used for estimation purposes (a value of 4 in this case), so long as a range based on the standard deviation about the mean is given as well.

However, more likely is that the large distribution of estimated ratios suggests that there is no clear, reproducible relationship between the amount of spent fuel and surrogate fuel aerosols produced from a blast of given intensity. Thus, it is argued that *no* ratio is acceptable. Rather, the inconsistent data suggest that the only way to determine spent fuel response to a detonation is to detonate a cask containing spent fuel and analyze the results. Short of doing this, the correlation used by Luna is arbitrary, non-conservative, and unacceptable.

## 2.3. SCAP computer code used without sufficient benchmarking

The Luna study attempts to utilize a computer model as a replacement for actual experimentation in order to determine the possible damage caused by two HEDD's on state-of-the-art shipping casks. However, the code that they use admittedly does not model multi-layered targets well. The Luna study "benchmarks" the SCAP code against the Sandoval full-scale test and determines that the code predicts penetration depth well, but underestimates the size of the hole created by the penetration. In an attempt to remedy this, the Luna report multiplies the predicted hole size by a factor of 2.0 to obtain "correct" results, then proceeds to do the same when modeling other cask designs. This approach is seriously incorrect. It assumes that the code will consistently model all cask layer or shell arrangements, including different numbers of layers, which is incorrect. With no experimental data to prove this, this assertion is unacceptable. It cannot be assumed that a computer code which, when used to model multi-layered targets could result in "serious difficulties in comparing SCAP modeling output and experimental data" (Robinson), would be expected to model, for example, a lead-steel interface with the same degree of incorrectness as a lead-uranium interface. Therefore, until an experimental proof of the merits of using the SCAP code to model the behavior of a shaped charge strike on a uranium-shielded cask is performed, the code cannot be considered validated. Further, since the code underestimated the true size of the hole in the Sandoval experiments, it cannot be assumed that this code will provide a conservative approximation of penetration damage. This leads to the call for a full set of experiments designed to determine the true effect of a HEDD explosion on cask integrity.

## 2.4. Omission of two important sabotage scenarios

### 2.4.1. Nevada intermodal transfer station sabotage event

The EIS, on pg. J-95, states that section J.1.5 evaluates the effects of sabotage on intermodal transfer stations. However, there is no section J.1.5, and there is no mention of this potential sabotage event again. It is essential to perform an analysis of the likely effects of a successful sabotage event on an intermodal transfer station because of its unique conditions. For one, shipping casks at an intermodal station will be stationary. This eliminates some of the problems associated with striking a moving target optimally that were presented in the EIS. Also, this makes the possibility of a multiple-cask release possible. Third, the appeal among potential saboteurs of attacking a station rather than a truck or train must be addressed. Intermodal transfer will also occur at reactor sites without rail access. All of these factors suggest that the potential for sabotage at an intermodal station must be addressed in a comprehensive manner.

2.4.2. Barge transport sabotage event

The EIS does not consider the consequences of a possible sabotage event on a barge shipment of spent nuclear fuel. As this is one of the transportation options being considered, it is important to consider the effects of a successful sabotage event, including the breach of shipping casks and release of radioactive material into the air and water, especially near populated areas, water supplies, or natural environments. It is essential to address this concern, especially since there was no discussion of the consequences of severe barge accidents, which were determined by the EIS to be not reasonably foreseeable.

## 2.5. Failure to identify/profile potential "Threat Groups"

It would be helpful to provide some general profiles of potential "Threat Groups" in terms of characterizing exactly what these groups are capable of doing, and the relative likelihood of each group performing a sabotage act. This would help in determining what types of weapons, forces, expertise, etc can be expected to be utilized by different groups, providing the DOE with a better estimate of what safeguards must be put in place. The *Final Environmental Impact Statement: U.S. Spent Fuel Policy, Storage of Foreign Spent Power Reactor Fuel* (1980: DOE/EIS-0015) provides a list of "Threat Groups" to nuclear fuel storage and transportation; a similar, but updated, list would be helpful.

## 2.6. Improper dismissal of considering the probability of terrorist events

The EIS and the Luna report both consistently state that, since sabotage events are not randomly occurring, no estimation of their probability can be made, other than assuming they are "extremely rare." However, some comment should be made concerning the increase in large-scale terrorist attacks and how this relates to the need for sufficient safeguards against such attacks. Even though attacks are not random events, some effort should be made to identify trends, such as the increase in attacks on American soil over the last few years. This provides a proper foundation through which to analyze the level of protection required from terrorist attacks.

## 2.7. Failure to present a true "worst case scenario" for consequence analysis

2.7.1. Use of "averaged" wind conditions instead of wind blowing in one direction

The inputs used by the DOE in determining health effects of a successful sabotage scenario assume generalized wind conditions. For a true worst-case scenario, the impact of a radiological release directly downwind from a large population center, such as an office building, prison, stadium, etc. must be addressed. The use of wind conditions averaged over all directions dilutes the effect of a single-direction wind event.

2.7.2. Use of "average" (neutral) weather conditions, instead of worst-case conditions

The EIS states that, because the time and place of a sabotage event cannot be predicted, average weather conditions for the entire United States must be used. However, it seems likely that potential saboteurs will, to the degree feasible, plan sabotage events around those weather conditions that are the most damaging. Thus, for a true "worst case" sabotage scenario, weather conditions leading to the greatest consequences should be used.

2.7.3. "One bullet assumption"

As has been previously discussed, the consideration of only a single HEDD strike in the simulation of a sabotage event is unrealistic. Terrorists who are serious about causing a significant release of radioactive material, and who have the means of obtaining armor-penetrating weaponry, will likely bring a complete arsenal, including several armor-penetrating devices, incendiary devices, etc. Therefore, cask response to multiple missile penetrations, especially if they are fired in succession such that missiles strike an already damaged cask, must be addressed. It is extremely likely that the damage done to an already-penetrated cask will be substantial. This has not been assessed by the DOE and must be in order for the sabotage portion of the EIS to be considered complete.

2.7.4. Failure to consider effects of breached cask coupled with long-duration fire

The EIS assumes that there will be no significant secondary effects on the cask after missile impact, since the casks themselves are not flammable. However, the trucks and trains carrying them are flammable. Further, there is the possibility of deliberately causing a fire, either by truck bomb or other method, to intensify the damage from a penetrated cask. This scenario must be taken into account.

## 2.8. **Failure to assess social, psychological, environmental, or economic costs**

In order to be able to truly assess the consequences of a successful sabotage event, the full scale of effects must be studied. The DOE has commissioned studies addressing the psychological impacts of radiation accidents on the public, but similar studies have not been performed for this EIS. In addition, no consideration of the cost of cleanup of such an event is given. Below is a skeleton outline of the various factors not considered by the EIS that need considerable attention.

2.8.1. Social/psychological costs not addressed
- 2.8.1.1. Increased fear of nuclear energy, and nuclear industry
- 2.8.1.2. Fear of vulnerability to attack (see Oklahoma City bombing)
- 2.8.1.3. Susceptibility of foreign-born citizens to discrimination
- 2.8.1.4. Distrust of government that transports materials capable of such destruction

2.8.2. Environmental costs not addressed
- 2.8.2.1. Groundwater and/or surface water contamination→ more human costs
- 2.8.2.2. Loss of land use near site for significant amount of time

2.8.3. Economic costs not addressed
- 2.8.3.1. Cleanup costs
- 2.8.3.2. Decontamination costs
- 2.8.3.3. Lost workdays due to radioactive contamination of roads, buildings, etc
- 2.8.3.4. Loss of tourism in Las Vegas, eg, due to contamination or fear
- 2.8.3.5. Evacuation costs
- 2.8.3.6. Relocation costs

## 3. Inputs to computer models predicting exposure levels

### 3.1. Use of temperature and strain as independent variables

Refer to Resnikoff, 1993. In many severe accidents, high impacts are coupled with vehicle fires. In predicting probabilities of accidents of a given severity, the probability of fire of a certain severity is multiplied by the probability of an impact of a given strain. This tends to underestimate the "true probability" of strain-fire accidents, as these two variables are not independent. This is another artifact of the Modal study needing revision.

### 3.2. Inconsistent assumptions made in RADTRAN4 and RISKIND

3.2.1. DOE employs RADTRAN4 for total risk, summing individual accident probabilities multiplied by consequences. RISKIND is employed to assess the maximum accident consequences. The assumptions employed should be identical, but they are not. RADTRAN4 assumes ingestion of contaminated food after an accident in rural areas in determining collective population dose; RISKIND assumes no radiological dose to populations from ingestion of contaminated food after an accident in determining maximum accident scenarios. It is unclear why these two inputs are different.

3.2.2. In calculating effects to the maximally exposed individual in an accident scenario, the EIS assumes that this person is located 360 meters (~1200 ft) from the site. In calculating effects to the maximally exposed individual in a sabotage scenario, the EIS assumes this person is 140 meters (~460 ft) from the site. It is unclear where these distances came from, or why they are different.

### 3.3. **Incident-free exposure assumptions**

3.3.1. Escorts

DOE based its estimates of annual dose to escorts on regulations that we believe are insufficient to ensure the safety of the transportation vehicles. We recommend that these requirements be increased so that there is always at least one armed escort travelling in a separate vehicle from all truck shipments, and in separate rail cars for all train shipments. This will increase the estimated dose to escorts.

3.3.2. Individuals stuck in traffic

DOE assumes that individuals exposed to radiation dose due to being stuck in traffic near a transportation vehicle will occur only once per individual. However, personal driving patterns are not random, since people (especially commuters) tend to be on the same road at the same time of day. Therefore, persons being stuck in traffic near a transportation vehicle once are likely to be stuck multiple times.

### 3.4. **Population density**

The EIS uses average population densities from the 1990 Census to estimate the "worst-case" accident and sabotage scenarios. This ignores time-dependent, such as daytime population densities in cities due to worker commuting (Manhattan's population doubles every day), tourist population densities, special-event and localized densities. The maximum population densities used in the RISKIND code should reflect these factors.

### 3.5. **Characteristics of spent fuel used in accident consequence estimates**

3.5.1. Age of spent fuel

Simply put, the longer a given type of fuel is removed from a reactor prior to shipment, the less radioactive it is. Fuel which has cooled for a long time has had the time to undergo decay reactions, reducing its level of radioactivity. The DOE assumes in its estimates a spent fuel age of 25.8 years, even though fuel is only required to be cooled for 5 years prior to transportation. This results in a reduced estimate of hazard. Unless the DOE can show through legal requirements that spent fuel will be aged 25.8 years prior to shipment, it is not appropriate to use this age in its exposure assessments for incident-free and accident scenarios.

A more likely scenario is that older fuel, already stored in storage casks at reactor sites or at the proposed PFS storage facility in Utah, will remain stored while newer fuel, stored in fuel pools, but aged more than five years, will first be transported off the reactor site so that reactors can be decommissioned more rapidly. DOE has established an acceptance quota for reactor fuel; for utilities, the most advantageous use is to further reactor decommissioning. Further, DOE would have to pay the cost of casks and transportation of this newer fuel. Older fuel would then be shipped at a much later date.

In a 25.8-year period, important radioactive contaminants in irradiated fuel will have decayed away. For example, $Co^{60}$, a main contributor to radiation dose from crud spallation, has a half-life on the order of 5 years. Concentrating on 25.8-year fuel decreases the amount of $Co^{60}$ modeled by a factor of $2^5$, seriously reducing possible radiological effects in the event of a release.

## 4. Improper attention to Intermodal Transfer Station

4.1. Crash scenarios analyzed

**4.1.1.** Airplane crash scenario

The airplane crash scenario assumes that the crash velocities will be those typical of takeoff and landing operations. As a worst-case scenario, the potential impact of a crashing military jet traveling at 600mph should be considered. This is likely to cause release of some radioactive material.

## 5. Economic analysis of transportation costs

5.1. The EIS did not assess the costs of severe accidents when assessing the transportation costs involved in the Yucca Mountain Project. In order to aid in the adequate preparation for potential accidents, an estimate of the true cost of remedying such an accident is essential. This assessment must include, but is not limited to, the following: emergency costs, surface cleanup costs, decontamination costs (of roadways, buildings, groundwater, surface water, etc.), hospital costs to injured parties, lost workdays due to building contamination, economic losses due to fear of contamination, loss of tourism (e.g., in the event of an accident in Las Vegas), evacuation costs, relocation costs, contaminated food embargo costs, insurance costs, legal costs, governmental costs, and so forth.

## Summary:

The above points are not exhaustive: however, they give a good indication of some of the major deficiencies in the EIS's treatment of transportation. Because of these deficiencies, it is recommended that DOE perform a completely new transportation assessment, using new experimental data. This new experimental data involves sabotage, transportation accident frequencies, and transportation accident release fractions and consequences. For the sabotage experiments, it is recommended that new tests be performed subjecting modern rail and truck casks to multiple strikes with a TOW 2 missile or its equivalent. The computer model used in the Luna report is unjustified and unacceptable. For the accident release fractions, it is recommended that the DOE perform a new Modal Study, using modern truck and rail casks and developing new parameters with which to measure accident severity and cask response. Further, modern data needs to be collected concerning the effect of speed limit on accident distributions.