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GEOLOGIC ASPECTS OF DISPOSAL OF
HIGHLY RADIOACTIVE NUCLEAR WASTE

BY

NENAD SPOLJARIC

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Nenad Spoljaric

INTRODUCTION

This report was prepared to provide a simple but comprehensive overview of programs and concepts of highly radioactive waste disposal. This report is not based on original research, but was prepared from data and information reported in voluminous publications of the U. S. Department of Energy, the Nuclear Regulatory Commission, the U. S. Environmental Protection Agency, and the U. S. Geological Survey.

The importance of nuclear waste disposal for future development of nuclear energy in the United States was formally recognized in 1976 when the National Waste Terminal Storage Program was established. The Program is directed by the Office of Nuclear Waste Management (ONWM) in the U. S. Department of Energy.

The Department of Energy is directed by law (the Atomic Energy Act of 1954, The Energy Reorganization Act of 1974, and the Department of Energy Organization Act of 1977) to develop technology for safe disposal and management of highly radioactive wastes.

On February 12, 1980, President Carter called for a National Plan for Radioactive Waste Management strongly emphasizing the development of technology for safe disposal of nuclear waste in mined geologic repositories.

The chronology of the United States' developments in the disposal of radioactive wastes is shown in Table 1.

At present there are four major projects in progress: The program at the Office of Nuclear Waste Isolation in Columbus, Ohio; the Basalt Waste Isolation Program in Hanford, Washington; the Nevada Nuclear Waste Storage Investigation at the Nevada Test Site; and Seabed Project. All these projects involve

TABLE 1. DEVELOPMENTS RELATED TO NUCLEAR WASTE DISPOSAL PROGRAM.*

1957	National Academy of Sciences/National Research Council recommendation for disposal of nuclear waste in salt deposits.
1963- 1967	Project Salt Vault—A demonstration of emplacement of encapsulated nuclear materials in a salt mine in Kansas.
1968	Evaluation of basalts in Hanford, Washington begins.
1970	Work on the proposed pilot facility at Lyons, Kansas begins.
1972	Termination of work at Lyons. Search for pilot facility site continues in Kansas and expands to New Mexico. U.S. Geological Survey studies Gulf Coast region salt domes. USGS begins studies in Paradox basin in Utah.
1974	Waste Isolation Pilot Plant (WIPP) facility proposed for New Mexico. Evaluation of salt domes as a host geology begins.
1976	National Waste Terminal Storage (NWTS) Program established. Broad program of geologic exploration proposed in 36 states. Evaluation of geologic formations at Nevada Test Site (NTS) begins. Evaluation begins of Permian basin in Texas.
1977	Evaluation begins of Salina salt basin in Michigan, Ohio, and New York. Evaluation begins of Palo Duro sub-basin in Texas.
1978	Study areas recommended in Gulf Interior and Salina regions. President Carter establishes the Interagency Review Group on Nuclear Waste Management (IRG). Office of Nuclear Waste Isolation (ONWI) formed. IRG issues report in draft form; solicits comments; conducts public meetings; holds sessions with representatives of various interest groups.
1979	IRG issues report in March. Investigations of nonsalt geologies accelerated on IRG recommendation. Work proceeds at three salt basins (Gulf Coast, Paradox, and Permian), as well as at Hanford, NTS, and WIPP. Efforts begin to organize State Planning Council to aid in information exchange between federal and state officials. Department of Energy issues draft Generic Environmental Impact Statement (GEIS) proposing that emphasis should be on mined repositories as disposal technology.

*Source: ONWI-19, 1979.

many different fields of science. It is important that the data generated in these studies are readily available to all the scientists involved in the nuclear waste disposal program. The management scheme shown in Figure 1 was designed to allow for this internal flow of information.

In addition, contacts are maintained with the Association of American State Geologists and with several foreign countries having similar programs underway. Particularly close consultations are carried out with the Federal Republic of Germany, Canada, and Sweden.

The Delaware Geological Survey does not anticipate disposal of highly radioactive waste in Delaware. Nevertheless, this report was prepared because Delaware citizens have expressed general concern about nuclear power issues and we seek to clarify one geologic aspect of these issues.

BACKGROUND

The realization that our present energy sources, such as oil and natural gas, are finite, has led to an increasing emphasis on nuclear energy, i.e. nuclear power plants. The electric energy produced by such power plants may become more important in the future not only in the United States, but also throughout the world.

The basic component of a nuclear power plant is a reactor. To understand the operation of a reactor it is necessary to understand the process upon which the reactor itself is based.

All matter is made up of atoms that consist of nuclei (containing almost all the mass) surrounded by orbiting negatively charged electrons. The nucleus is composed of one or more protons (positively charged particles) and one or more neutrons (no charge). The particular element is determined on the basis of the number of protons. The number of electrons is equal to the number of protons and thus the total charge of an atom is neutral. The number of protons is also called the atomic number.

Each element can have various numbers of neutrons which gives rise to isotopes of the same element with different total mass. All the isotopes of all the elements are often referred to as nuclides.

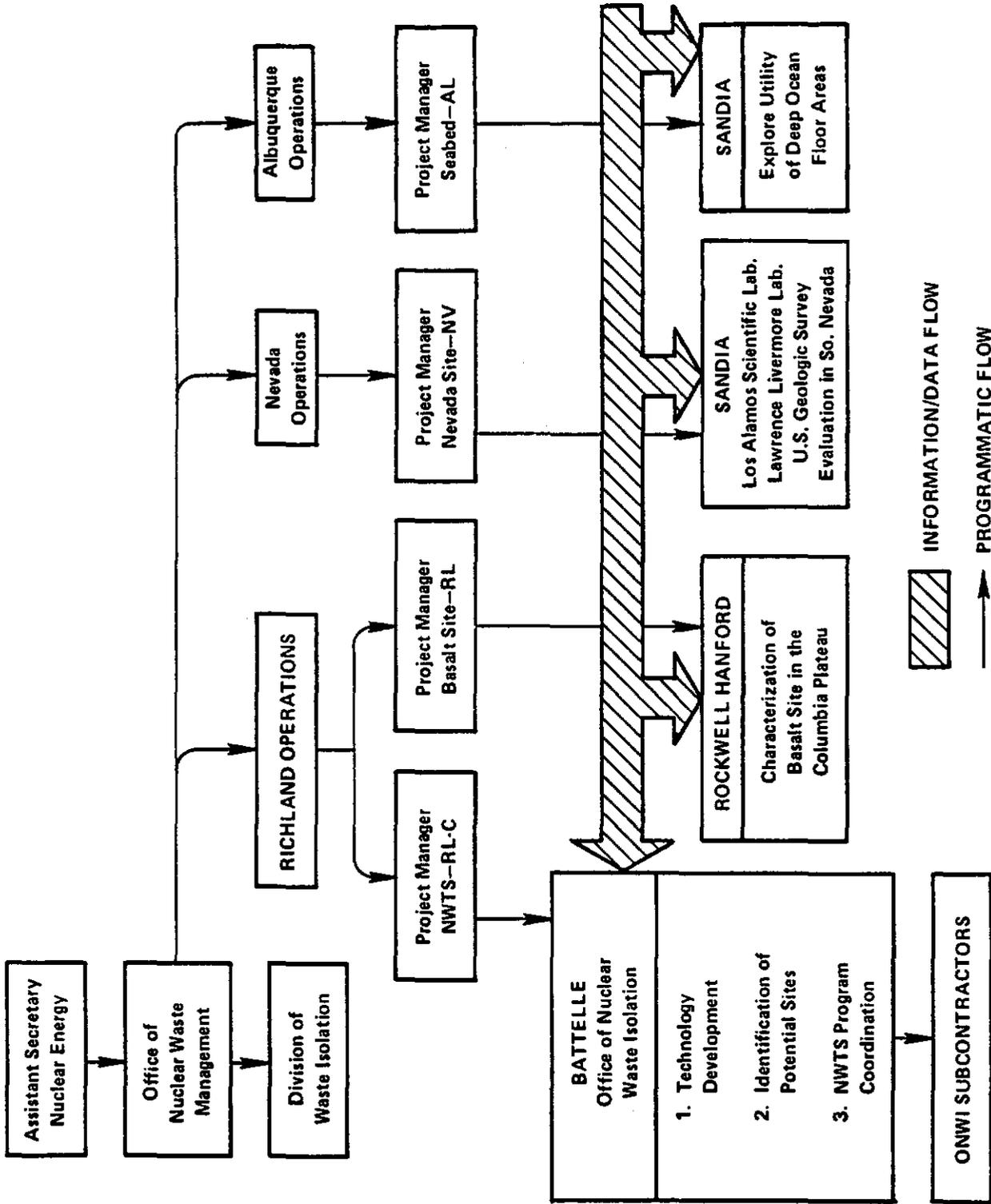


Figure 1. Management scheme of the nuclear waste disposal program (Source: DOE-RL-C-14, 1980).

Many nuclides are unstable and change into other nuclides. Such a change is accompanied by emission of radiation. The time it takes for one-half the mass of a nuclide to change (decay) into another is called its half-life. The radioactive elements found in nature, such as uranium and thorium, have very long half-lives: over one billion years.

A nuclear power plant utilizes heat produced in the reactor to convert water into steam which runs turbines which, in turn, produce electricity. The heat is produced by the fission process (splitting of the nucleus into two or more parts) which takes place when a neutron is absorbed by heavy elements such as uranium (Fig. 2). This process takes place within the nuclear fuel (Fig. 3) (natural uranium). The heat generated is removed by heavy water (water in which the hydrogen atoms consist of deuterium, the stable isotope of hydrogen of mass 2) that flows over the nuclear fuel. The hot heavy water passes through heat exchangers (boilers) thus transferring the heat to ordinary water to produce steam.

During the fission process new nuclides form, many of which are unstable. For example, one of the products is plutonium. Plutonium, on absorbing a neutron also gives off heat, other fission products, and more neutrons.

As the fission process progresses the number of neutrons of the fission products becomes so large that their presence in the reactor core begins to cause a reduction in the nuclear reaction. When this happens the fuel (Fig. 3) is removed from the reactor and the unused fission material, plutonium in particular, is recovered.

Problems

Recovered unused fission material has to be disposed of in a safe manner. Because it is highly radioactive, it cannot, and should not, be disposed of in a conventional manner, such as in landfills.

The future utilization of nuclear energy in the United States depends to a great extent on the development of technology for the safe disposal of nuclear waste (Fig. 4).

Highly radioactive waste can be either water containing highly radioactive materials in solution, or spent or reprocessed nuclear fuel from reactors. Power plants generate

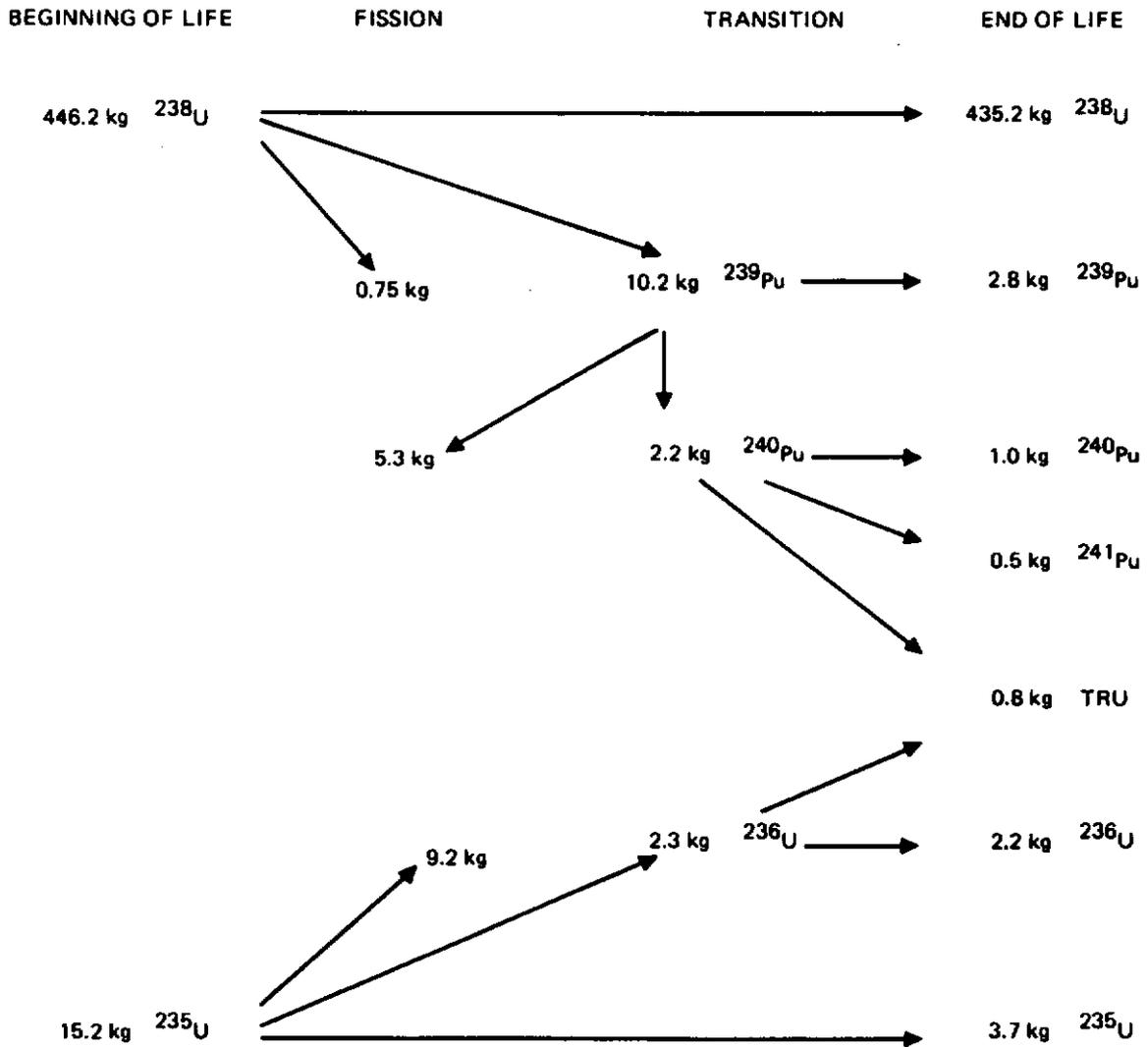


Figure 2. Isotopic changes in nuclear fuel during burnup (Source: ONWI-39).

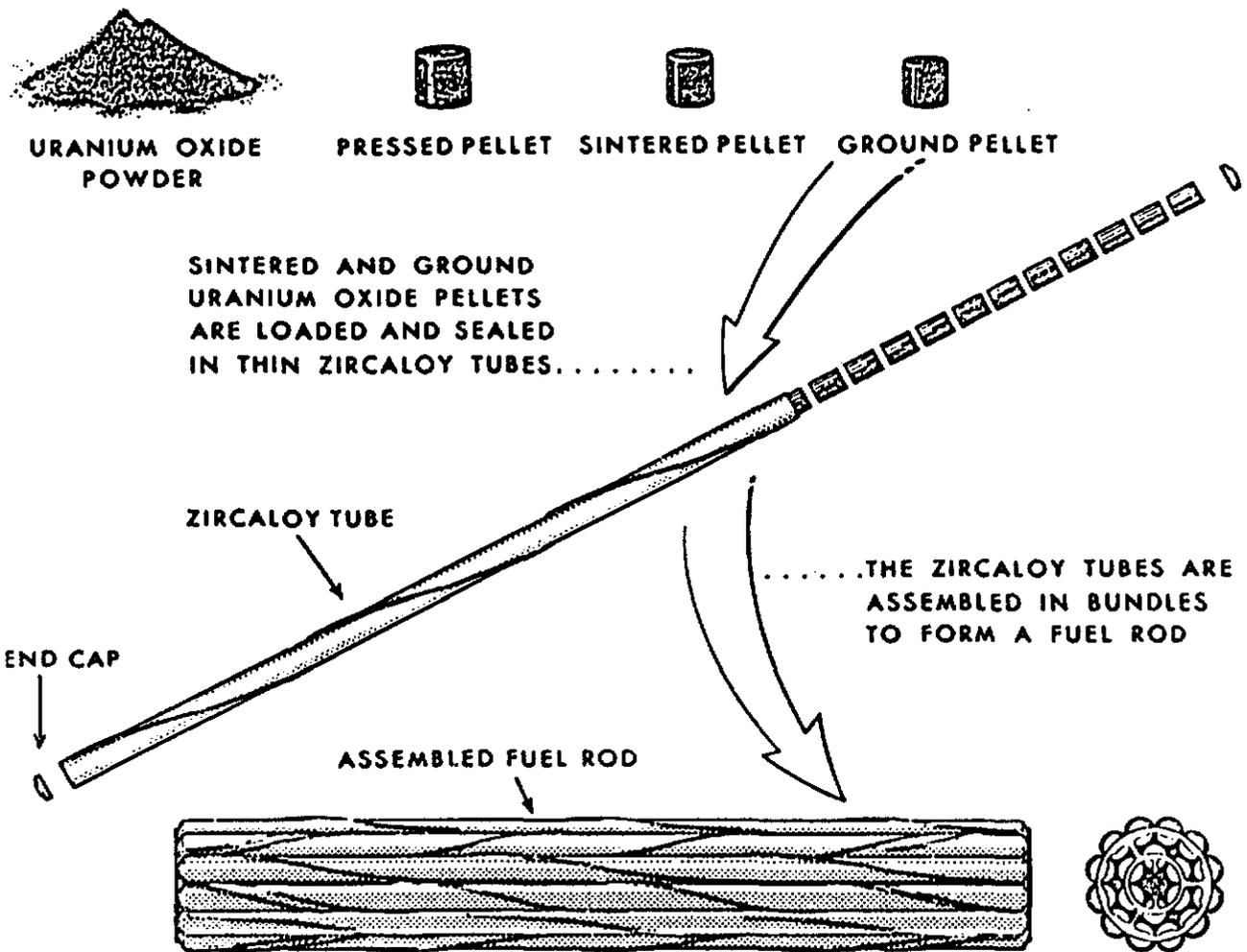


Figure 3. Steps leading to assembled nuclear fuel rod (Source: ONWI-39).

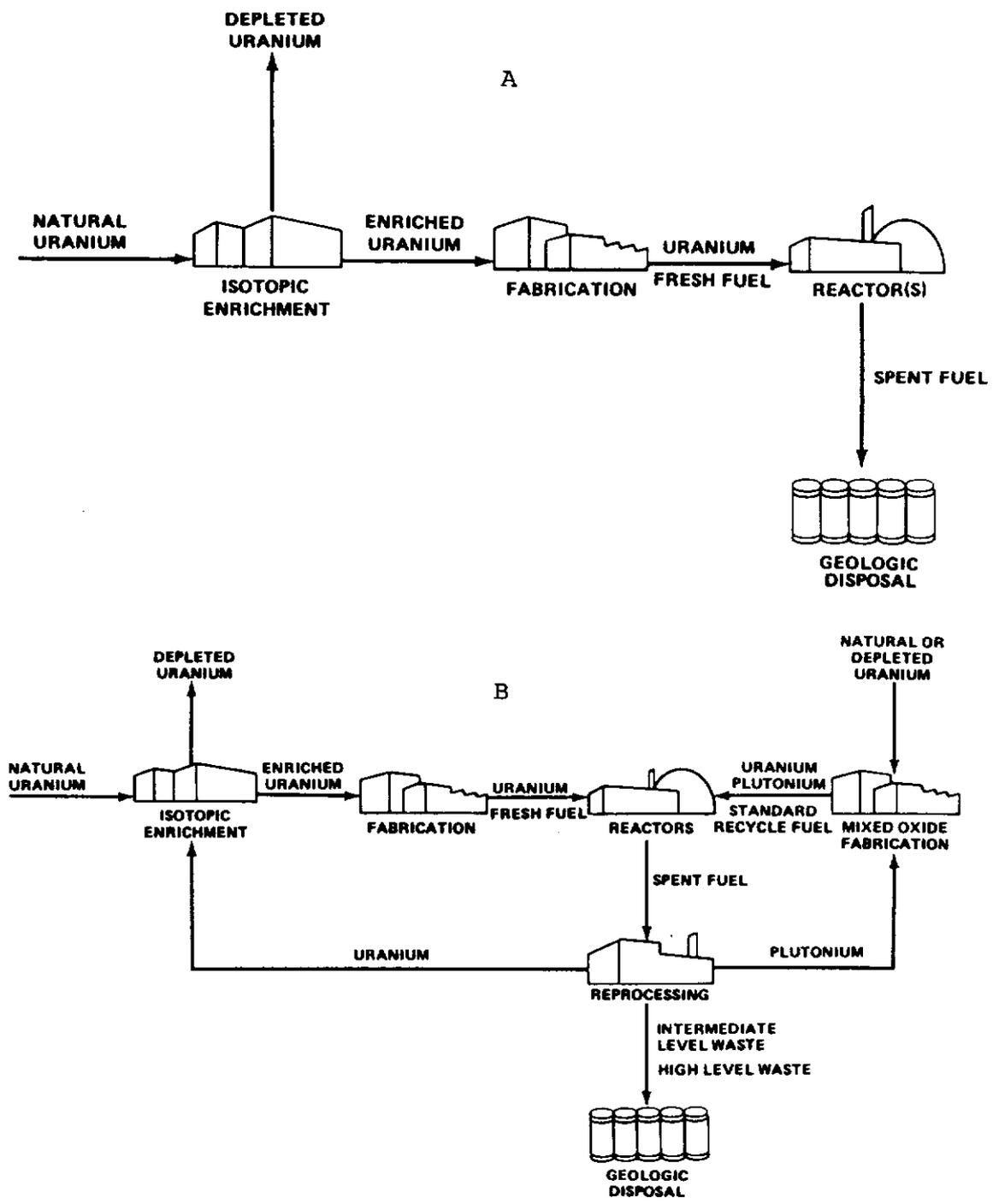


Figure. 4. Schematic diagram of once-through (spent fuel) (A), and reprocessed (high level waste) (B) cycles (Source: ONWI-39, 1979).

other waste as well, and although they are produced in large quantities, they are not as radioactive as spent fuel.

Radioactive wastes that contain more than a specified amount of radionuclides heavier than uranium are called transuranic. They are of particular concern because they have long half-lives and emit alpha rays.

There are about 70 operating commercial nuclear power reactors in the United States (U. S. Department of Energy, 1980). This represents about 50,000,000 kilowatts of electrical generating capacity. The amounts of projected growth of generated energy and spent fuel up to and including the year 2020 are shown in Table 2, and the amount of radioactivity and heat generated by spent nuclear fuel are shown in Figure 5.

Clearly, the disposal of highly radioactive waste must be carried out in a way so that no health hazard exists. It must be stressed that no generally accepted technology for the management and disposal of such waste has yet been developed although extensive research is underway.

Present Methods of Disposal

Most of the spent fuel and high level waste is kept in temporary storage facilities located either in the vicinity of or away from the nuclear power plants.

Water-Pool Storage

The method of temporary storage of spent and reprocessed fuel in water-filled basins is used world-wide. The fuel is either placed in special baskets (unpacked) or into stainless steel canisters (packaged) before storage in water pools. Waste is cooled by circulating water (Aikin, Harrison, and Hare, 1977).

Canyon-type Storage

Nuclear waste is stored in rocks in large cells and shielding is provided by thick concrete walls. Nuclear waste is cooled by either natural or forced convection of air or a non-reactive gas. The gas is either cooled and recirculated or filtered and discharged into the environment (Anderson and Meyer, 1980; Fig. 6).

TABLE 2.* Projected growth of Nuclear Energy (in Gwe).**

CASE	Year	1985	1990	1995	2000	2005	2010	2015	2020
Low		85	125	142	160	198	235	263	290
Medium		96	129	155	180	223	265	293	320
High		105	140	165	200	272	345	402	560

* Source: GJO-111, 1980.

** Gwe = 1 million watts.

A

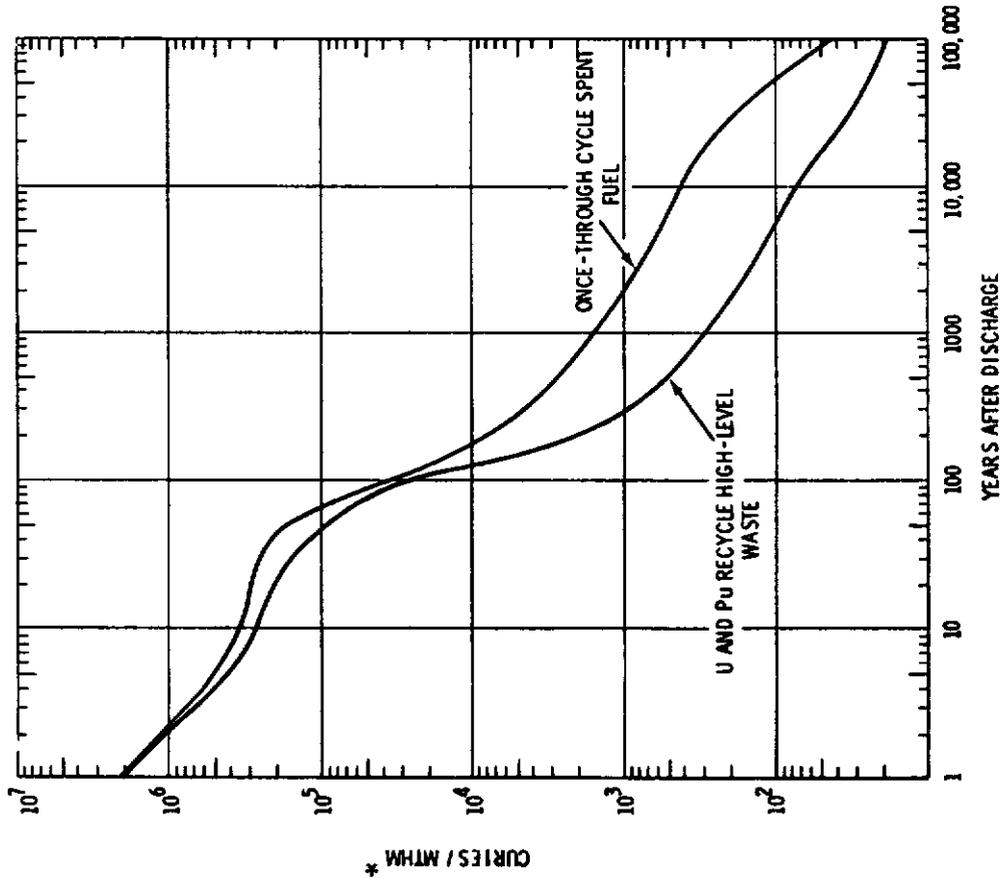
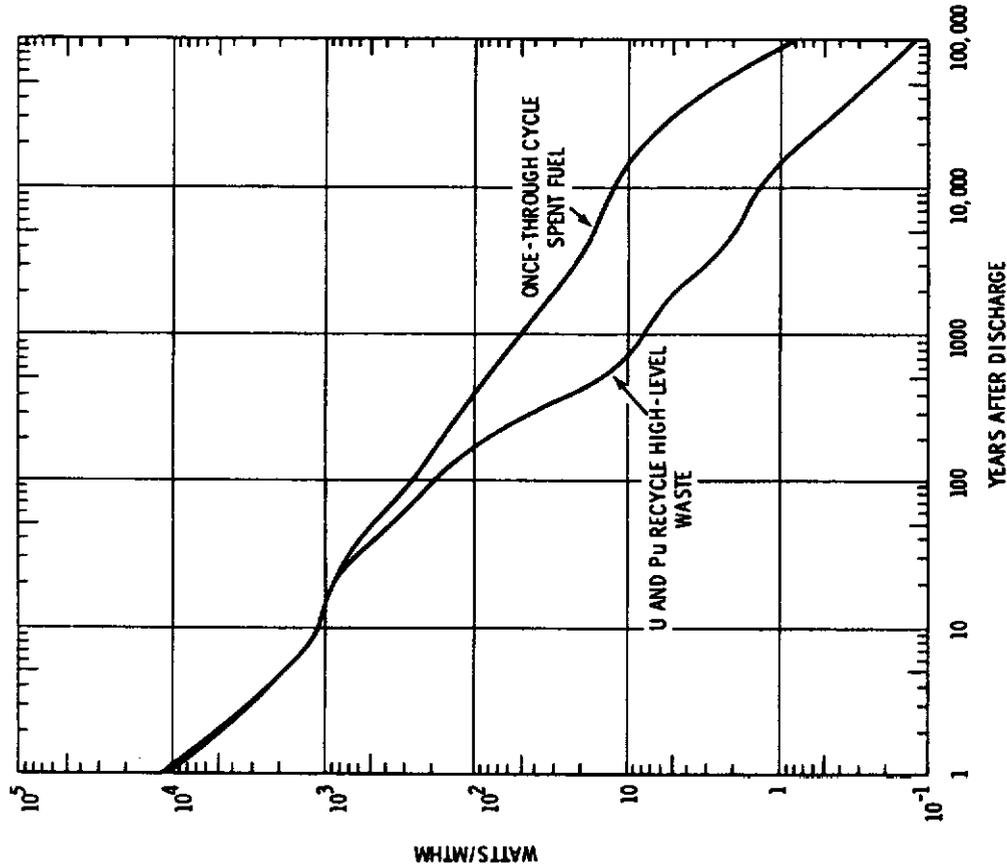


Figure 4. Radioactivity in Spent Fuel and High-Level Waste as a Function of Time (A)
 (Source: DOE/EIS-0046F, 1980)

B



Heat Generation Rate of Spent Fuel and High-Level Waste as a Function of Time (B)
 *MTHM = metric tons of heavy metal in original fuel.

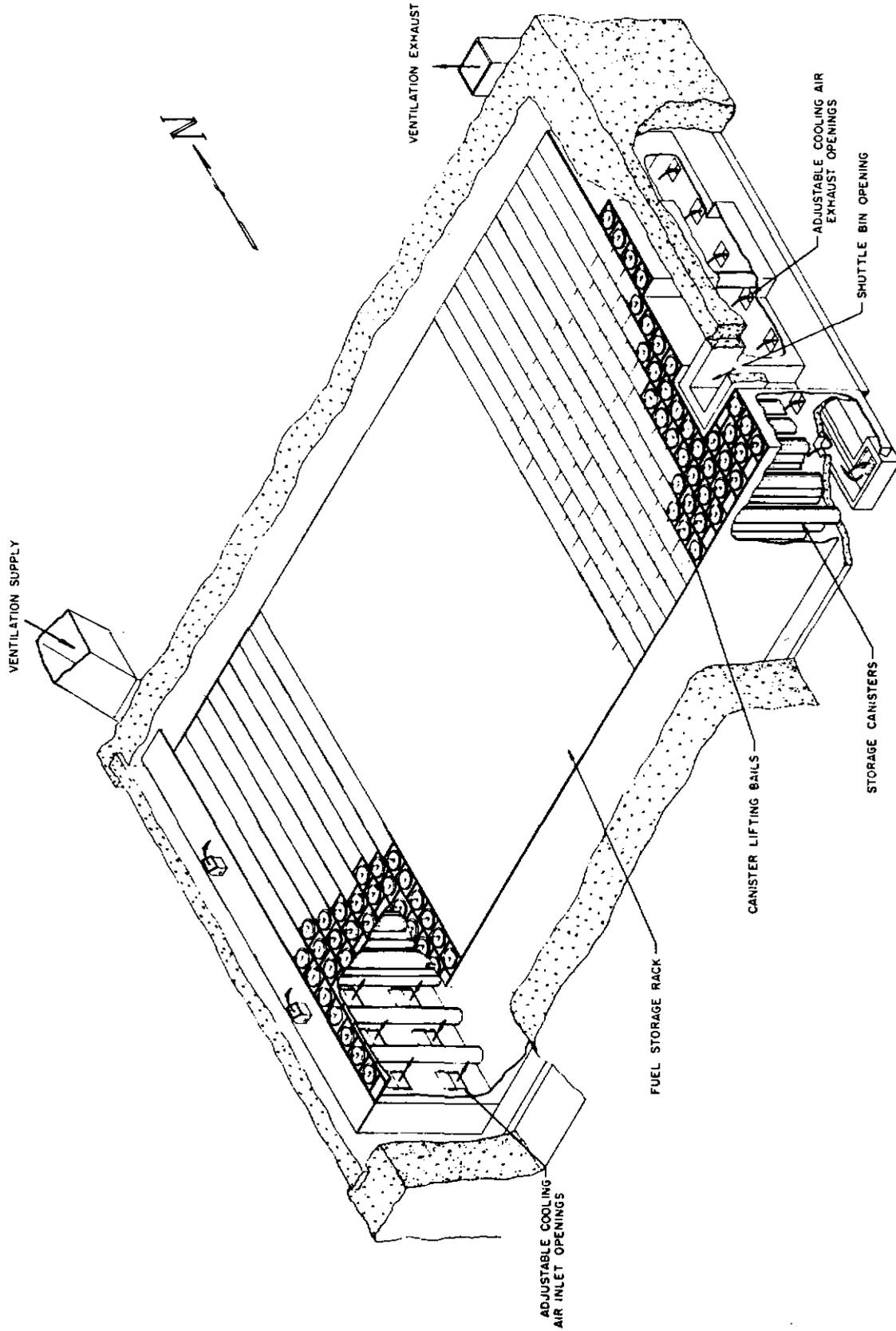


Figure 6. Diagrammatic presentation of canyon-type storage facility.
 (Source: NUREG/CR-1223, 1980).

Caisson-type Storage

Nuclear waste is stored in shallow holes in the ground. Shielding is provided by the ground and concrete plugs. Cooling is maintained by natural conduction of heat through the ground (Anderson and Meyer, 1980; Fig. 7).

Cask-type Storage

Nuclear waste is stored in concrete cylinders on the earth's surface with shielding provided by the thick concrete walls. Cooling is accomplished by conduction through the walls (Anderson and Meyer, 1980; Fig. 8).

Types of Reactor-Generated Wastes

Solid, liquid, and gaseous wastes are generated by nuclear reactors.

In addition to spent fuel, the solid waste includes pieces of equipment, valves, and pipes, which have all become radioactive. A considerable amount of the solid waste can be compacted and thus reduced in size for easier disposal.

The liquid waste comes from a variety of sources such as decontamination facilities and floor drains. The radioactivity of this waste is reduced by dilution (Aikin, Harrison, and Hare, 1977).

The gaseous waste is made up of several radioactive gases such as: krypton, xenon, and tritium. The radioactive components of waste gases are reduced to safe levels by filters, such as charcoal (Aikin, Harrison, and Hare, 1977).

PRINCIPAL CONCEPT OF DISPOSAL

Mined Geologic Repository

Requirements

The repository must be deep enough to be protected from any possible disturbances or disruptions at the surface such as erosion, climate, and weathering. The actual depth is

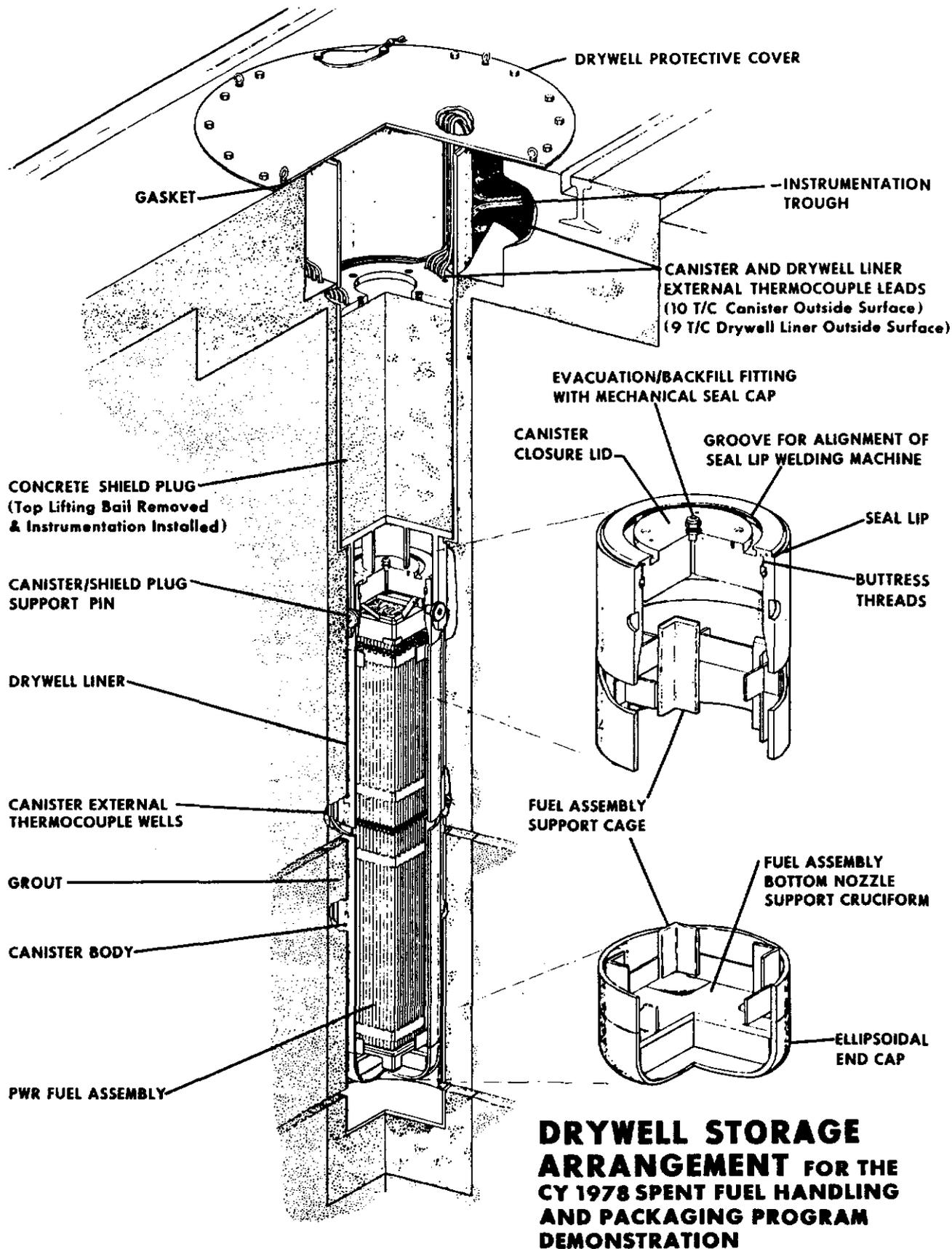


Figure 7. Caisson-type storage facility (Source: NUREG/CR-1223, 1980).

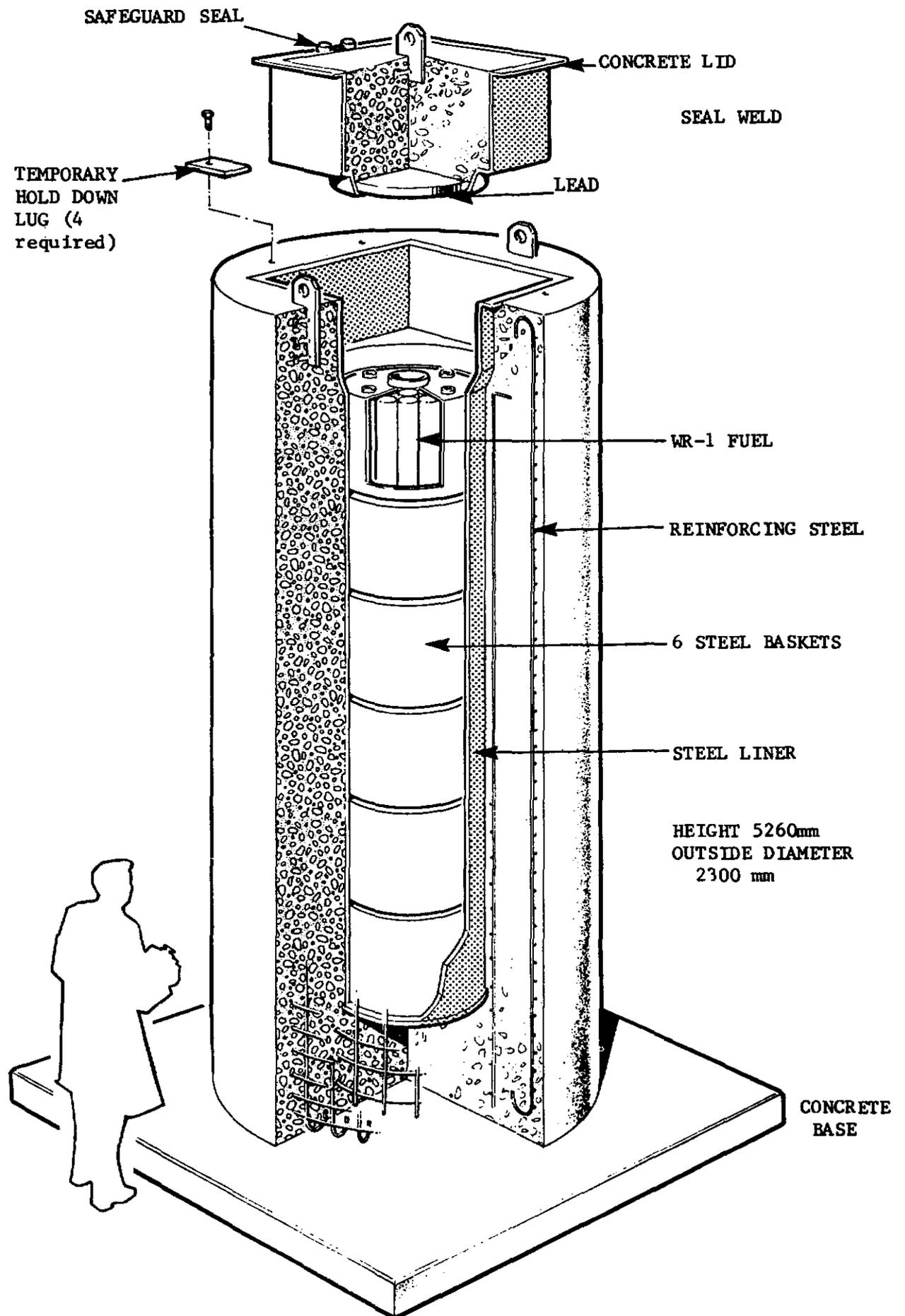


Figure 8. Cask-type storage facility (Source: NUREG/CR-1223, 1980).

dependent on many variables and would be determined individually for every specific site.

The host rock mass must be large enough to assure geologic isolation and adequately disperse or contain all of the perturbations and loads induced by the repository itself (U. S. Department of Energy, 1980).

Other factors that will also have to be carefully considered are the inclination of rock layers, rock fractures, and faults. The repository site should be geologically calm, that is, there should have been no earthquakes or volcanic eruptions over at least the past 100 million years.

In addition to geology, hydrologic factors would play an important role in selecting a prospective repository site. Ground water is present in varying degrees in nearly all rocks. The disposal of nuclear waste requires that the host rock allow for only a minimum amount of water percolation, thus preventing water contaminated with radioactive materials from reaching areas where it may pose health hazards.

Surface water such as lakes or rivers must not be present in the repository area to avoid flooding or entrance of water into the repository.

Host Rocks

Shales

Shale is a rock formed by compaction and consolidation of mud. Mud is a sediment composed predominantly of clays and silts. Shales are laminated and can break easily along the planes of lamination, are not strong, contain large amounts of moisture (water), but have low primary permeability.

Clay minerals composing shales have a capacity to exchange elements in their structure (ion exchange property) with those from the surrounding environment. Chemical changes and temperature may significantly affect the strength and volume of shales (ONWM and USGS, 1980). Sometimes shales contain fractures that may be filled with other minerals such as calcite.

Shales are widespread in the United States and occupy large areas, particularly in the central part of the country.

Salt Deposits

Salt rocks showing promise as host rocks for disposal of high level nuclear waste are found in two forms: salt domes and bedded salt (ONWM and USGS, 1980) often interbedded with other sedimentary rocks such as shale or limestones. Salt rocks are known to flow slowly through the ground either laterally or upward, breaking through overlying rocks and forming domes or diapirs.

Although heat may reduce the strength of salt rocks, high thermal conductivity of salt is conducive to heat dissipation, which is important from the standpoint of nuclear waste disposal. Water percolation or permeability in undisturbed salt beds is essentially nonexistent. The ability of salt to flow (creep) is an advantageous characteristic because it tends to seal discontinuities (ONWM and USGS, 1980). The prospective salt deposits are located mainly in the Great Lakes area and central and southern parts of the United States.

Basaltic Rocks

Basalts are dark colored volcanic rocks of large areal extent which solidified from cooling lava at the earth's surface. In the United States they are mainly concentrated in the Great Lakes area and northwestern part of the country.

Basalts are usually very dense and very strong, have low primary porosity and permeability, and contain very little moisture. Sometimes basalts may have well developed joints (secondary porosity and permeability) that may or may not be filled with other minerals, decomposed basalt, or water.

Basalts are generally unaffected by temperature changes (ONWM and USGS, 1980).

Granitic rocks

Granite is a hard, crystalline, intrusive, igneous rock, usually light colored and found as large bodies formed beneath the earth's surface by consolidation of cooling molten magma.

The primary porosity and permeability of granite are very low. Granite is strong, rigid, and does not deform

easily, although it may crack due to the expansion or contraction of some minerals (ONWM and USGS, 1980).

Granites are not bedded but often contain joints (planes and partings) that may be partially open (secondary porosity and permeability). Large granite bodies are found in many parts of the United States.

Selection of the Site

The selection of a repository site will be a long and detailed process. The Nuclear Regulatory Commission is developing licensing criteria while the Department of Energy (Gray, et al., 1976) is preparing performance criteria. The site selection process described below is hypothetical although it closely follows the criteria considered by DOE and NRC.

The steps that would be followed in complying with these criteria when adopted, should be, and would be, based on the necessity to minimize the risk of releasing radioactivity into the environment. The actual selection of a repository site would be done in three general stages (DOE Final EIS, Vol. 2, 1980).

In Stage I a broad regional site selection process would be initiated. This would be followed by a more detailed investigation of promising smaller areas in Stage II. The specific sites would be studied in detail in Stage III leading to the final selection of the most suitable site.

A general outline of the criteria considered in each of the three stages is shown in Figure 9. Details of investigations of specific sites may vary depending upon particular conditions and characteristics of the area and the entire procedure is subject to review.

Disposal of Waste

The following discussion deals with disposal in salts, granites, shales, and basalts. It should be stressed that although there may be specific and particular requirements applicable to different rocks, the fundamental principles of waste disposal are applicable to all disposal sites.

One of the most important factors to be considered is the heat generated by wastes and its dissipation through the host rock (DOE Final EIS, Vol. 1, 1980). Dissipation depends on

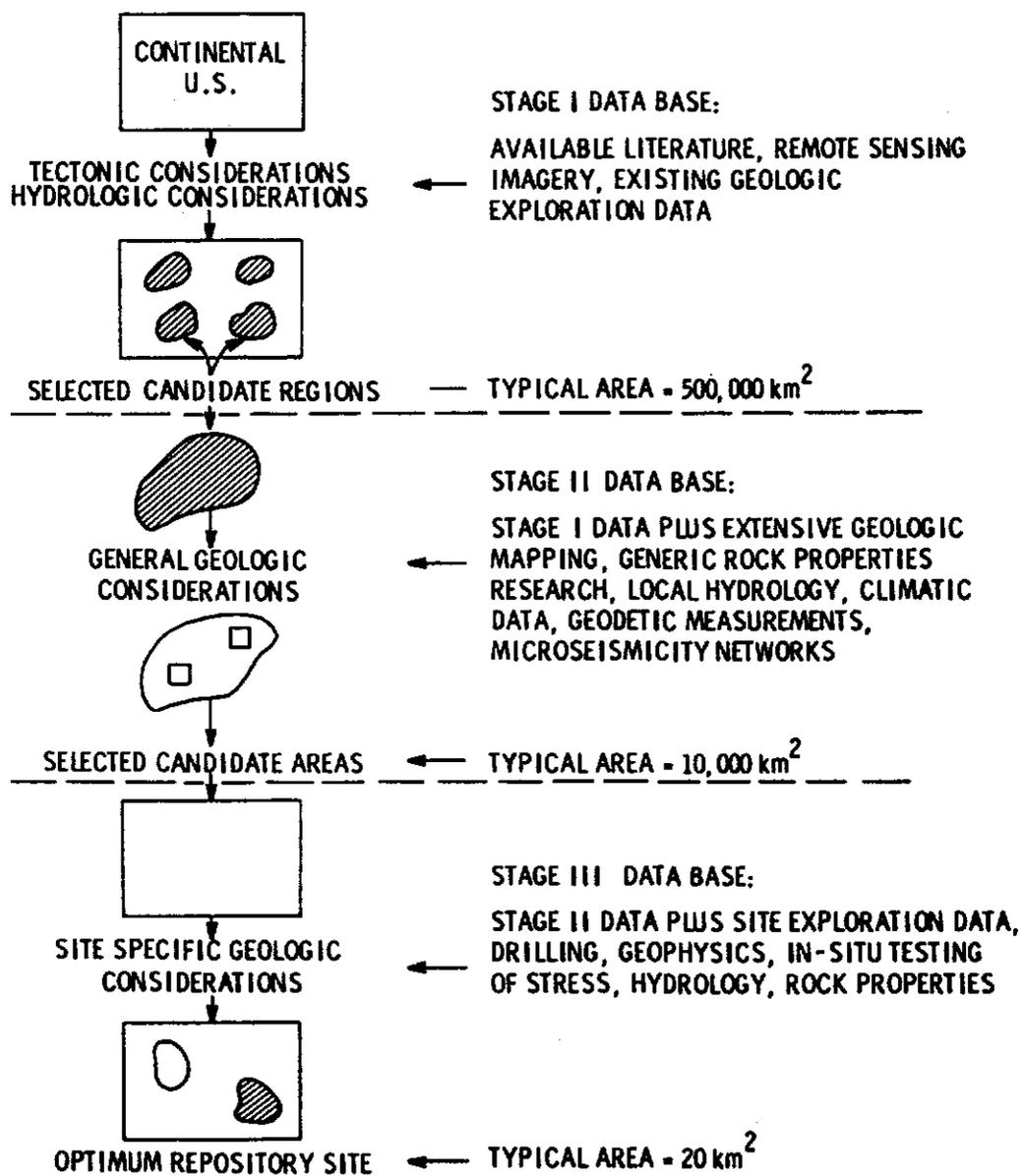


Figure 9. Three major stages leading to the selection of a repository site (Source: DOE/EIS-0046F).

the spacing of individual canisters containing waste and the characteristics of the host rock. For example, 2 - 6 times more waste can be stored in equal volume of granite or basalt than salt (DOE Final EIS, Vol. 1, 1980).

Theoretically, a geologic repository would be located at the depth of between 600 m and 1,000 m and would occupy an area of about 800 hectares (2,000 acres). During the first five years of operation the interaction of waste with the repository rocks would be investigated, a variety of scientific observations made, and other studies conducted. Results of these studies may demonstrate the need for modification of the existing repository design and improvements in the design and operation of future repositories.

The concept of a geologic repository is shown in Figure 10. Projections and estimates of the maximum amount of waste and maximum number of canisters in repositories of different rock types are shown in Table 3.

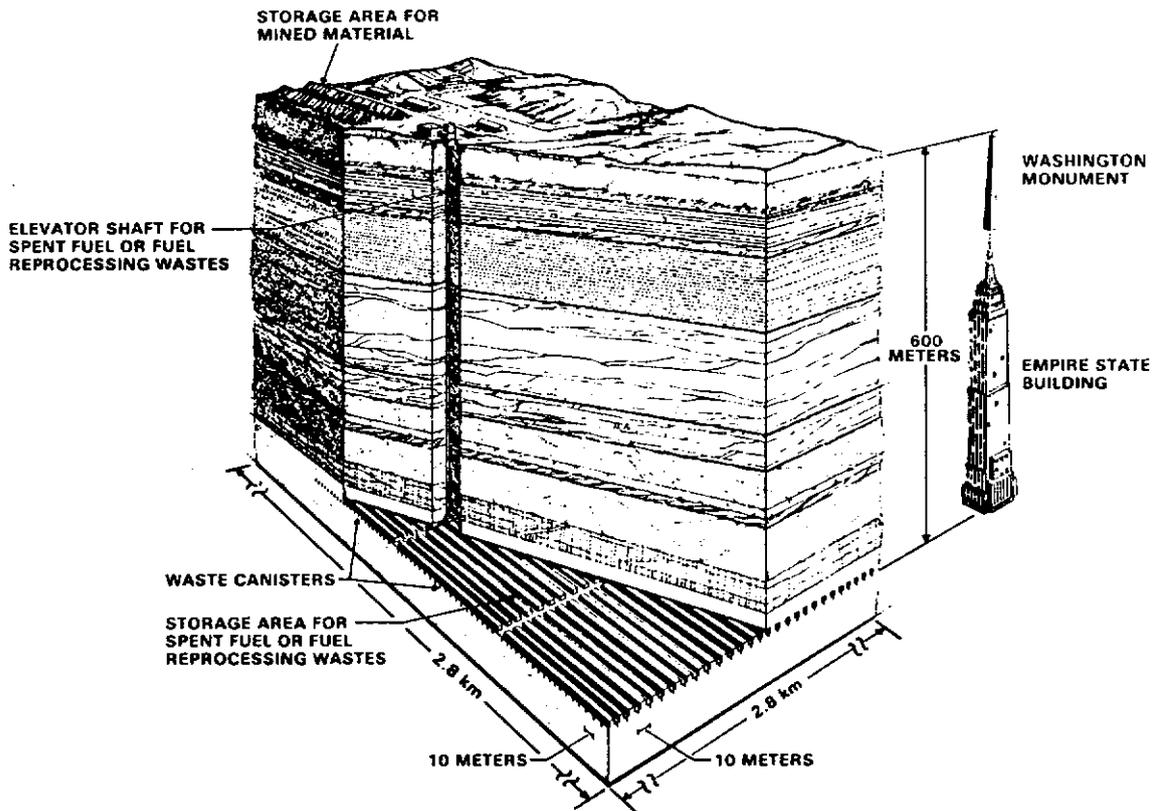


Figure 10. Probable design of underground mined geologic repository (Source: DOE/EIS-0046F)

TABLE 3. Estimates of maximum amount of waste and maximum number of canisters to be stored in repositories composed of different rock types.*

Rock Types	PWR**		BWR***		Total MTHM****
	Canisters	MTHM****	Canisters	MTHM****	
Salt	68,200	31,500	104,000	19,600	51,100
Granite	162,700	75,100	246,300	46,500	121,600
Shale	86,300	39,800	131,000	24,700	64,500
Basalt	162,700	75,100	246,300	46,500	121,600

* Source: DOE/EIS-0046F

** PWR = Waste from reactors using pressurized water cooling system.

*** BWR = Waste from reactors using boiling water cooling system.

**** MTHM = Metric tons of heavy metal in original fuel.

Very Deep Hole Disposal

Nuclear waste would be placed in holes as much as 10,000 m (32,800 feet) deep, in rocks of great strength and low permeability (DOE Final EIS, Vol. 1, 1980). The actual depth would have to be decided for every specific site and would have to provide effective isolation of the waste from the biosphere.

Among other geologic factors that would be considered are: rock composition, resistance to earthquakes and other destructive geologic processes, ground and surface waters, stresses in the rocks, and the effect of heating by waste on the host rock (DOE Final EIS, Vol. 1, 1980).

The main problems with this concept are lack of technology to conduct very deep drilling, inability to retrieve waste, and difficulties in keeping the hole open while the waste and sealing plug are being emplaced (DOE Final EIS, Vol. 1, 1980).

Because of the high cost only unprocessed spent fuel rods and high level waste would be disposed of; transuranic wastes would be most likely placed in mined geologic repositories (DOE Final EIS, Vol. 1, 1980).

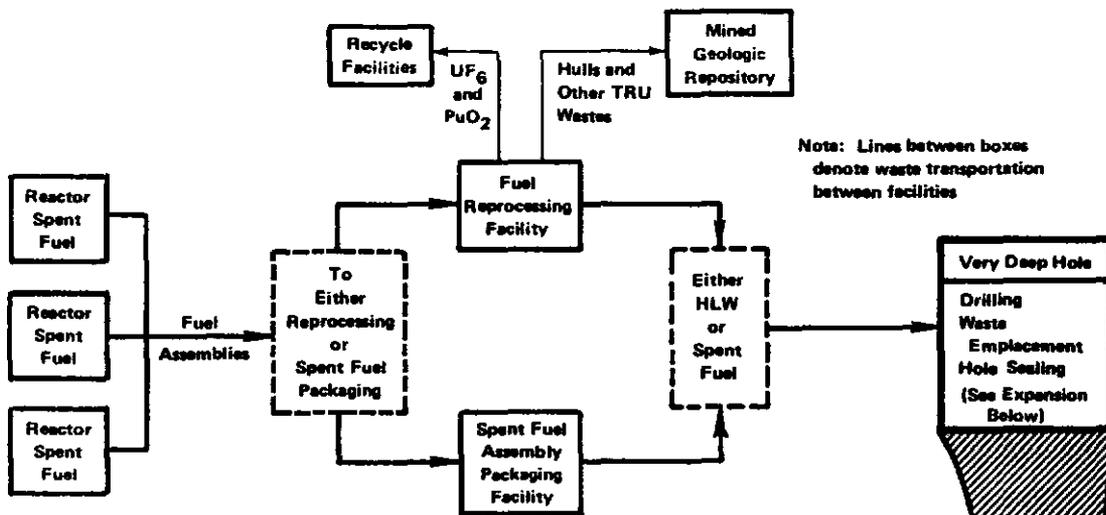
Very deep hole system would be designed for disposal of 10,200 canisters per year of spent fuel or 2,380 canisters of high level waste (DOE Final EIS, Vol. 1, 1980).

With a 40-year repository operation period, emplacement of spent fuel would require 68 holes per year with 150 canisters placed in each. High level waste would require emplacement of 375 canisters per hole in six to seven holes per year (Bechtel, 1979a). The basic outlines of the disposal and management system are shown in Figure 11.

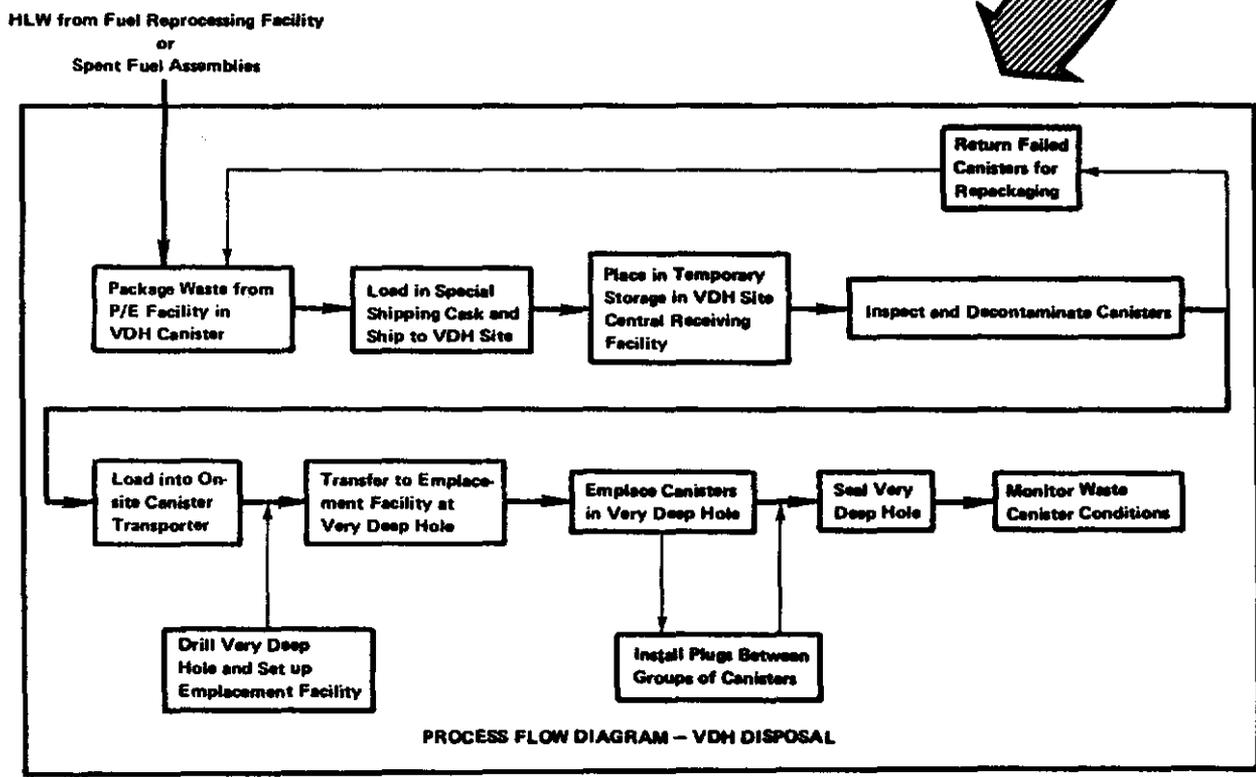
After all waste canisters are emplaced, the hole would be sealed to isolate the waste from the biosphere by plugging it with cement or crushed rocks or both.

Rock Melting Concept

This concept calls for placement of radioactive waste into rock cavities. The heat generated by the waste would melt the surrounding rocks, eventually incorporating the waste. It is anticipated that in about 1,000 years the melt would solidify, trapping the radioactive waste (DOE Final EIS,



FUEL CYCLE DIAGRAM - VERY DEEP HOLE DISPOSAL



PROCESS FLOW DIAGRAM - VDH DISPOSAL

Figure 11. Very deep hole disposal concept; outline of disposal management system (Source: DOE/EIS-0046F, 1980).

Vol. 1, 1980). Once hardened, the homogeneous mixture of waste and rock would be very resistant to leaching thus providing even better long-term containment than mined geologic repositories (Bechtel, 1979a).

This disposal procedure would require high level waste, dissolved in water, to be injected into a cavity. The heat generated by the waste would drive off steam which would be pumped to the surface (Fig. 12). At the surface the steam would be condensed and recirculated to cool the waste in the cavity during the waste emplacement phase. This would be a closed system and no radiation would be released into the environment (Bechtel, 1979a).

After about 25 years the cavity would be filled and the waste would be allowed to dry. The inlet hole would be sealed. The waste temperature would then begin to rise and rock melting would commence. It has been calculated that it would take about 65 years before the melt would begin to solidify. During the melting phase the heat would prevent ground water from entering the waste area (DOE, 1979). When the rock-waste melt solidified, the radioactivity of the mass would be less than that of the uranium ore from which nuclear fuel was originally extracted (DOE Final EIS, Vol. 1, 1980).

The technological issues that would have to be solved before initiation of rock-melting concept (DOE Final EIS, Vol. 1, 1980) are:

- a) The necessary geologic information cannot be predicted with available knowledge.
- b) Data on rock-waste interaction are lacking.
- c) No engineering or technical design of the facilities has been attempted.

Island Disposal

The fundamental ideas and procedures of island disposal are shown in Figures 13 and 14.

The waste disposal would be similar to the mined geologic repository discussed elsewhere in this report. At this time the U. S. Department of Energy has no program to actively investigate this concept (Deutch, 1978).

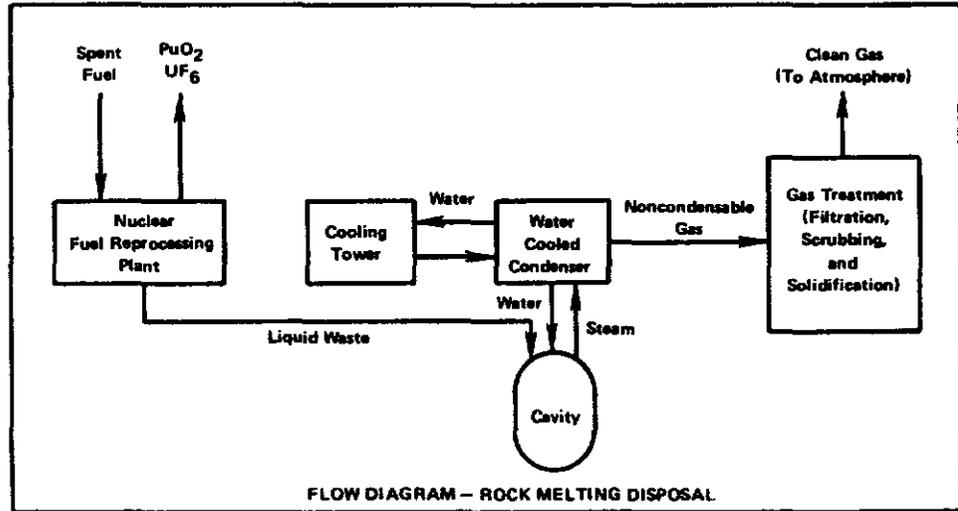
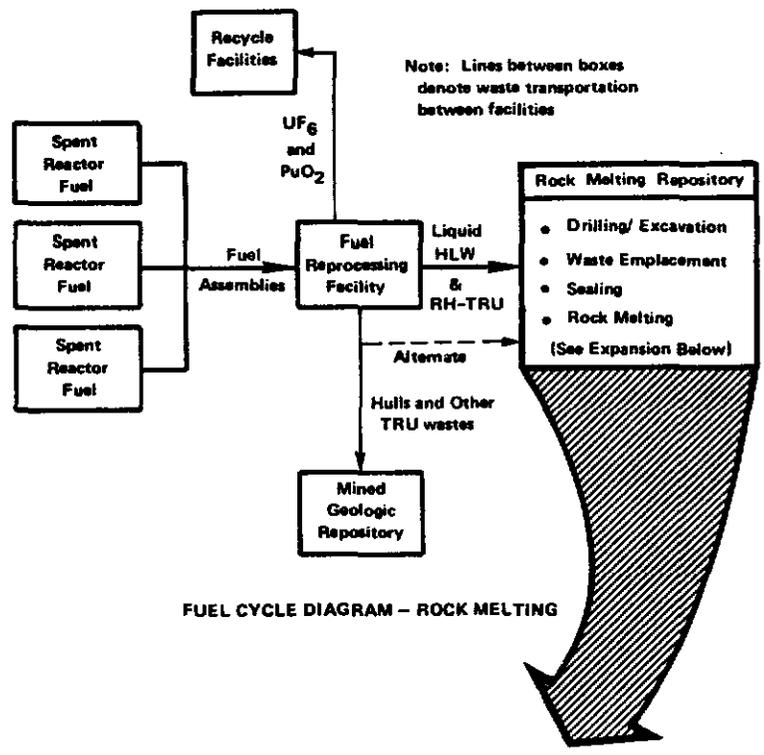


Figure 12. Rock melting disposal concept; outline of disposal management system (Source: DOE/EIS-0046F, 1980).

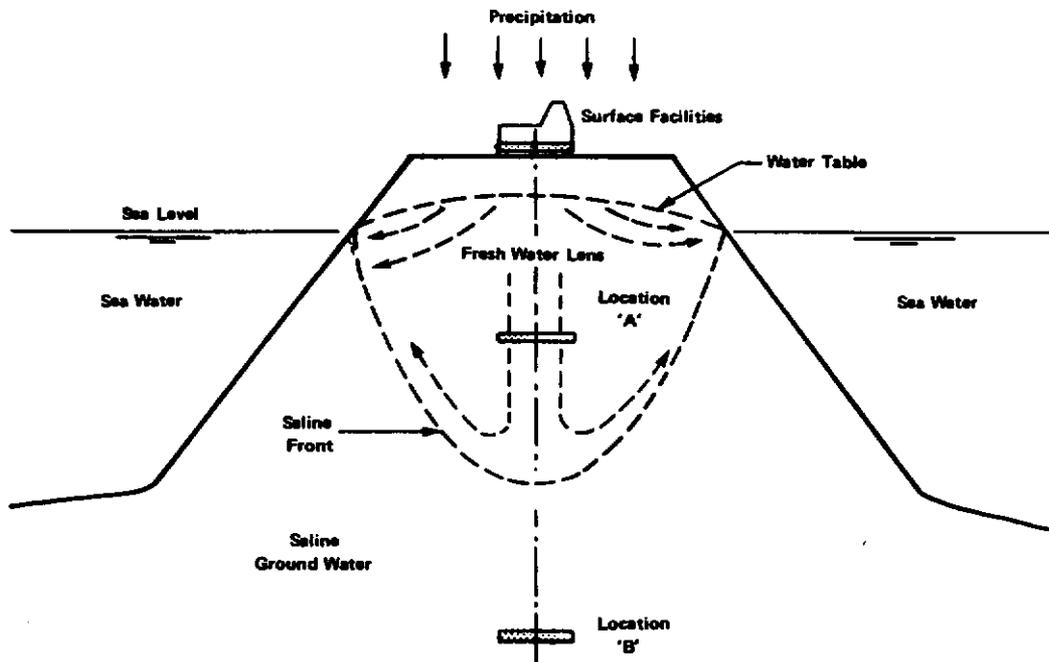


Figure 13. Design concept of island disposal repository (Source: DOE/EIS-0046F, 1980).

The island concept is attractive because it could provide an international repository if the needed arrangements and agreements could be reached (DOE Final EIS, Vol. 1, 1980).

There are three different classes of islands which could be used as waste disposal repositories (DOE Final EIS, Vol.1, 1980):

- a) Continental islands, situated on continental shelves.
- b) Ocean islands.
- c) Islands in inland areas or in seismically active island arc areas.

The handling, disposal, and retrieval of waste canisters, and sealing of full repositories would be done fundamentally in the same way as described for mined geologic repositories. The main advantage of island disposal would be that of an additional barrier of fresh and ocean water (Fig. 13), and isolation and distance from inhabited (populated) areas.

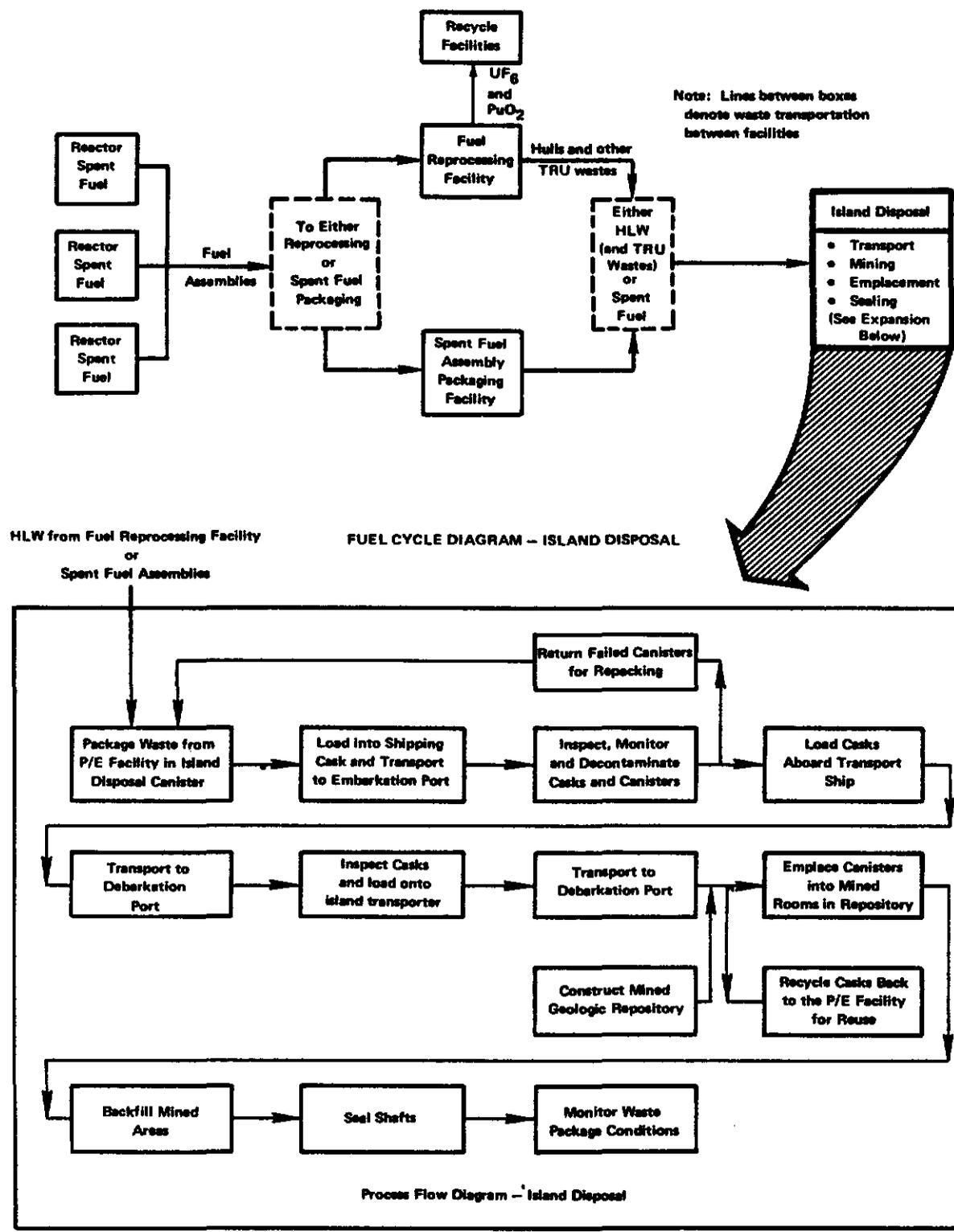


Figure 14. Island disposal; outline of disposal management system (Source: DOE/EIS-0046F, 1980).

Disposal in Ocean Sediments (Subseabed)

Nuclear waste would be emplaced in ocean sediments in areas that have been stable for millions of years. The actual emplacement would be accomplished by placing the waste in "penetrometers" (Bechtel, 1979): needle-shaped projectiles that, when dropped from a height, penetrate the bottom sediments.

The penetrometer would have a nose cone to aid in penetration and tail fins for guidance. They would be designed to penetrate about 30 m (90 feet) into the bottom sediments. It has been shown that the holes made as the penetrometers entered the sediments would close spontaneously. Means would be provided to track each canister to ensure proper penetration and spacing (DOE Final EIS, Vol. 1, 1980).

The canisters would be designed so that waste containment would be maintained for several hundred years (DOE Final EIS, Vol. 1, 1980).

It is anticipated that any possible escape of radioactive components from the canisters would be a slow process so that leaked waste would be effectively diluted and dispersed. In addition, the great depth of the water column would constitute a barrier to human intrusion. The evidence at hand suggests that ocean-bottom clays could provide long-term containment of the nuclides (except for the elements iodine and technetium) through their sorbtion, ion-exchange properties, and very low permeabilities (DOE Final EIS, Vol. 1, 1980). The outline of the procedure is shown in Figure 15. This disposal method would be applicable mainly to spent fuel and high level waste.

There are many problems related to this disposal method that have not yet been resolved. It appears that the total area required for the disposal would be about 520 km²/year (215 mi²/year) for high level waste and 930 km²/year (354 mi²/year) for spent fuel waste with the spacing of 300 m (984 ft) between canisters and the total waste of about 5,000 metric tons/year (DOE Final EIS, Vol. 1, 1980).

Ice Sheet Disposal

Continental ice sheets could provide isolation of nuclear waste. There are three possible ways of disposal in ice: a) canisters emplaced in shallow holes; b) an anchored cable attached to canisters for possible retrieval of waste, and c) storage facilities located on the surface with eventual slow

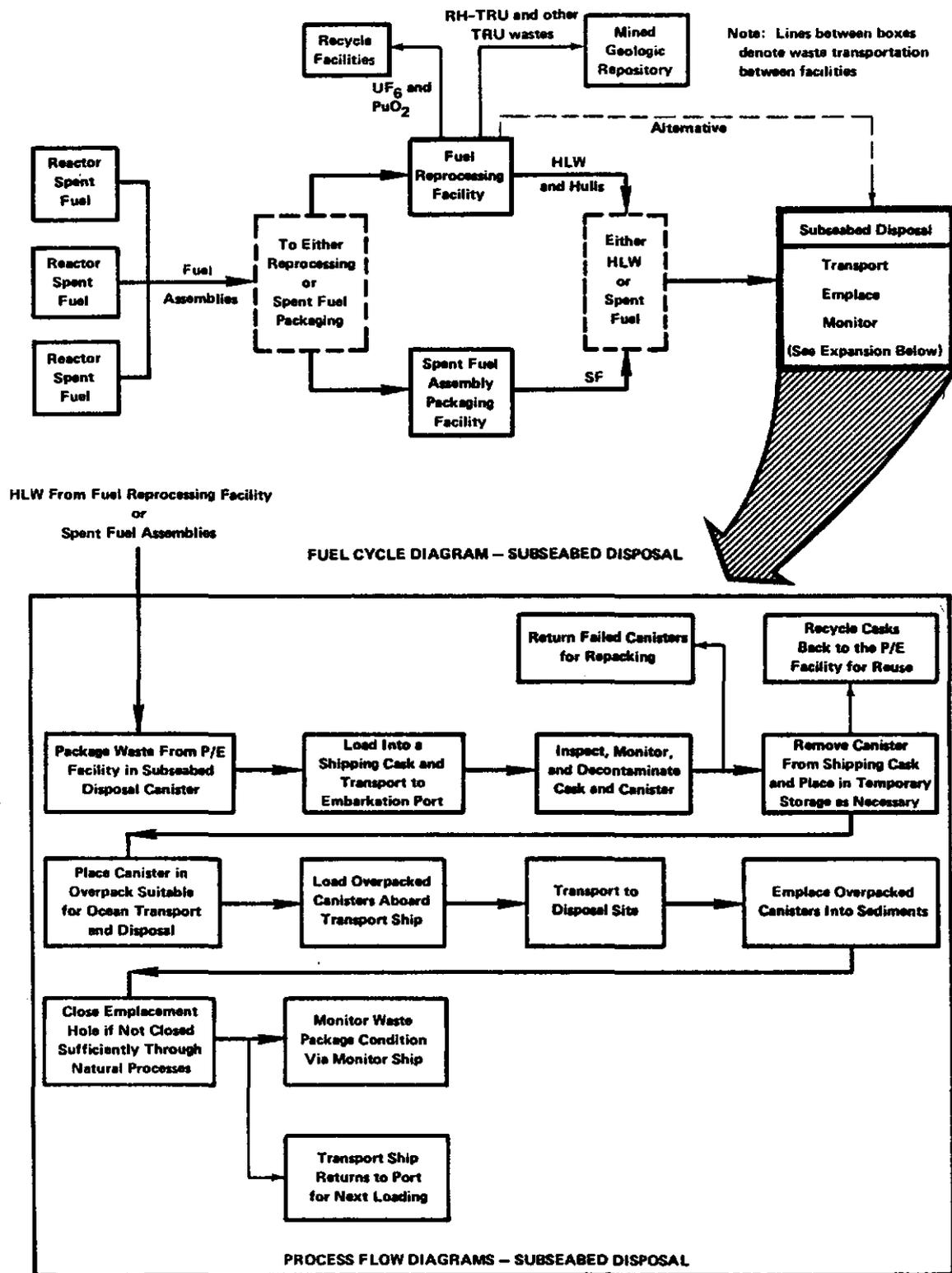


Figure 15. Subseabed disposal; outline of disposal management system (Source:DOE/EIS-0046F, 1980).

melting into the ice sheet (Battelle, 1974; EPA, 1979; ERDA, 1976) (Fig. 16). The main advantages of ice sheet disposal are remoteness from populated areas, cooling, and ice barriers.

The outline of the procedure is shown in Figure 17. The disposal would probably be carried out either in the Antarctica or the Greenland ice sheets.

In the canister meltdown concept the rate of descent through ice would be on the order of 1 to 1.5 m/day (Final EIS, Vol. 1, 1980). Assuming an ice sheet 3,000 m (9,900 ft) thick, meltdown to the bedrock would take 5 to 10 years. The canister would be designed so that it would maintain a vertical path from ice surface to bedrock.

The anchor emplacement concept is similar to the meltdown concept except that cables 200 m to 500 m long (660 feet to 1,650 feet) would be attached to the canisters before lowering them into the ice sheet. Instrument leads could be attached to the canisters for monitoring their condition after emplacement.

The surface storage facility concept would require large storage units constructed above the snow surface (EPA, 1979). The set-up is shown in Figure 16. The canisters would be placed in cubicles inside the facility and air cooled. During the water emplacement phase the canisters would be retrievable. The facility would be maintained above the ice for a maximum of 400 years after construction. When the limit of the jack-up pilings was reached the entire facility would act as a heat source and begin to melt down through the ice sheet (Battelle, 1974).

Among the factors that are not well understood to effectively employ ice-sheet disposal concepts are: ice dynamics, climatic variations, possible effect of the waste on the delicate glacial environment, and motion of continental ice sheets and its effect on the waste canisters (Philbert, 1958; Zeller et al., 1973; Philbert, 1975).

Well Injection

Well injection technology is well developed, is widely used by the oil industry, and has also been utilized recently in disposal of various wastes.

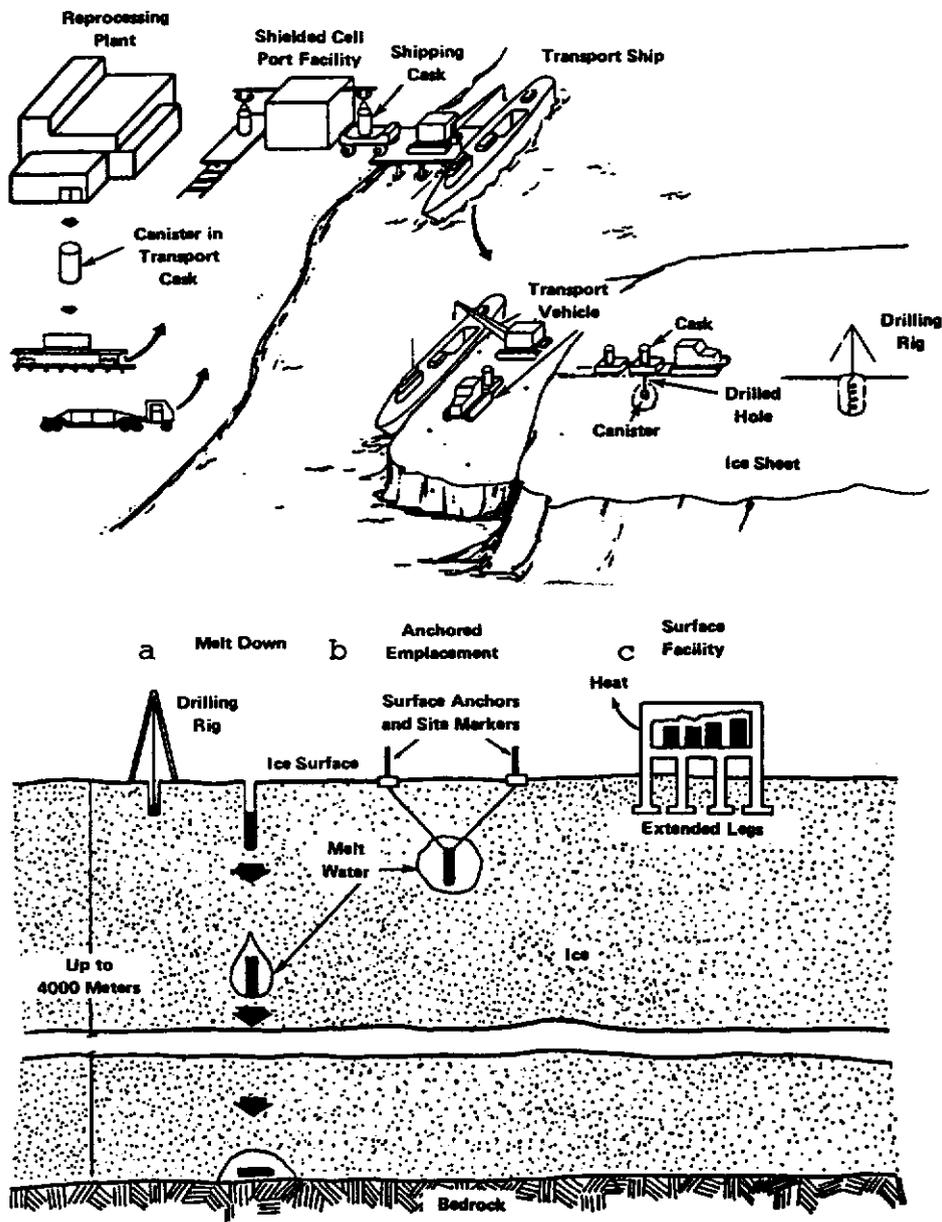
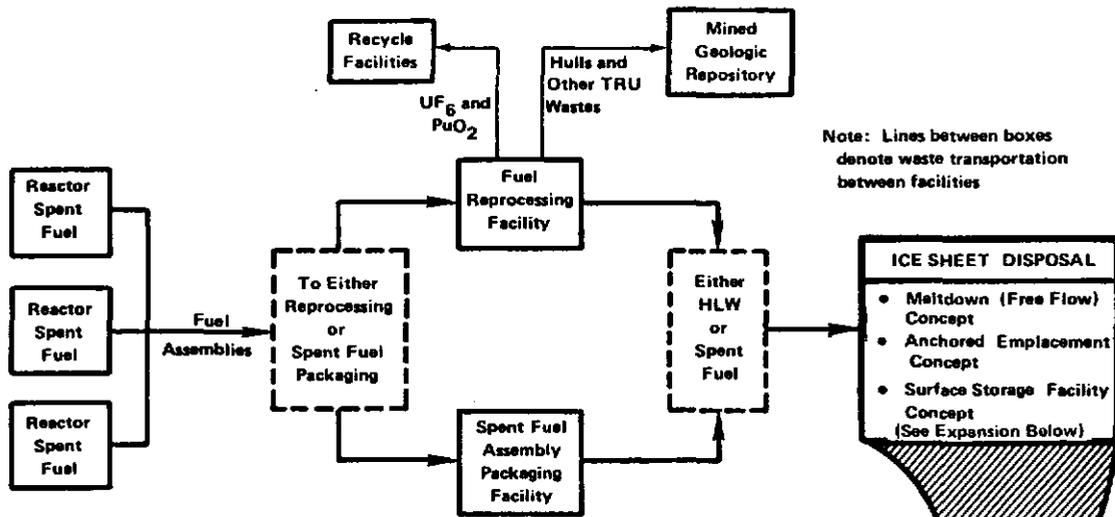
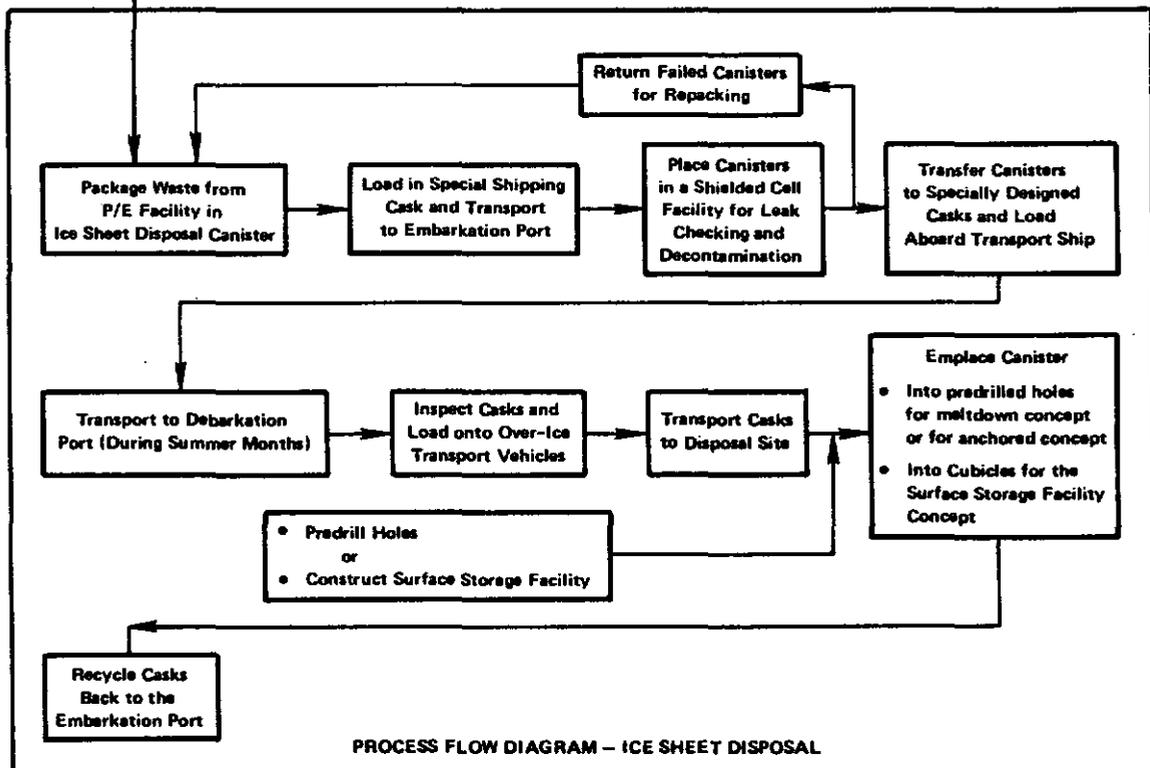


Figure 16. Schematic presentation of ice sheet disposal concept; a) melt down, b) anchored emplacement, and c) surface storage (Source: DOE/EIS-0046F, 1980).



FUEL CYCLE DIAGRAM - ICE SHEET DISPOSAL

HLW from Fuel Reprocessing Facility
or
Spent Fuel Assemblies



PROCESS FLOW DIAGRAM - ICE SHEET DISPOSAL

Figure 17. Ice Sheet Concept; outline of management system (Source: DOE/EIS-0046F, 1980).

Well injection using grout was developed at the Oak Ridge National Laboratory for the injection into shales of remotely handled transuranic liquid radioactive waste (ERDA, 1977).

Because of the availability of detailed data and successful application of this technique in similar disposal fields, well injection is thought by some to be an economical alternative in radioactive waste disposal.

The schematic outline of the procedure is shown in Figure 18.

Injection Concept

In the deep well injection concept the waste would be fed into porous or fractured rocks. To protect freshwater aquifers, the injection zone would have to be well below the aquifers and isolated by relatively impermeable layers such as shales or salts.

The increase of the total fluid volume in an injection zone would be accomplished by compression of any fluid already present, and expansion of the host rock. Injection is possible at depths of several thousand meters (DOE Final EIS, Vol. 1, 1980).

Although the overall site area has not been yet calculated, it is anticipated that it would have to be greater than 1,270 hectares (3,140 acres) and its final size would depend on the maximum horizontal dimension of the injection zone, the size of control zone around the repository, and the total amount and type of waste to be injected (DOE Final EIS, Vol. 1, 1980).

Grout Injection Concept

Grout injection into shale would require that liquid waste or irradiated fuel be mixed with cement or clay and the slurry be injected into impermeable shale formations. The fractures would have to be horizontal. Vertical or inclined fractures could result in waste migrating toward the surface where it would pose health hazards. The grout would set a few hours after injection thus fixing the waste in the shale (DOE Final EIS, Vol. 1, 1980).

The site would have to be composed of flat-lying shale layers. Favorable conditions, which would bring about

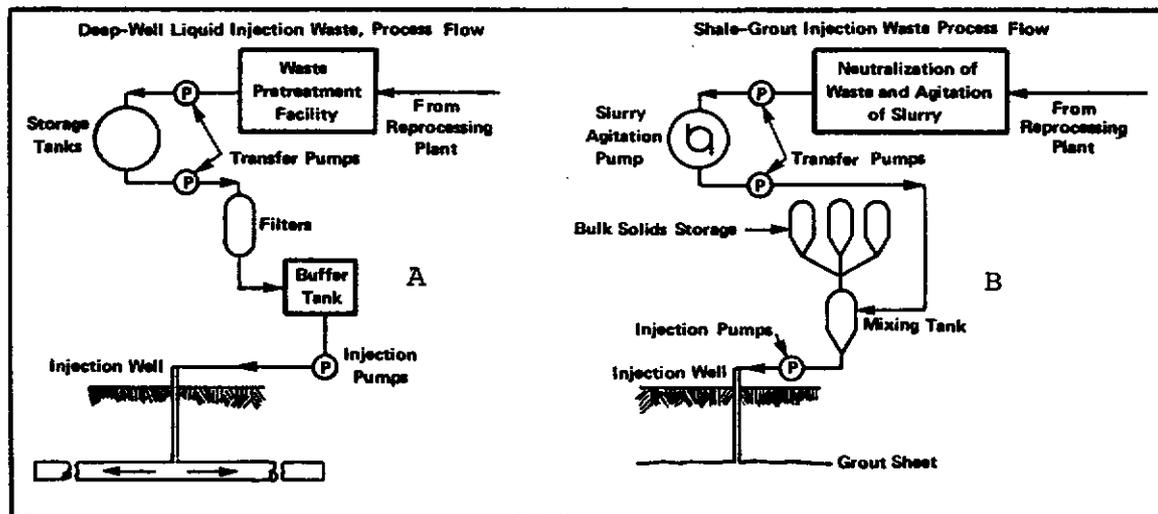
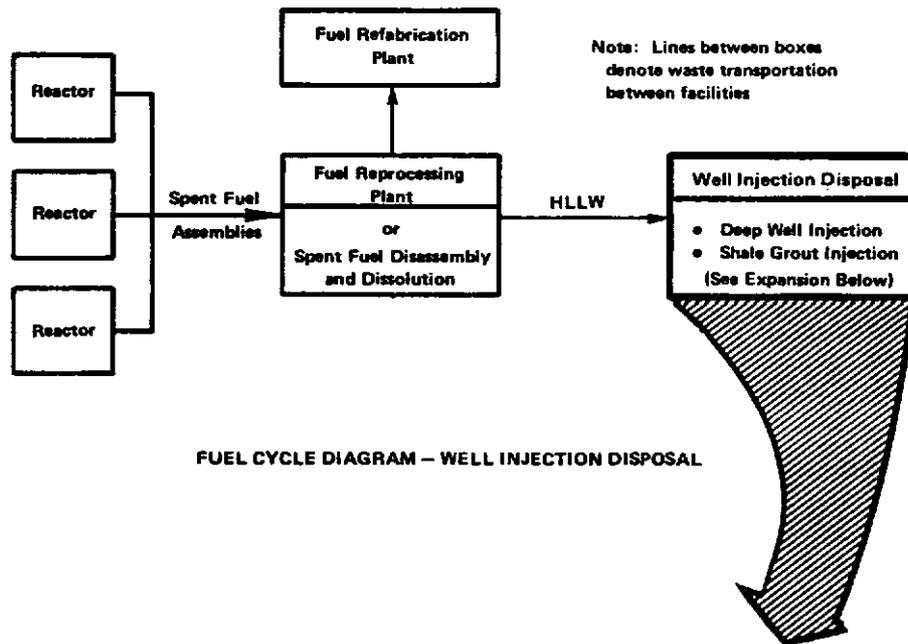


Figure 18. Well injection; outline of management system.
 A. Liquid injection.
 B. Grout injection.
 (Source: DOE/EIS-0046F, 1980).

horizontal fracturing, are usually found to a maximum depth of 1,000 m (3,300 ft). An overall site area for grout injection would have to be greater than 1,270 hectares (3,140 acres); the actual size would depend on the specific conditions (DOE Final EIS, Vol. 1, 1980).

Transmutation Concept

This concept is attractive because it is designed to reduce the long-term risk to the public posed by long-lived radionuclides. Spent fuel would be reprocessed to recover uranium and plutonium. The remaining high-level waste would be separated into actinides* and fission-products. The fission products would be concentrated, solidified, and sent to a repository for disposal. The actinides would be mixed with recycled uranium and plutonium, fabricated into fuel rods, and reinserted into the reactor. Numerous recycles would result in nearly complete transmutation of the waste actinides.

The main problems of this concept are security and possible environmental and health hazards due to extensive and repeated handling of radioactive waste.

Space Disposal

Space disposal would enable the waste to be permanently removed from the Earth and Earth's environment. The waste would be packaged in special containers for insertion into a solar orbit where it would remain for at least one million years.

Space shuttle would carry the waste containers to an Earth orbit from where the containers would be propelled into a solar orbit. After a container had been properly placed in the orbit, there would be no long-term risk, as in other concepts. The problems inherent in the space disposal concept, however, are the risk of launch accident and failure of the Earth orbit.

The plan of the concept is shown in Figures 19 and 20.

STUDIES IN PROGRESS

Thus far the geologic studies of salt dome deposits have made considerable progress and a selection of a site is

* Actinides : Radioactive elements with atomic numbers larger than 88.

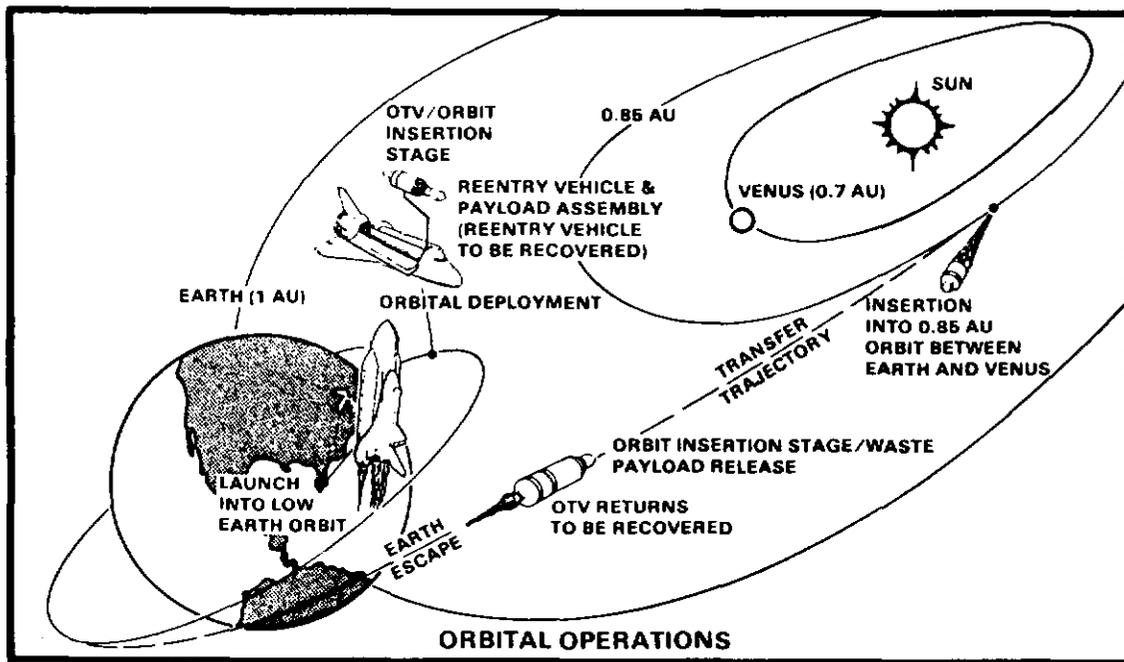


Figure 19. Diagrammatic presentation of space disposal (Source: DOE/EIS-0046F, 1980).

scheduled for March 1981. An investigation of basalt areas is also currently underway and a site selection is planned for September 1981 (DOE Final EIS, Vol. 1, 1980).

Investigation of Salt Deposits

Investigations of the suitability of salt deposits for nuclear waste repositories are being conducted in four regions: Salina Salt Region, the Paradox Basin, the German Basin, and the Gulf Interior Region (Fig. 21). In the Gulf Interior Region the study of salt domes is in progress, while in the other three regions bedded salt is investigated. The main reasons leading to the selection of these four salt regions were the abundance of thick layers of salt and the occurrence of these layers at a depth appropriate for construction of repositories.

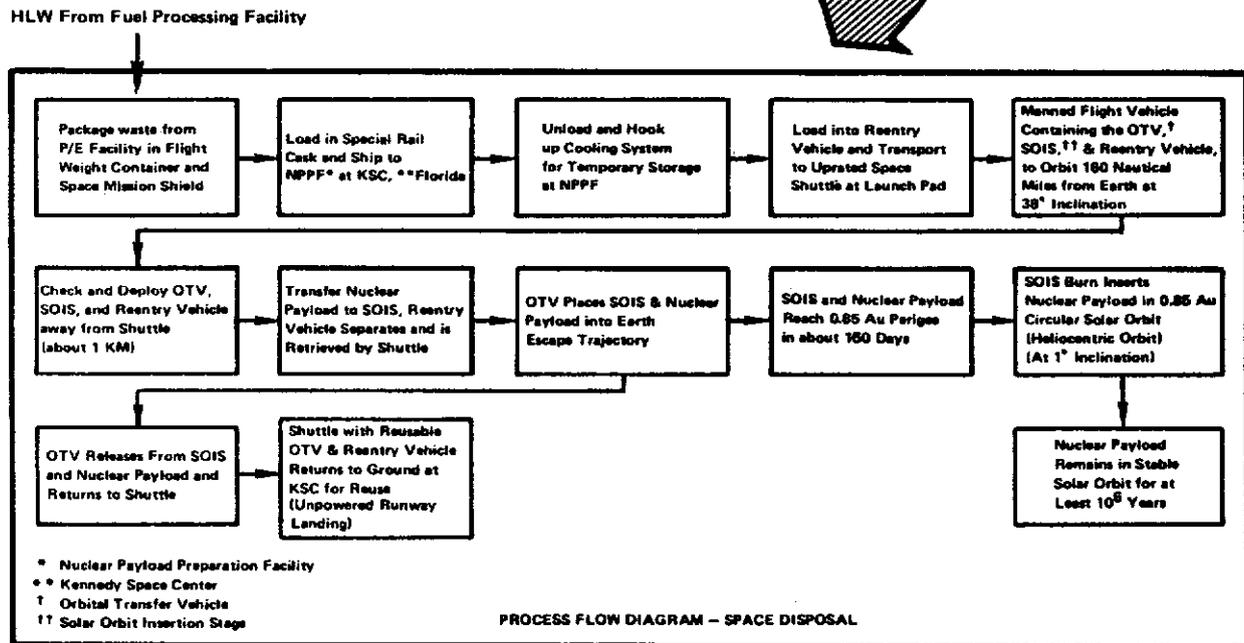
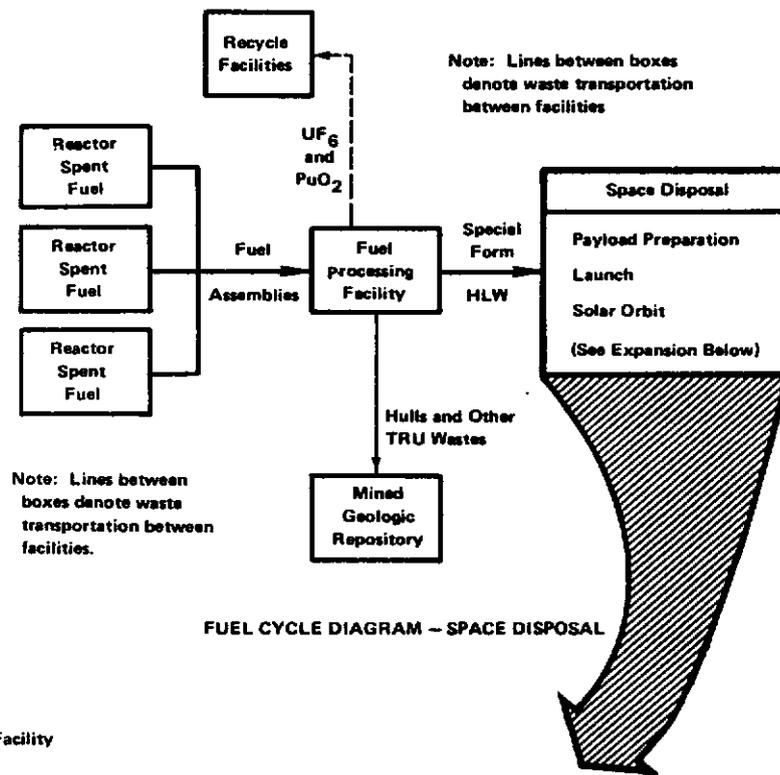


Figure 20. Space disposal; outline of disposal management (Source: DOE/EIS-0046F, 1980).

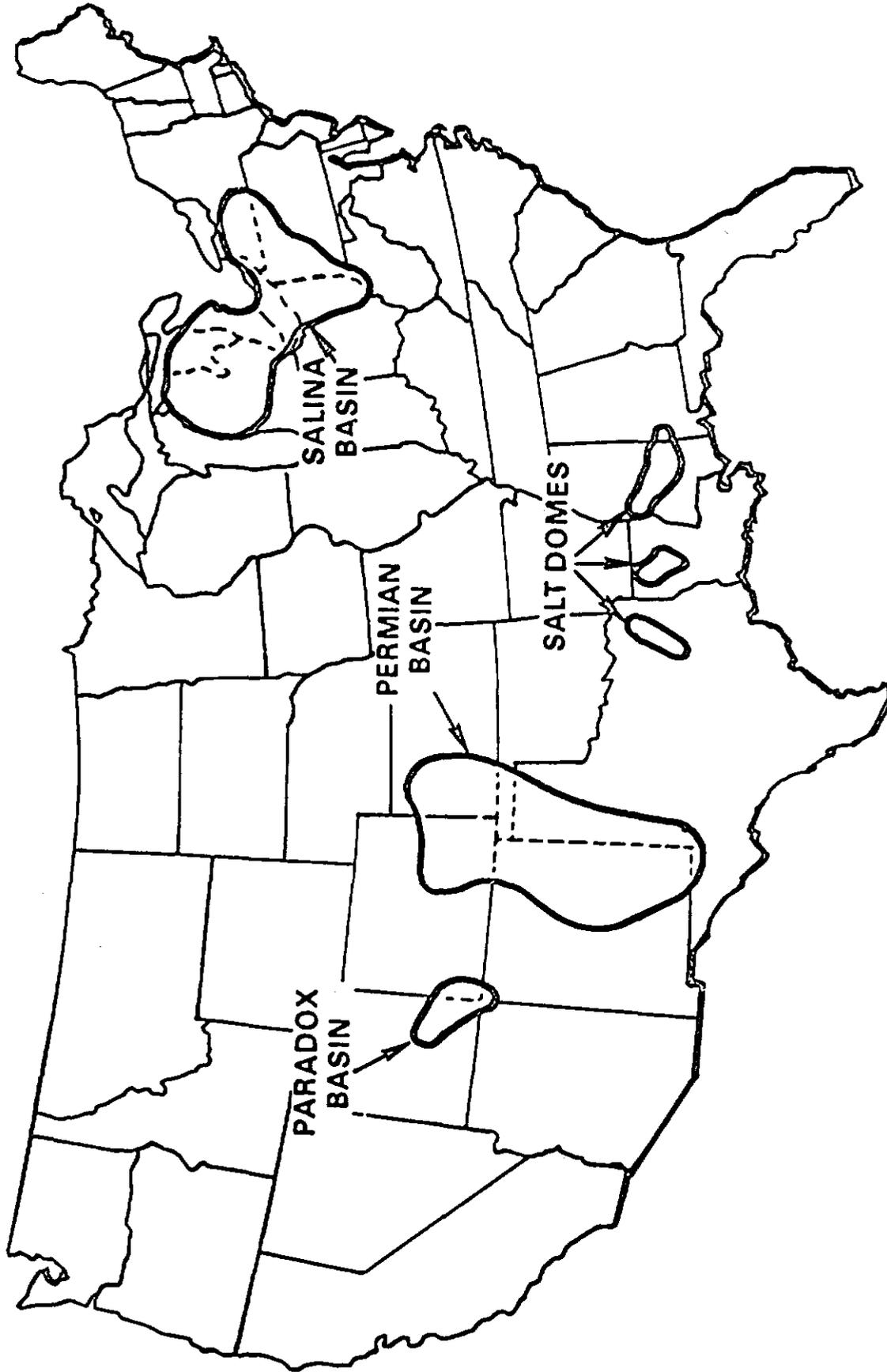


Figure 21. General location areas of salt basins investigated (Source: DOE/EIS-0046F, 1980).

In the Salina Basin a geologic reconnaissance investigation has been completed and further, more detailed study will be conducted in selected areas of Ohio and New York. No detailed investigation has yet been initiated.

In the Paradox Basin four smaller areas have been chosen for more detailed work: Salt Valley, Lisbon Valley, Gibson Dome, and Elk Ridge: all in Utah. These detailed studies are currently in progress.

In the Gulf Interior Region the work completed so far has led to the selection of eight salt domes for more detailed study: Vacherie and Rayburn's in Louisiana; Richton, Cypress Creek and Lampton in Mississippi; and Oakwood, Keechi, and Palestine in Texas. The Palestine Dome has been found unsuitable and eliminated from consideration. The investigations of the remaining seven domes is presently underway.

Investigation of Basalts

Geologic and hydrologic studies of the Hanford Site basalts in Washington State have been in progress since 1977. The results at hand indicate that the site may be suitable for a nuclear waste repository.

Investigation of the Nevada Test Site

The investigation of the Nevada Test Site is limited to the southwest part of the Site due to the limitations imposed by military testing. The volcanic rocks in the Yucca Mountain area are currently being studied. The results indicate that this area may be suitable for disposal of radioactive waste.

DEPARTMENT OF ENERGY ASSESSMENT OF PROPOSED WASTE DISPOSAL CONCEPTS

The assessment of the disposal concepts (Table 4), as perceived by the Department of Energy, is discussed in the Final Environmental Impact Statement (Volume 1, October 1980).

The mined geologic repository is the preferred concept considering the ranking factors shown in Table 4. Extensive research is already underway into various aspects of this concept.

TABLE 4. Criteria used in assessment of disposal concepts.*

	<u>Radiological Standards</u>	<u>1,000-Year Containment</u>	<u>10,000-Year Isolation</u>	<u>Developmental Time</u>	<u>Scientific Breakthroughs</u>	<u>Predictive Capability</u>	<u>Industry Size</u>	<u>Fuel Cycles</u>	<u>Reactor Design</u>	<u>Ability to Correct or Mitigate Failure</u>	<u>Maintenance & Surveillance</u>
Mined Repository	X	X	X	X	X	X	X	X	X	X	X
Very Deep Hole	X	X	X	X	X	X	X	X	X	No	X
Rock Melt	X	No	No	X	X	X	X	X	X	No	No
Island Mined Repository	X	X	X	X	X	X	X	X	X	X	X
Subseabed	X	X	X	X	X	X	X	X	X	X	X
Ice Sheet	X	X	No	No	X	No	X	X	X	No	X
Well Injection	X	No	No	X	X	X	X	X	X	No	X
Transmutation	X	NA	NA	No	X	X	No	X	X	X	X
Space	X	X	X	X	X	X	X	X	X	No	X

X = The concept appears to have the potential to meet this standard based on available evidence.
 No = The concept does not appear to have the potential to meet this standard based on available evidence.
 NA = This standard is not applicable to this concept.

* Source: DOE/EIS-0046F, 1980, Vol. 1.

Subseabed and island disposal concepts appear to be equally acceptable. However, the Department of Energy gives preference to the subseabed concept because of several serious uncertainties associated with the island concept, such as long-term effect of radioactivity on the geologic and hydrologic environments.

The very deep hole disposal concept ranks high and is in some ways superior to the mined geologic repository. However, some of the important drawbacks of this concept are: development of deep drilling technology, lack of sufficient understanding of geology at great depths, and difficulties of monitoring canisters containing radioactive waste. Therefore, although the Department of Energy recommends continued development of this concept, the Department considers it inferior to the subseabed concept.

The main weaknesses of the space disposal concept are risks of accidents during launching, failure during earth-orbit phase, and possible conflicts with international law. Because of these weaknesses, the Department of Energy does not recommend future development of this concept.

Rock-melting, ice sheet, well injection, and transmutation concepts do not rank high as possible alternative disposal methods. The weaknesses of these concepts include: uncertain ability to contain radioactive waste and inability to predict effects of waste on disposal sites and their surroundings.

CONCLUDING REMARKS

The future utilization of nuclear energy in our economy will, to a great extent, depend upon development of a technology for safe disposal of highly radioactive wastes.

According to the Department of Energy assessment, disposal in a mined geologic repository is the most suitable concept, and most of the future research and funding will probably be directed toward development of this method. It is anticipated that the first permanent repository will be available around the turn of the century.

The safe disposal of highly radioactive waste and related matters have been, and will be in the future, subjected to scientific and public scrutiny. It is hoped that this report will assist the citizens of our State to better understand this very complex problem.

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