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DEPARTMENT OF ENERGY

46 FR 26677

May 14, 1981

Program of Research and Development for Management and Disposal of Commercially Generated Radioactive Wastes; Record of Decision

Dated: April 16, 1981.

TEXT: This Record of Decision has been prepared pursuant to the Regulations of the Council on Environmental Quality, 40 CFR Part 1505, on the selection of a strategy for the disposal of commercially-generated radioactive wastes and the supporting program of research and development.

Decision

The United States Department of Energy has decided to (1) adopt a strategy to develop mined geologic repositories for disposal of commercially-generated high-level and transuranic radioactive wastes (while continuing to examine subseabed and very deep hole disposal as potential backup technologies) and (2) conduct a research and development program to develop repositories and the necessary technology to ensure the safe long-term containment and isolation of these wastes.

Description of Alternatives

Three alternatives were considered:

(1) Emphasize Mined Repositories. The research and development program for waste management would emphasize use of mined repositories in geologic formations in the continental United States capable of accepting radioactive wastes from either the once-through or reprocessing cycles (while continuing to examine subseabed and very deep hole disposal as potential backup technologies). The program would concentrate on identifying specific locations for the construction of mined repositories. This action would not preclude further study of other disposal methods as possible supplementary methods for handling of specific isotopes.

(2) Parallel Technology Development. The research and development program would emphasize the parallel development of several disposal methods. The research and development program would be structured to bring the knowledge and development status of two or three disposal concepts to an approximately equal level. Based upon the Department's current evaluation, the likely candidate technologies for this parallel development strategy would be:

a. Geologic disposal using conventional mining techniques,

b. Placement in sediment beneath the deep ocean (subseabed),

c. Disposal in very deep holes.

Other disposal methods which were analyzed as candidates for consideration included:

a. Disposal by injection of liquid waste into underground cavities resulting in melting of surrounding rocks,

b. Geologic disposal on islands,

c. Disposal by melting into continental ice sheets,

d. Injection into porous or fractured strata beneath the earth's surface,

e. Transmutation of waste actinides in reactors to change to stable or short-lived isotopes, and

f. disposal by rocket transport into space.

(3) No-Action. Under this alternative, the Department's research and development programs for radioactive waste disposal would be eliminated or significantly reduced and a decision on a plan to dispose of commercially-generated wastes would be deferred indefinitely.

Basis for Decision

The Department has decided to proceed with a programmatic strategy favoring the disposal of commercially-generated radioactive wastes in mined geologic repositories. This decision is based on the Department's commitment to the early and successful solution of the Nation's nuclear waste disposal problem so that the viability of nuclear energy as a future energy source for America can be maintained. The decision also will save money by focusing Federal funds on the further development of the most advanced disposal technique.

Environmental effects considered for each of the three programmatic alternatives -- mined repositories, parallel technology and no-action -- included regional and world-wide radiological impacts, commitment of natural resources and cost. Environmental effects were considered for five nuclear power growth scenarios and for both the once-through and reprocessing fuel cycles. Comparison of 70-year whole-body dose accumulations from normal operations revealed somewhat higher doses for the parallel technology than for the mined repository alternative, but the differences were not large enough to be significant and doses were only a small fraction of the naturally occurring dose even for the highest nuclear growth cases examined. Dose accumulations for the no-action alternative were somewhat lower. The analysis of the no-action alternative did not, however, consider the need for, and environmental effects of, additional facilities when those in use have exceeded their design lifetime, since it was assumed that no Federal funds would be used.

In reaching its decision to emphasize mined geologic repositories, the Department considered the requirements for economic resources. Required resources considered for each of the three programmatic alternatives included steel, cement, diesel fuel, gasoline, propane, electricity, and manpower. Requirements for the parallel technology generally ranged two-to-three times higher than those for the mined repository alternative. In no case was the quantity of a required resource more than a small fraction of the current United States rate of production of the resource.

The Department's decision also included a consideration of total system cost, i.e., the cost of waste treatment, storage, transport and disposal. The Department's research and development and repository site qualification costs, which are to be recovered through fees charged to the utilities for storage and disposal, were also considered. Based on cost information summarized in its Final Environmental Impact Statement, the Department concludes that the parallel technology alternative is generally more costly than the mined repository alternative. This cost of waste management and disposal is expected to add about two-to-six percent to the consumer's cost of electricity.

The no-action alternative could be construed as contrary to the mandate given the Department of Energy by law, and in any event would be undesirable because of the temporary nature of the present storage of wastes and the need to construct additional facilities for extended storage as present facilities reach their design lifetime. The Department also feels the no-action alternative is unacceptable because of the long-term radiological risk posed by the lack of effective containment of the wastes. The Department has, for these reasons, rejected the no-action alternative.

A number of waste disposal methods other than mined repositories were evaluated in the Department's Final Environmental Impact Statement. Factors which were considered in evaluating each of these disposal methods included: (1) Radiological effects during the operational period, (2) non-radiological effects, (3) compliance with existing National and international law, (4) independence from future development of the nuclear industry, and (5) potential for corrective or mitigating actions. The analysis of each of these factors showed a clear preference for the mined geologic alternative.

From a consideration of technical feasibility, only two of the alternative waste disposal methods appeared promising enough to warrant further study: subseabed and very deep hole. For subseabed, the Department has decided to continue studies of the environmental technical, legal, and institutional feasibility of isolating wastes within the sedimentary geologic formations of the deep seabed. This concept is considered a longer-term supplementary disposal method to mined repositories. The Department also feels that very deep hole disposal warrants some additional study as a possible backup for high-level waste disposal. Further development of the very deep hole concept will emphasize the capability to take corrective or mitigating actions.

While not a viable alternative for the disposal of all high-level wastes, the Department has concluded that space disposal may be profitably studied for its application to special disposal concerns, e.g., more remote isolation of long lived and environmentally mobile radionuclides such as <99> Tc and <129> I.

The other disposal methods considered by the Department (island, transmutation, rock melt, ice sheet, and well-injection) were found to have no clear advantage over mined geologic disposal and to provide no additional complementary function. In some cases these other technologies appeared clearly less desirable (for instance, in the rock melt disposal concept the waste is expected to be liquid for the first 1000 years and thus is most mobile during the period of greatest fission product hazard).

Although the level of knowledge of alternative technologies to mined geologic disposal is not comparable, sufficient evidence exists to support the Department's finding that there is little likelihood that any of these technologies would be superior, from an environmental perspective, to the geologic alternative.

Discussion of Environmentally Preferable Alternative(s)

Based on the information presented in the Final Environmental Impact Statement, the Department concludes that the environmental impacts of the program to emphasize mined repositories are similar to those of the parallel technology development program. The evaluation of long-term effects presented in the Final Environmental Impact Statement indicates that mined geologic disposal, and those other technologies which justify further consideration, would have similar environmental impact. The Department has concluded that the no-action alternative is environmentally unacceptable from a long-term perspective and that neither of the two remaining programmatic alternatives can be identified as clearly preferred from an environmental viewpoint.

Mitigation

Given the programmatic nature of the proposal, it is difficult to address specific measures that will be taken to minimize adverse environmental impacts resulting from this decision. However, the Department will evaluate the adverse impacts of specific site characterization activities and repository construction at each candidate site in site specific environmental impact statements and will undertake mitigation activities where appropriate. Mitigation activities which may be needed were considered in Section 5.4 of the Final Environmental Impact Statement. Conditions which may require mitigation include fugitive dust depositions from surface handling of mined material and runoff to nearby surface waters.

Conclusion

The Department has considered the benefits, impacts, and costs of reasonable alternatives and has concluded that the research and development program on disposal of commerically-generated radioactive wastes should focus on mined geologic repositories, while continuing to examine subseabed and very deep hole disposal as potential backup technologies.

Mahlon E. Gates,

Acting Assistant Secretary for Nuclear Energy.
[FR Doc. 81-14496 Filed 5-13-81; 8:45 am]

BILLING CODE 6450-01-M

DOE/EIS-0046F-V.1

Environmental Impact Statement Management of Commercially Generated Radioactive Waste. Volume - 1

U. S. Department of Energy
Washington, D.C.

October 1980

CHAPTER I

SUMMARY

In the course of producing electrical power in light water reactors (LWRs), the uranium fuel accumulates fission products until the fission process is no longer efficient for power production. At that point the fuel is removed from the reactor and stored in water basins to allow radioactivity to partially decay before further disposition. This fuel is referred to as "spent fuel." Although spent fuel as it is discharged from a reactor is intensely radioactive, it has been stored safely in moderate quantities for decades. Spent fuel could be reprocessed, and about 99.5% of the remaining uranium and newly formed plutonium could be recovered for reuse. However, present policy dictates that spent LWR fuel reprocessing will be indefinitely deferred because of concern that widespread separation of plutonium could lead to proliferation of nuclear weapons. As a result, spent fuel is currently stored for possible future reprocessing or disposal. Storage or disposal must be designed so that nuclear waste will not be a present or future threat to public health and safety.

The United States Department of Energy (DOE) has the responsibility to develop technologies for management and disposal of certain classes of commercially generated radioactive wastes (namely high-level and transuranic).[a] High-level waste is defined as either the aqueous solution from the first-cycle solvent extraction, where spent fuel is reprocessed for recycle of uranium and plutonium, or spent fuel if disposed of. High-level waste is also intensely radioactive.

Other wastes are generated during reprocessing that, although larger in volume than high-level wastes, are less intensely radioactive. Wastes that contain more than a specified amount of radionuclides of atomic number greater than that of uranium are called transuranic (TRU) wastes. TRU wastes are categorized here as either remotely handled (RH) or contact-handled (CH) wastes, depending on the requirements for radiation protection of personnel. Special attention must be given to TRU wastes because they contain alpha particle-emitting nuclides that are of particular concern as a result of their long half lives and tenacious retention if incorporated in the body. Other waste forms that include neither high-level nor TRU are so-called low-level wastes.[b]

The principal objective of waste disposal is to provide reasonable assurance that these wastes, in biologically significant concentrations, will be permanently isolated from the human environment. To provide input to the decision on a planning strategy for disposal of these radioactive wastes, this Statement presents an analysis of environmental impacts that could occur if various technologies for management and disposal of such wastes were to be developed and implemented.

(a) In a message to Congress on February 12, 1980, the President reiterated the role of DOE as lead agency for management and disposal of radioactive wastes.

(b) Low level wastes, other than those originating at DOE facilities, are managed and disposed of by licenses in accordance with regulations of the NRC.

The DOE is proposing a program strategy emphasizing development of conventionally mined waste repositories, deep in the earth's geologic formations, as a means of disposing of commercially-generated high-level and TRU wastes. Adoption of this program strategy constitutes a major federal action for which the National Environmental Policy Act of 1969 (NEPA) requires preparation of a detailed environmental impact statement (EIS).

This summary highlights the major findings and conclusions of this final Statement. It reflects the public review of and comments offered on the draft Statement. Included are descriptions of the characteristics of nuclear waste, the alternative disposal methods under consideration, and potential environmental impacts and costs of implementing these methods. Because of the programmatic nature of this document and the preliminary nature of certain design elements assumed in assessing the environmental consequences of the various alternatives, this study has been based on generic, rather than specific, systems. At such time as specific facilities are identified for particular sites, statements addressing site-specific aspects will be prepared for public review and comment.

1.1 THE NEED FOR WASTE MANAGEMENT AND DISPOSAL

There are now about 70 operating commercial LWR power reactors in the United States, which represent approximately 50 GWe[a] of installed nuclear powered electrical generating capacity. The amounts of spent fuel accumulated for the present (1980) inventory and for alternative nuclear power generating scenarios considered in this Statement are shown in Table 1.1.1.

TABLE 1.1.1. Total Spent Fuel Disposal or Reprocessing Requirements

Nuclear Power Growth Assumption			
Case	Scenario	Energy Generated, GWe-yr[a]	Spent Fuel Discharged, MTHM[b]
1	Present Inventory Only--Reactors Shut Down in 1980[c]	200	10,000
2	Present Capacity (50 GWe)[c] and Normal Reactor Life	1,300	48,000
3	250 GWe System by Year 2000 and Normal Reactor Life (No new reactors after Year 2000)[d]	6,400	239,000
4	250 GWe System by Year 2000 and Steady State Capacity to Year 2040 (New reactors to maintain output)[d]	8,700	316,000
5	500 GWe System by Year 2040[d]	12,100	427,000

(a) Energy generated is based on the total accumulated through the year 2040.
(b) MTHM = metric tons (1000 kg = about 1.1 U.S. tons) of heavy metal in original fuel. One MTHM of spent fuel consists of about 96% uranium, 1% plutonium and 3% fission products.
(c) Reprocessing is not applicable to Cases 1 and 2 because in Case 1 there is no need for reprocessing and in Case 2 no economic incentives exist for reprocessing.
(d) Waste management impacts of nuclear power generation through the year 2040 are considered for these scenarios.

The total radioactivity in one MTHM of LWR fuel and equivalent HLW for various times after discharge from a reactor is shown in Figure 1.1.1. Similarly, the heat generation rate in this fuel is illustrated in Figure 1.1.2. These figures show that a reduction by a factor of about 1,000 in radioactivity relative to one-year-old fuel is reached in about 300 years for spent fuel and in about 200 years for uranium and plutonium recycle high-level waste. The heat generation rate is lower by a factor of 100 for spent fuel at about 300 years and for recycle high-level waste at about 150 years.

(a) One GWe = 1×10^9 watts.

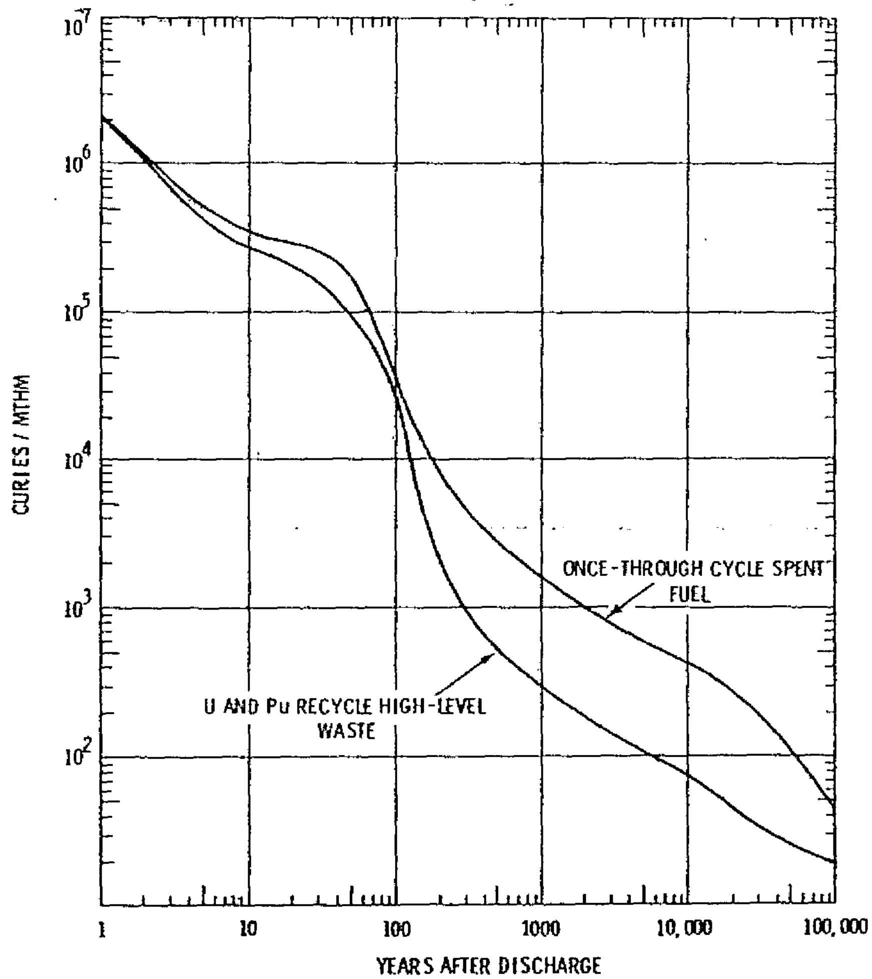

FIGURE 1.1.1. Radioactivity in Spent Fuel and High-Level Waste as a Function of Time

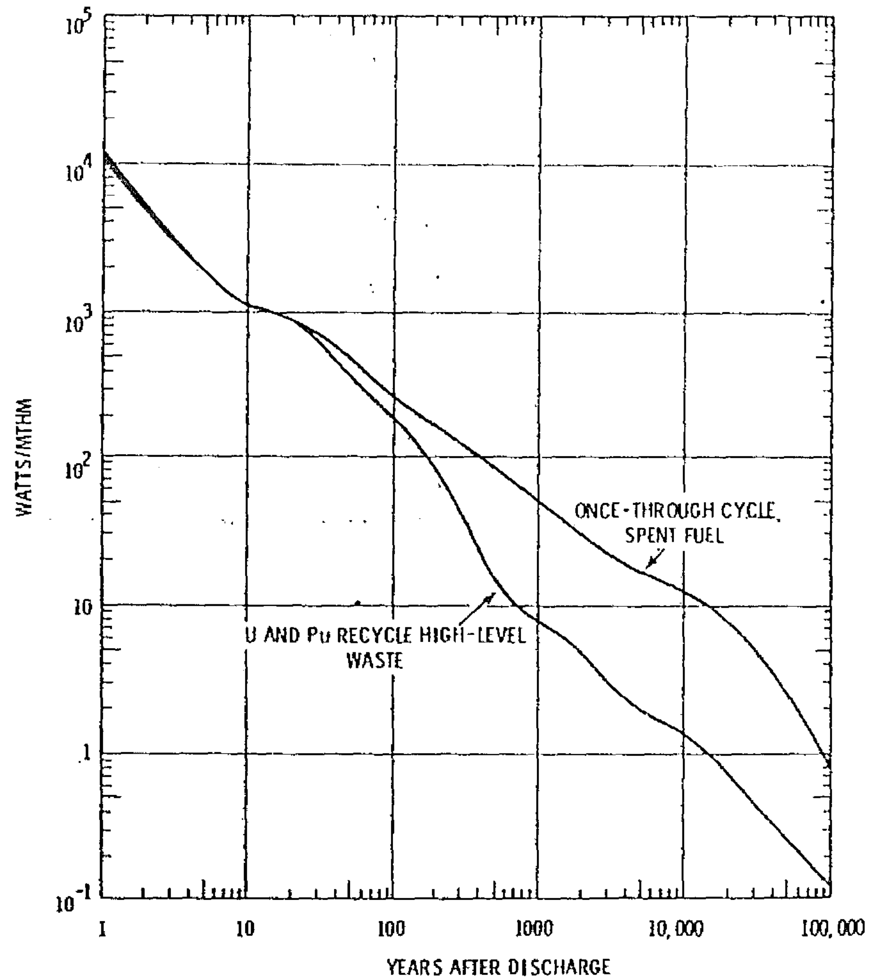

FIGURE 1.1.2. Heat Generation Rate of Spent Fuel and High-Level Waste as a Function of Time

The President, in his February 12, 1980 message on radioactive wastes, called for waste disposal facilities that could receive wastes from both the commercial nuclear power production program and the national defense program. Since defense wastes are not explicitly treated in this Statement, it is not intended to provide environmental input for disposal decisions on defense wastes. However, in a generic sense, systems that can adequately dispose of commercial radioactive wastes can reasonably be expected to adequately dispose of defense wastes, since the processed wastes from the national defense program produce lower temperatures and lower radiation intensities than do wastes from the same quantity of similarly processed commercial fuel. Thus, assuming that other factors are equal, repository loading criteria would generally be less stringent (in terms of quantities of waste per unit area) for defense wastes than for commercial wastes. For this reason certain of the analyses of impacts presented in this EIS should be of use in the preparation of EIS's on the long term management of high-level and TRU defense waste.

1.2 THE PROGRAMMATIC ALTERNATIVES

The programmatic alternatives considered in this Statement are:

- Proposed Action. The research and development program for waste management will emphasize use of mined repositories in geologic formations in the continental U.S. capable of accepting radioactive wastes from either the once-through or reprocessing cycles (while continuing to examine subseabed and very deep hole disposal as potential backup technologies). This action will be carried forward to identify specific locations for the construction of mined repositories. The proposed action does not preclude further study of other disposal techniques. For example, the selective use of space disposal for specific isotopes might be considered.

- Alternative Action. The research and development program would emphasize the parallel development of several disposal technologies. This action implies an R&D program to bring the knowledge regarding two or three disposal concepts and their development status to an approximately equal level. Based upon the Department of Energy's current evaluation, the likely candidate technologies for this parallel development strategy would be:

  1) geologic disposal using conventional mining techniques
  2) placement in sediment beneath the deep ocean (subseabed)
  3) disposal in very deep holes.

  At some later point, a preferred technology would be selected for construction of facilities for radioactive waste disposal.

- No Action Alternative. This alternative would eliminate or significantly reduce the Department of Energy's research and development programs for radioactive waste disposal. Under this alternative, existing spent fuel would be left indefinitely where it is currently stored and any additional spent fuel discharged from future operation of commercial nuclear power plants would likewise be stored indefinitely in water basin facilities either at the reactors or at independent sites.

1.3 THE PROPOSED ACTION

The proposed action is to select and pursue a programmatic strategy that would lead to disposal of existing and future commercially generated radioactive high-level and transuranic wastes in mined repositories in geologic formations. This Statement addresses environmental impacts related to implementing such disposal[(a)]. The programmatic strategy will direct effort and concentrate resources on a research and development program leading to repositories and to site-selection processes. Some support will be provided to further evaluate the alternatives of subseabed disposal and disposal in very deep holes.

Environmental impacts related to repository construction, operation, and decommissioning are analyzed in this Statement as are the impacts of predisposal waste treatment, storage and transportation to the extent they might effect selection of a disposal option. Environmental impacts are developed for individual example facilities and for systems based on the power growth scenarios described in Table 1.1.1 This very broad or generic approach to evaluating the environmental issues provides a comprehensive overview of the likely consequences of the proposed action and constitutes the first phase of DOE's NEPA implementation plan for waste management and disposal (DOE/NE-0007 1980). This plan for waste management and disposal is based on a tiered approach, which is designed to eliminate repetitive discussions on the same issues and to focus on important issues ready for decision at each level of environmental review. Thus, as more site- or facility-specific decision points are approached, and before each such decision and before conducting of activities that may cause an adverse impact or limit the choice of reasonable alternatives, additional environmental assessments, or impact statements will be prepared as appropriate.

The proposed research and development program for waste management will emphasize use of mined repositories in geologic formations capable of accepting radioactive wastes from either the once-through or reprocessing cycles. This program will be carried forward to identify specific locations for the construction of mined repositories.

Initially, site characterization programs will be conducted to identify qualified sites in a variety of potential host rock and geohydrologic settings. As qualified sites are identified by the R&D program, actions will be taken to reserve the option to use the sites, if necessary, at an appropriate time in the future. Supporting this site characterization and qualification program will be research and development efforts to produce techniques and equipment to support the placement of wastes in mined geologic repositories.

The Department of Energy proposes that the development of geologic repositories will proceed in a careful step-by-step fashion. Experience and information gained in each phase of the development program will be reviewed and evaluated to determine if there is sufficient knowledge to proceed to the next stage of development and research. The Department plans to proceed on a technically conservative basis allowing for ready retrievability of the emplaced waste for some initial period of time.

(a) Disposal of radioactive wastes in mined geologic repositories was stated by the President in his February 12, 1980 message as the interim planning strategy to receive emphasis pending environmental review under NEPA.

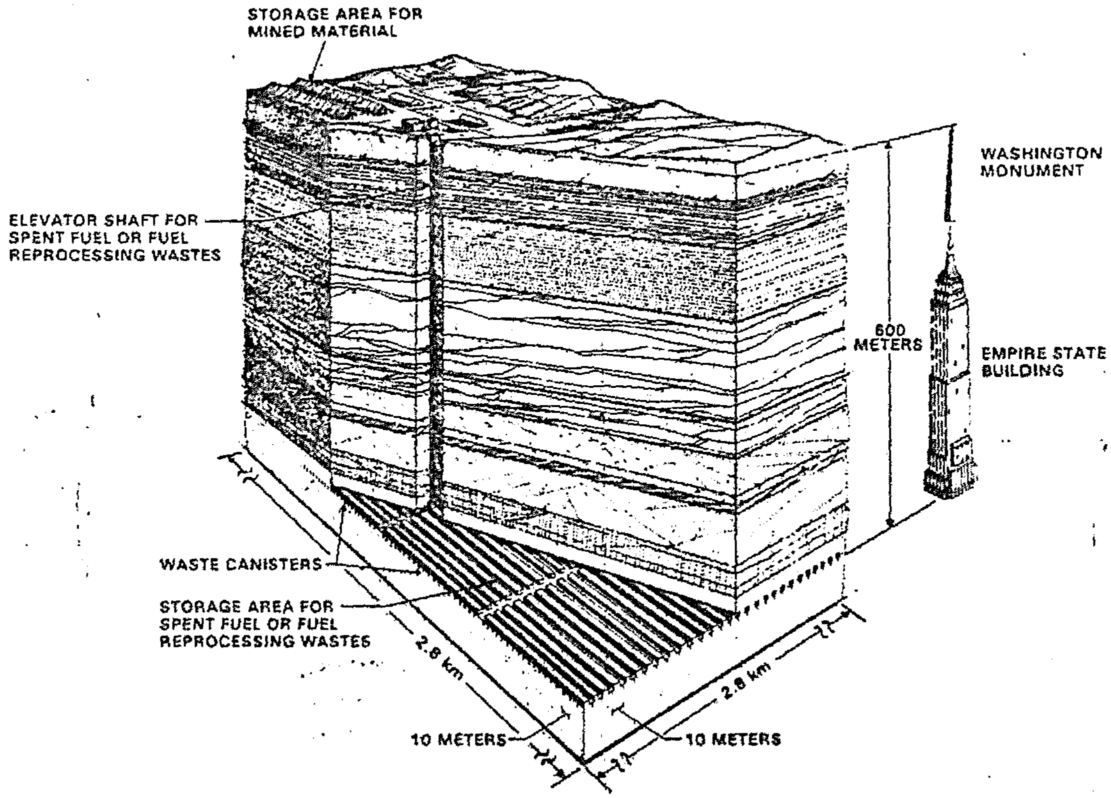

FIGURE 1.3.1 Deep Underground Geologic Waste Repository

1.3.1 Mined Geologic Disposal of Radioactive Wastes

The concept of mined geologic disposal of radioactive wastes is one in which canistered high-level wastes and other wastes in canisters, drums, boxes or other packages, as appropriate to their form, radioactive waste content and radiation intensity, are placed in engineered arrays in conventionally mined rooms in geologic formations far beneath the earth's surface. An artist's rendering of the geologic disposal concept is shown together with more familiar structures for comparison in Figure 1.3.1.

Geologic disposal, as analyzed in this Statement, also employs the concept of multiple barriers. Multiple barriers include both engineered and geologic barriers that improve confidence that radioactive wastes, in biologically significant concentrations, will not return to the biosphere. Engineered barriers include the waste form itself, canisters, fillers, overpacking, sleeves, seals and backfill materials. Each of these components may be designed to reduce the likelihood of release of radioactive material and would be selected based on site- and waste-specific considerations. Geologic barriers include the repository host rock and adjacent and overlying rock formations. While engineered barriers are tailored to a specific containment need, geologic barriers are chosen for their in-situ properties for both waste containment and isolation.

1.3.2 An Example Geologic Repository

For purposes of illustration and for estimating the environmental impacts of development and implementation of waste disposal in geologic repositories, an example repository was postulated that would have an underground area of about 800 hectares (2000 acres) and would be located about 600 meters (2000 ft) underground. This repository area provides for reasonable waste disposal capacity and is achievable from both construction and operational points of view using conventional room and pillar mining techniques. Actual repositories may be larger or smaller than 800 hectares (ha) depending upon site-specific characteristics.

In this Statement salt, granite, shale and basalt are considered as examples of repository host rock. These rock types represent a range of characteristics of candidate earth materials representative of geologic formations that might be considered but other rock types such as tuff may also be suitable candidates.

Because of restrictions of radioactive waste heat loading on the host rock (to prevent or restrict effects on the rock structure) and other structural considerations, different spacing of waste canisters (containers) would be required and would result in different repository waste capacities for a given rock type and repository area.

The number of 800-ha example repositories required for disposal of spent fuel or reprocessing wastes under the different nuclear power growth assumptions described in Section 1.1 is given in Table 1.3.1. The ranges given reflect the different load capacities (both from a permissible heat load standpoint and because of the different fractions of the 800 ha available for waste emplacement) of repositories in the different host rocks.

TABLE 1.3.1. Number of 800 Hectare Example Repositories Required for Various Nuclear Power Growth Assumptions

Case	Nuclear Power Growth Assumption	Number of Repositories: Spent Fuel	Number of Repositories: Reprocessing Wastes
1	Present Inventory Only Reactors Shut Down in 1980	0.03 to 0.1	(a)
2	Present Capacity and Normal Life	0.2 to 1	(a)
3	250 GWe System by Year 2000 and Normal Life	1 to 4	2 to 5
4	250 GWe System by Year 2000 and Steady State[(b)]	2 to 5	3 to 6
5	500 GWe System by Year 2000[(b)]	2 to 7	4 to 9

(a) If all reactors are shut down in 1980 or if nuclear power were to be restricted to present capacity there would be no economic incentive for reprocessing.
(b) Required by Year 2040.

As shown in Table 1.3.1 the subterranean area needed for spent fuel or reprocessing wastes from the power-generating scenarios considered in this Statement ranges from approximately 24 ha (60 acres) to about 7,200 ha (18,000 acres or 24 mi^2) depending upon the scenario and the choice of repository media. The larger numbers of repositories for reprocessing wastes are required principally because of the large volumes of TRU wastes requiring disposal.

Once licensing approvals are obtained, an approximate 5-year repository construction period is estimated. The operating period may range from 1 to 30 years or more depending c the size of the industry served and on the number of repositories operating concurrently.

1.3.3 Environmental Impacts Associated with Construction and Operation of Example Geologic Repositories

Environmental impacts associated with construction and operation of geologic repositories include radiological impacts, both in the short and long term, land and other resource commitments, and impacts related to ecological, nonradiological, aesthetic, and socioeconomic aspects. In the case of socioeconomic, aesthetic, and ecological impacts and hypothetical failures of repositories in the long term, impacts are summarized for a single 800-ha repository, as might be built in salt, granite, shale or basalt and containing either spent fuel or reprocessing wastes. Radiological impacts of waste management and disposal, resource commitments and dollar costs are summed in Section 1.7 for total system requirements for power growth assumptions given in Table 1.1.1.

1.3.3.1. Radiological Impacts

Radiological impacts that might be associated with repository construction (mining), operation and decommissioning, as well as those that might result from unplanned events either before or after the repository was closed were analyzed in detail. The estimated 70-year whole-body dose to a hypothetical regional population (2 million persons) from radon and radon daughter products as a result of repository mining operations ranges from less than one to 100 man-rem depending on host rock. During the time the repository was receiving wastes (6 to 20 years), normal operations might add about 1 man-rem to this total. During these time periods, the regional population would have received from about 1,000,000 to 4,000,000 man-rem from naturally occurring, undisturbed radionuclides. Thus, construction and operation of a geologic repository under normal conditions do not constitute a significant radiological impact.

Accidents occurring during operation of the repository that might have radiological impacts were also investigated. The accident believed to have the largest potential radiological consequence is the dropping of a waste canister down the repository shaft and rupture of the canister on impact. The 70-year whole-body doses to the regional population from such accidents were determined to total to less than 6000 man-rem for 20 years of waste emplacement in a repository. During the same period the regional population would receive about 4,000,000 man-rem from naturally occurring sources. However, doses to workers in the repository from radioactive material released in the event of a canister drop could be fatal (greater than 7,000 rem in first year following the accident). Engineered precautions similar to those outlined in Section 5.4 are expected to preclude such consequences and to reduce doses to workers to safe levels.

Results of a total system analysis of radiological and other impacts for the various power generating projections are summarized in Section 1.6. For those interested in details of environmental aspects of the complex interactions of predisposal and disposal activities, and power growth assumptions, Chapter 7 should be consulted.

1.1.3.2 Resource Commitments

Various resources would be required in the construction and operation of geologic repositories. Ranges of some of the more important resource commitments, as a function of host rock, are presented in Table 1.3.2. The values given are based on a normalized energy production basis of one GWe-yr (about 9 billion kWh, equivalent to one large reactor operating for one year).

Even at an installed nuclear power capacity of 250 GWe operating over several decades the tabulated material and energy commitments are but a small fraction of that used for the

TABLE 1.3.2 Resource Commitments Associated with Construction and Operation of Geologic Waste Repositories, Normalized to 1 GWe-yr

	Spent Fuel Repositories	Fuel Reprocessing Waste Repositories	Approximate U.S. Annual Production
Propane, m^3	1.6 - 2.0	1.5 - 3.3	1×10^6
Diesel Fuel, m^3	1.2×10^2 - 1.7×10^2	1.7×10^2 - 2.5×10^2	4×10^8
Gasoline, m^3	1.2×10^1 - 1.5×10^1	1.1×10^1 - 2.4×10^1	6×10^8
Electricity, kw-hrs	1.0×10^6 - 1.1×10^6	1.3×10^6 - 1.8×10^6	2×10^{12}
Manpower, man-yrs	1.6×10^1 - 1.7×10^1	1.8×10^4 - 3.3×10^1	4×10^6 (a)
Steel, MT	2.5×10^1 - 6.1×10^1	6.2×10^1 - 1.0×10^2	1×10^8
Cement, MT	2.2×10^1 - 2.6×10^1	2.9×10^1 - 6.7×10^1	7×10^7
Lumber, m^3	1.7 - 2.1	1.6 - 3.5	3×10^9

(a) Construction and mining.

total economy. To give additional perspective to the consumption of energy as fossil fuel and electricity, each was converted to units of energy expended in deep geologic disposal of waste per unit of energy produced by the fuel from which the waste came. In the case of spent fuel 0.04% of the energy produced was consumed in geologic waste disposal and in the case of fuel reprocessing wastes 0.05% of the energy produced was consumed. On this basis it is concluded that the irretrievable commitment of the above materials is warranted.

1.1.3.3 Socioeconomic Impacts

Socioeconomic impacts associated with the construction and operation of repositories are dependent largely on the number of persons who move into the locality in which the facility will be located. Site characteristics that are especially important in influencing the size of the impacts include the availability of a skilled local labor force, secondary employment, proximity to a metropolitan area, and demographic diversity (population size and degree of urbanization) of counties in the commuting region. An additional factor in the generation of impacts is the time pattern of project-associated population change. For example, a large labor force buildup followed closely by rapidly declining project employment demand could cause serious economic and social disruptions both near the site and within the commuting region.

In this Statement impacts are estimated for three reference sites, identified as Southeast, Midwest, and Southwest. These areas were chosen because siting of facilities in those regions is plausible and because they differ substantially in demographic characteristics, thus providing a reasonable range of socioeconomic impacts.

In general, the reference Southwest site is more likely to sustain significant socioeconomic impacts than are the other two sites, because it has a smaller available unemployed construction labor force, lacks a nearby metropolitan center, and is subject to the generation of greater secondary employment growth than are the other sites. If a repository were to be built in an area where demographic conditions approximated those of the Southwest site, a detailed analysis of site-specific socioeconomic impacts would be needed to help prevent serious disruptions in provision of necessary social services.

Table 1.3.3 presents the manpower requirements for construction and operation of a single waste repository accepting either spent fuel or reprocessing wastes.

TABLE 1.3.3. Manpower Requirements for Construction and Operation of a Single Waste Repository (three peak years)

Repository Medium	Average Annual Employment: Spent Fuel Repository Construction	Spent Fuel Repository Operation	Reprocessing Waste Repository Construction	Reprocessing Waste Repository Operation
Salt	1700	870	2000	1300
Granite	4200	1100	3000	1300
Shale	2200	880	2100	1200
Basalt	5000	1100	3800	1500

1.3.3.4 Land Use, Ecological Impacts and Other Impacts

At an 800-ha repository, above ground facilities (including mining spoils piles) would occupy about 200 to 300 ha depending on geologic media. An additional 10 ha would be used for access roads. An 800-ha area above the subterranean repository would be set aside at the surface, and mineral and surface rights would be restricted. This surface land, except that occupied by mining spoils piles, could be returned to its former use when the repository surface facilities are decommissioned after sealing and closure of the repository. Presently an area equal to 3,200 ha, centered over the repository, is considered necessary for exclusion of nearby subsurface activities. Subsurface activities could be restricted as long as institutional control exists. (It is expected that this issue will be more closely examined for site-specific applications. Present plans call for a repository design that does need not to rely on institutional controls after closure.)

The main ecological concern of repository construction and operation is the potential for airborne and waterborne contamination of the environs as a result of the very large mine spoils piles. Land near repositories in salt could be contaminated by windblown salt;

nearby streams could be harmed by runoff contaminated with salt. Removal of the salt to a nonharmful environment, such as through dilute dispersal at sea or stabilization of the salt piles could obviate the problem. Repositories in shale do not appear to pose as serious a problem, although alteration of pyrite, a mineral found in shales, could lead to contamination of streams. The spoils piles from repositories in granite and basalt are not expected to have a significantly adverse affect on the environment.

It is possible that for any rock type the pile of rock left on the surface will have an adverse aesthetic impact. The possibility also exists that these spoils piles of rock (millions of MT), if arranged properly, could become markers identifying the locations of the repositories--although some would maintain that such markers eventually might actually enhance the probability of archaeological exploration.

It is concluded that, in a generic sense, neither land use nor ecological impacts are of such a magnitude as to deter development of geologic repositories or their use for disposal of nuclear radioactive wastes from commercial power generation.

1.3.4 Environmental Impacts in the Long Term

Planned functioning of the geologic repository after closure will result in very little in the way of environmental impacts. So long as institutional controls exist there will probably be some control of land useage above the repository. There will probably be some monitoring performed until future generations decide to discontinue monitoring. Although heat from the waste will ultimately reach the surface over the repository, the estimated temperature rise is expected to be less than 0.5°C in all cases. Small amounts of uplift and subsidence might occur for repositories in salt and shale but probably none for repositories in granite and basalt. During planned functioning of the waste repository after closure there will be no health effects attributable to the repository.

Although waste repositories will be sited, loaded, and sealed with every expectation that long term radiological impacts will be nonexistent, the ways in which a repository might fail, the likelihood of its failure, and the consequences to the human environment of such failure were investigated in detail. At 600 m below the earth's surface, it is extremely improbable that wastes in biologically important concentrations would ever reach the human environment. Nevertheless, several events were postulated that might release repository contents, and estimates were made of the possible consequences of such release, in terms of radiation dose to, and postulated health effects among, the public. In brief, these events were:

- Impact of a giant meteorite directly over the repository releasing some of the repository contents to the atmosphere (which is believed to have consequences on the order of other events such as volcanism and nuclear warfare that might breach a repository)
- Faulting or other fracturing of the host rock, followed by flooding of the repository with water and either a) contamination of an emergent stream, b) slow ground-

water transport to the biosphere, or c) contamination of a near surface aquifer that had been tapped by a well

- human intrusion by drilling for exploration
- solution mining of salt in the case of a repository in salt.

The doses to the regional population were calculated for each event and then the number of radiation-related health effects was determined by applying a conversion factor of from 100 to 800 health effects (50 to 500 fatal cancers plus 50 to 300 serious genetic disorders per million man-rem (as developed in Appendix E). The results were then multiplied by the probability (where determinable) that the event would occur, to obtain a measure of expecte societal risk.

Societal risk in each case where probabilities could be estimated were very small; for example, in the case of breach by a giant meteorite whose probability was estimated to be 2×10^{-13}/yr and where the largest calculated consequences were 1.4×10^{5} health effects the societal risk amounted to 3×10^{-8} health effects/yr, and in the case of faulting and flooding the societal risk amounted to 3×10^{-11} health effects/yr. For comparison, the expected societal risk from lightning in the population of 2 million, in the reference environment, is about 1 fatality per year. In the worst case of general contamination of water, not more than one radiation-related fatality was projected to result over a 10,000-year period.

Although believed to be highly unlikely because of the extreme depth of the repository, no probability could be assigned to the act of drilling into a repository. If, however, drilling did take place within the surface projection of the repository area and to the depth of the repository, the probability was determined to be 0.005 per 1000 drill holes (based on relative cross-sections and spatial density of canisters in the repository) that a waste canister would be intercepted. If drilling took place about 1000 yrs after disposal and a high-level waste canister were penetrated, the contaminated drilling mud, when brought to the surface, could result in a small increase in risk of adverse health effects occuring among about two dozen people postulated to live in the immediate area, if no cleanup takes place.

Even if drilling into the repository were to occur without canister penetration the drill hole might constitute a conduit for entry of water into the repository. Mechanisms to return the water to the biosphere are more difficult to postulate. Regardless, if this event took place, the consequences are believed to be significantly less than those resulting from faulting and flooding scenarios also discussed in this Statement.

Because of the abundance of salt in this country, and its frequent location at depths much less than 600 m, the chance of solution mining near a repository in bedded salt formations is believed to be remote. However, solution mining in a domed salt formation is

(a) The production rate of the hypothetical salt solution mine was estimated to be sufficient to supply salt for about 40 million people.

believed to be much more likely. Part of the reason for this is that there may be geologic surface features that suggest the presence of domed salt; however these features are absent for deeply bedded salt. Assuming that a repository in salt was breached in the course of solution mining for salt and that salt was mined for one year before it was discovered to be contaminated, doses about one-tenth of those from naturally occurring sources were calculated to result among the 40 million people assumed to be consuming the contaminated salt.[a] Health effects were also estimated to be about one-tenth of those that might be attributable from natural background.

1.4 ALTERNATIVE ACTION--BALANCED DEVELOPMENT OF ALTERNATIVE DISPOSAL METHODS[a]

The alternative program strategy calling for balanced development of several alternative methods requires selection of some other disposal alternative(s) in addition to mined geologic repositories. The following disposal methods are analyzed as candidates for consideration in the alternative waste disposal program. and from this analysis, mined geologic, very deep hole, and subseabed disposal are identified as the most likely candidate technologies for balanced development.

1.4.1 Very Deep Hole Waste Disposal Concept

A very deep hole concept has been suggested that involves the placement of nuclear waste in holes in geologic formations as much as 10,000 meters (6 miles) underground. Potential rock types for a repository of this kind include crystalline and sedimentary rocks located in areas of tectonic and seismic stability.

Spent fuel or high-level waste canisters could be disposed of in very deep holes. However, it is not economically feasible to dispose of high-volume wastes (e.g., TRU) in this manner and thus another alternative, such as deep geologic repositories, is also required if spent fuel is reprocessed. There is some question whether or not drilling of holes to the depths suggested and in the sizes required can be achieved.

The principal advantage of the very deep hole concept is that certain (but not all) wastes can be placed farther from the biosphere, in a location where it is believed that circulating ground water is unlikely to communicate with the biosphere.

1.4.2 Rock Melt Waste Disposal Concept

The rock melt concept for radioactive waste disposal calls for the direct placement of liquids or slurries of high-level wastes or dissolved spent fuel, with the possible addition of small quantities of other wastes, into underground cavities. After the water has evaporated, the heat from radioactive decay would melt the surrounding rock. The melted rock has been postulated to form a complex waste form by reaction with the high-level waste. In about 1000 years, the waste-rock mixture would resolidify, trapping the radioactive material in what is believed to be a relatively insoluble matrix deep underground. Since solidification takes about 1000 years the waste is most mobile during the period of greatest fission product hazard.

Not believed to be suitable for rock melt disposal are wastes from reprocessing activities such as hulls, end fittings, and TRU wastes remaining after dissolution. Because of the inability to accommodate these wastes, some other disposal method would have to be used in conjunction with the rock melt disposal concept.

(a) Analyses developed in this Statement under the alternative program evaluate the environmental impacts of deferring implementation of a disposal program until the year 2030. This situation can also be interpreted as demonstrating impacts that would result from a delayed disposal program.

1.4.3 Island-based Geologic Disposal Concept

Island-based disposal involves the emplacement of wastes within deep stable geological formations, much as in the conventionally mined geologic disposal concept and in addition relies on a unique hydrological system associated with island geology. Island-based disposal would accommodate all forms of waste as would conventionally mined geologic disposal; however, additional port facilities and additional transportation steps would be required. Remoteness of the probable candidate islands has been cited as an advantage in terms of isolation.

1.4.4. Subseabed Disposal Concept

It has been suggested that wastes could be isolated from the biosphere by emplacement in sedimentary deposits beneath the bottom of the deep sea (thousands of meters below the surface), which have been deposited over millions of years. The deposits have been shown by laboratory experiments to have high sorptive capacity for many radionuclides that might leach from breached waste packages. The water column is not considered a barrier, however it will inhibit human intrusion and can contribute to dilution by dispersal of radionuclides that might escape the sediments.

One subseabed disposal system incorporates the emplacement of appropriately treated waste or spent reactor fuel in free-fall needle-shaped "penetrometers" that, when dropped through the ocean, would penetrate about 50 to 100 m into the sediments. A ship designed for waste transport and placement would transport waste from a port facility to the disposal site and would be equipped to emplace the waste containers in the sediment.

Subseabed disposal is an attractive alternative disposal technique because technically it appears feasible that, at least for high-level waste and spent fuel, the waste can be placed in areas having relatively high assurance of stability. If at some point in time all of the barriers failed, the great dilution and slow movement should retard the return of radionuclides to the human environment in biologically important concentrations. The research needed to technically permit subseabed disposal to go forward has been projected not to be as costly or time consuming as some other alternatives. On the other hand, like island-based geologic disposal, the subseabed concept has the disadvantage of the need for special port facilities and for additional transportation steps in comparison to mined repositories on the continent.

As noted, subseabed disposal is believed to be technologically feasible; however, international and domestic legal problems to its implementation would require favorable resolution. Whether subseabed disposal can provide isolation of wastes equal to that of mined geologic repositories has not been fully assessed. Because of volume considerations, subseabed disposal does not appear practical for TRU wastes and some other method would be required for their disposal.[(a)]

(a) Trenches in the ocean floor have been suggested as a means of disposing of higher volume, but less radioactive wastes.

1.4.5 Ice Sheet Disposal Concept

Disposal in continental ice sheets has been suggested as a means of isolating high-level radioactive waste. Past studies have specifically addressed the emplacement of waste in either Antarctica or Greenland. The alleged advantages of ice sheet disposal, which are disposal in a cold, remote area and in a medium that should isolate the wastes from man for many thousands of years, cannot be proven on the basis of current knowledge.

Proposals for ice sheet disposal of high-level waste and/or spent fuel suggest three emplacement concepts:[a]

- Passive slow descent--waste is emplaced in a shallow hole and the waste canister melts its own way to the bottom of the ice sheet
- Anchored emplacement--similar to passive slow descent but an anchored cable limits the descent depth and allows retrieval of the canister and prevents movement to the bottom of the sheet.
- Surface storage--storage facility supported above the ice sheet surface with eventual slow melting into the sheet.

Ice sheet disposal, regardless of the emplacement concept, would have the advantages of remoteness, low temperatures, and isolating effects of the ice. On the other hand, transportation and operational costs would be high, ice dynamics are uncertain, and adverse global climatic effects as a result of melting of portions of the ice are a remote possibility. The Antarctic Treaty now precludes waste disposal in the Antarctic ice sheet. The availability of the Greenland ice sheet for waste disposal would depend upon acceptance by Denmark and the local government of the island itself.

A great deal of research appears to be needed before the potential of ice sheet disposal is determined. Even though the apparent bowl-shaped ice cap of Greenland would result in the wastes melting to the bottom of the bowl where they might remain permanently, the consequences of release of radioactive decay heat to the ice are uncertain. Because of weather extremes and environmental conditions on the ice sheets, difficulties are also predicted for transportation of the wastes to the site, waste emplacement and site characterization.

1.4.6 Well Injection Disposal Concepts

Two methods of well injection have been suggested: deep well liquid injection and shale/grout injection.

Deep well liquid injection involves pumping acidic liquid waste to depths of 1000 to 5000 m (3,300 to 16,000 ft) into porous or fractured strata that are suitably isolated from the biosphere by relatively impermeable overlying strata. The waste is expected to remain

(a) Present concepts for waste disposal in ice sheets call for TRU reprocessing waste to be placed in mined geologic waste repositories.

in liquid form and may thus progressively disperse and diffuse throughout the host rock. Unless limits of movement are well defined, this mobility within the porous host media formation would be of concern regarding eventual release to the biosphere.

For the shale/grout injection alternative, the shale is fractured by high-pressure injection and then the waste, mixed with cement and clays, is injected into the fractured shale formations at depths of 300 to 500 m (1000 to 1600 ft) and allowed to solidify in place in a set of thin solid disks. Shale has very low permeability and predictably good sorption properties. The formations selected for injection would be those in which it can be shown that fractures would be created parallel to the bedding planes and in which the wastes would be expected to remain within the host shale bed. This requirement is expected to limit the injection depths to the range stated above.

This alternative is applicable only to reprocessing wastes or to spent fuel that has been processed to liquid or slurry form. Therefore, well injection is not sufficient to dispose of all wastes generated, and a suitable additional technique would be required.

1.4.7 Transmutation Concept

In the reference transmutation concept, spent fuel would be reprocessed to recover uranium and plutonium (or processed to obtain a liquid high-level waste stream in the case where uranium and plutonium are not to be recycled). The remaining high-level waste stream is partitioned into an actinide waste stream and a fission product stream. The fission product stream is concentrated, solidified, and sent to a mined geologic repository for disposal. The waste actinide stream is combined with uranium or uranium and plutonium, fabricated into fuel rods, and reinserted into a reactor. In the reactor, about 5 to 7% of the recycled waste actinides are transmuted to stable or short-lived isotopes, which are separated out during the next recycle step for disposal in the repository. Numerous recycles would result in nearly complete transmutation of the waste actinides; however, additional waste streams are generated with every recycle. Transmutation, however, provides no reduction in the quantities of long-lived fission product radionuclides such as ^{99}Tc and ^{129}I in the fission product stream that is sent to geologic disposal.

1.4.8 Space Disposal Concept

Space disposal has been suggested as a unique option for permanently removing high-level nuclear wastes from the earth's environment. In the reference concept, high-level waste is formed into a ceramic-metal matrix, and packaged in special flight containers for insertion into a solar orbit, where it would be expected to remain for at least one million years. The National Aeronautics and Space Administration (NASA) has studied several space disposal options since the early 1970s. The concept involves the use of a special space shuttle that would carry the waste package to a low-earth orbit where a transfer vehicle would separate from the shuttle and place the waste package and another propulsion stage into an earth escape trajectory. The transfer vehicle would return to the shuttle while the remaining rocket stage inserts the waste into a solar orbit.

Space disposal is of interest because once the waste is placed in orbit its potentia for environmental impacts and human health effects is judged to be nonexistent. However, the risk of launch pad accidents and low earth orbit failures have not been determined.

The space disposal option appears feasible for selected long-lived waste fractions o radionuclides such as ^{129}I, or even for the total amount of reprocessed high-level waste that will be produced. Space disposal of unreprocessed fuel rods and other high volume wastes does not appear economically feasible or practical because of the large number of flights involved.

1.5 NO-ACTION ALTERNATIVE

The no-action alternative would leave spent fuel or reprocessing wastes at the sites generating the waste or possibly at other surface or near-surface storage facilities for an indefinite time. In this alternative, existing storage is known to be temporary and no consideration has been given to the need for additional temporary storage when facilities in use have exceeded their design lifetime. There seems to be no question but that at some point in time wastes will require disposal and that considerable time and effort will be required to settle upon an adequate means of disposal. It seems clear that development of acceptable means of disposal of wastes is sufficiently complex and of sufficiently broad national importance that coordination of research and development, construction, operation, and regulation at the Federal level is required and that the no-action alternative is unacceptable. Indeed, adoption of a no-action alternative by the Department of Energy could be construed as not permissible under the responsibility mandated to the Department by law. Neither would a no-action alternative be in accord with the President's message of February 12, 1980, when he stated that "...resolving...civilian waste management problems shall not be deferred to future generations."