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STUDIES OF ALTERNATIVE METHODS OF RADIOACTIVE WASTE DISPOSAL

INTRODUCTION

The Nuclear Waste Policy Act of 1982 (NWPA), signed into law by the President on January 7, 1983, establishes a national policy for the safe storage and permanent disposal of spent nuclear fuel and high-level radioactive waste (HLW).[1] The NWPA directs the U.S. Department of Energy (DOE) to develop and operate a system of waste disposal that emphasizes the use of deep-mined geologic repositories. Prior to the passage of the NWPA, DOE assessed the use of geologic repositories and other nuclear waste disposal alternatives in an Environmental Impact Statement (EIS) entitled the *Management of Commercially Generated Radioactive Waste* (DOE/EIS-0046F, October 1980). The EIS evaluated the following alternatives to deep-mined geologic repositories: subseabed disposal, emplacement in very deep holes, rock melt, island-based geologic, ice sheet, deep-well injection, and space disposal as well as the transmutation waste-form treatment, and indefinite surface storage. This backgrounder provides an overview of these nuclear waste disposal alternatives.

SUBSEABED DISPOSAL

The subseabed disposal concept involves the burial of solidified waste inside high-integrity canisters beneath the ocean floor. Since disposal would occur in the tectonically stable clay-rich sediments of the mid-plate regions, it is expected that the waste would remain isolated from the biosphere for extremely long periods of time and, therefore, not present a threat to plant and animal life. Movement of any waste isotopes escaping from the ocean sediments to the more biologically active near-surface water is expected to be a slow process, accompanied by dilution and dispersion. In addition, the great depth of the water constitutes a barrier to human intrusion.

Several potential problems remain, however. Most importantly, the feasibility of executing the concept has not been established. For example, it may be difficult to emplace the waste containers beneath the ocean floor to ensure containment until the waste decays to acceptable low levels. Additionally, the radionuclides may be altered by chemical reactions with the sediments. Even if subseabed disposal were to prove technically feasible, it may be difficult to develop an effective international, legal, and administrative structure to regulate and monitor a subseabed repository.

The Subseabed Disposal Program, a joint research effort between DOE, the Environmental Protection Agency, other Federal agencies, and international organizations (e.g., the Nuclear Energy Agency of the Organization for Economic Cooperation and Development) has been an ongoing program since 1974. However, recent and projected budget limitations on research and development expenditures have resulted in a reassessment of this program. As a result of this review, DOE did not request funds for the Subseabed Disposal Program in its fiscal year 1987 budget request to Congress. DOE's Office of Civilian Radioactive Waste Management (OCRWM) plans to conduct an orderly closing of the project while preserving the scientific information for future use.

DEEP HOLE DISPOSAL

The deep hole disposal concept involves the placement of waste canisters as far as 10,000 meters (approximately 6 miles) underground, a considerable distance from the accessible environment and below circulating ground water. At these depths, the nuclear waste may be

[1] Spent nuclear fuel refers to fuel that has been removed from a nuclear reactor core primarily because it can no longer sustain an efficient chain reaction. High-level radioactive waste, generated from the reprocessing of spent nuclear fuel to extract plutonium and the remaining usable uranium, results largely from defense nuclear activities.

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effectively contained while the waste decays to stable forms or levels that pose little threat to human health. To serve as a waste repository at these depths, the host rock must retain its character and structural stability under the heat and radiation conditions introduced by the waste.

The deep hole disposal concept was not defined as a proposed action in the EIS for the following reasons: (1) an incomplete understanding of the hydrologic characteristics of deep crystalline and sedimentary rock units, (2) the technical uncertainty associated with current drilling technologies that would have to be used to attain the extreme depths required to isolate nuclear waste from the biosphere, and (3) the lack of knowledge of in-situ rock mechanics properties under high pressure and temperature conditions.

ROCK MELT DISPOSAL

The rock melt disposal concept involves the emplacement of liquid or slurry waste into a deep underground hole or cavity. After the water in the waste has evaporated, the surrounding rock would melt from the heat generated by the decay of the radioactive waste. This process, in turn, would slowly dissolve the waste. The waste rock solution would slowly solidify, trapping the radioactive material in a relatively insoluble form deep below the surface of the Earth. The waste-rock-solidified conglomerate that would ultimately result is expected to be extremely leach resistant and, hence, could provide greater long-term containment of waste isotopes than could a mined geologic repository. Because less mining activity would be involved than for a mined geologic repository, the relative cost advantages of this concept could be substantial.

The rock melt disposal concept was not defined as a proposed action in the EIS largely because of the time required to monitor the process prior to full solidification of the nuclear waste. About 1,000 years would elapse before total solidification occurs. A lack of understanding of the heat transfer and phase-change phenomena in rock—information necessary to establish the stability of the molten rock matrix and to develop engineering methods for emplacement—would further complicate the monitoring task.

ISLAND GEOLOGIC DISPOSAL

The island geologic disposal concept involves the siting of deep-mined geologic repositories in islands. Preferred island locations are those in remote areas and devoid of known natural resources. Uninhabited islands that are hydrologically separated from large continental land masses offer potential advantages. Potentially adverse radiological health effects would be minimized. Further, any leakage of radioactivity into the island's ground water could be easily detected. Additionally, in the event of high-level radioactive waste leakage into the environment, the waste would be diluted by the surrounding seawater.

Drawbacks of the island geologic disposal concept include the risks associated with ocean transport of nuclear waste during adverse weather conditions. Additionally, many islands experience frequent and intense seismic and volcanic activity. Such activity could discharge the waste into either lava flows or into the atmosphere. Moreover, islands of volcanic origin have geologic foundations that are permeable and, hence, susceptible to interaction of fresh and marine water. The presence of water could contribute to the corrosion of waste canisters, leaching, and the eventual transport of radionuclides into the biosphere. Potential opposition from countries in the vicinity of a proposed island repository is an additional consideration.

ICE SHEET DISPOSAL

Without significant climatic changes, the Antarctic and Greenland ice caps could provide long-term isolation of nuclear waste from the biosphere. Three ice sheet disposal concepts have been considered: passive slow descent, anchor, and surface storage emplacement. Passive slow descent emplacement would allow for the waste canister to be placed in a shallow hole, eventually melting its way to the bottom of the ice sheet as heat is emitted from the radioactive decay process. Anchor emplacement parallels that of passive emplacement, but an anchor cable attached to the canister would limit the descent depth and enable retrieval of the waste canister. Surface storage emplacement requires the use of large storage units constructed above the snow surface and then filled with waste. The radioactive waste would act as a heat source causing the storage units to slowly melt their way to the bottom of the ice sheet.

An advantage of the ice sheet disposal concept is that the polar regions are uninhabited and desolate areas that would provide for the almost total isolation of the nuclear waste. The ice masses are thousands of meters thick, extend uniformly, and remain stable for long periods of time. At great depths (100 meters or more), ice behaves like a plastic and flows to seal fissures and to close cavities. Isolation of radioactive wastes would be ensured for long periods of time due to the very slow movement of ice.

Disadvantages of the ice sheet disposal concept include uncertainties surrounding both the disposal technologies and the impact of future climatic changes on the stability and size of the ice sheets. Another disadvantage is the expected high operational costs of ice sheet disposal because of the remoteness of the locations and the adversity of weather conditions. Ice sheet dynamics are not well known. Global climatic effects could accelerate the melting of large portions of ice masses from the heat generated from radioactive waste decay and thus open paths to the dispersion of waste. Finally, the Antarctic Treaty of 1959, of which the United States is a signatory, specifically prohibits the disposal of nuclear waste in the Antarctic.

DEEP-WELL INJECTION

The deep-well injection concept is the emplacement of liquid or slurried nuclear waste in deep geologic formations capped by an impermeable boundary layer. For acidic liquid waste, the method would involve the pressurized pumping of the waste to depths of 1,000 to 5,000 meters (3,300 to 16,000 feet) into a porous or hydrofractured geologic formation suitably isolated from the biosphere by relatively impermeable overlying strata. The waste would progressively disperse throughout the host rock. Deep-well injection is a working technology compared to technologies required to implement the rock melt and deep hole disposal concepts. Shale is considered a suitable geologic medium because of its ability to provide isolation of the waste from ground water and the environment.

The deep-well injection alternative requires either mechanical or chemical processing of spent fuel prior to its disposal, which is a possible drawback. Another possible limitation of the deep-well injection method concerns the mobility of a liquid waste form within a porous host rock formation. The combination of a liquid waste form and a porous rock body increases the chances that the waste could come into contact with the biosphere.

SPACE DISPOSAL

The National Aeronautics and Space Administration (NASA) and DOE have studied several space disposal concepts including the transport to and injection of nuclear waste into the sun or the emplacement of waste on the Earth's moon. These methods were found unsuitable for technical and space exploration reasons. Another concept involved sending reprocessed nuclear waste into a circular solar orbit about midway between Earth and the planet Venus. First, the space shuttle would carry the nuclear waste package to low Earth orbit. A transfer vehicle would then separate from the shuttle to 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 would move the waste into solar orbit.

Disadvantages of the space disposal concept include the possibility of launch failure and the potential inability of the waste packaging system to contain the waste in the event of such a failure. Additionally, the costs of launching nuclear waste into space would be very high. Therefore, the space disposal concept would be restricted to providing for the extraterrestrial isolation of long-lived radionuclides such as Iodine^{129} and Technetium^{99}. In turn, this method would require the reprocessing of high-level radioactive waste into specially tailored waste forms. Waste remaining on earth would have to be disposed of in a mined geologic repository. The use of extraterrestrial disposal, in conjunction with terrestrial disposal, would require an expected additional cost without achieving a significant reduction in long-term risk over emplacement of waste only in a mined geologic repository. Consequently, in April 1982, NASA and DOE agreed to discontinue further study of the space disposal concept.

TRANSMUTATION

Transmutation is not a disposal method but a treatment method for high-level radioactive waste that would be used in conjunction with specific disposal alternatives, such as the deep-mined geologic disposal option. The transmutation concept involves the reprocessing of spent fuel to recover uranium and plutonium (or processing to obtain a liquid high-level waste stream when uranium and plutonium are not to be recycled). The remaining high-level waste stream is partitioned into an actinide[2] waste stream and a fission product stream. The fission product stream is concentrated, solidified, and sent to a mined geologic repository for disposal. The actinide waste 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 percent 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 provides no reduction in the quantities of long-lived fission product radionuclides, such as Technetium^{99} and Iodine^{129} in the fission product stream that is sent to geologic disposal.

[2]Actinides are a group of elements that include uranium and all man-made transuranic elements (e.g., Berkelium and Californium). Fission products are nuclei (fission fragments) formed by the fission of heavy elements, plus the nuclides formed by the fission fragments' radioactive decay.

SURFACE STORAGE

The surface storage alternative would allow for existing spent fuel to be left indefinitely where it is being stored. Any additional waste discharges from the operation of commercial nuclear powerplants would be stored indefinitely in water basin facilities at the reactors or at other sites. Reprocessing of wastes is assumed not to be undertaken. This alternative would allow for delays and contingencies that could not have been foreseen in the research, development, and planning stages for deep-mined geologic disposal.

Disadvantages associated with the surface storage alternative include the extensive maintenance and monitoring activities that necessarily accompany surface storage, as well as the potential health and safety and environmental risks attendant to storing nuclear waste in relatively accessible locations.

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