# SUBSEABED DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE

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## ABSTRACT

Subseabed disposal of high-level radioactive waste is the only technical alternative or supplement to land-based geologic repositories that has been given serious attention by the United States or by any other nation. The goal of research on the subseabed disposal option has been to determine whether the concept is scientifically and environmentally feasible. To date, research results have identified no obstacles indicating that it would be infeasible. Some uncertainties and questions, however, still remain requiring that additional research be conducted. Funding for this research effort, however, was terminated in fiscal year 1987 for budgetary reasons. Other nations supporting this research program followed the United States and terminated or severely cut their complementary research efforts. It is uncertain whether Congress or the governments of these other nations will resume funding the research program in future years.

Several environmental and international factors point toward the need to resume funding subseabed disposal research. The United States could help develop this disposal option for nations that lack a viable domestic disposal option for their waste. At the same time, research on subseabed disposal would represent a low-cost "back-up" to land-based repositories, such as is mandated by the Nuclear Waste Policy Act of 1982. If developed, a multi-national subseabed repository could further the nuclear nonproliferation objectives of the U.S., which are better met if the waste is disposed of rather than stored.

## INTRODUCTION

In passing the Nuclear Waste Policy Act of 1982 (NWPA), Congress directed the Department of Energy (DOE) to develop a land-based system for the disposal of high-level radioactive waste (HLRW) and to continue research on other disposal options. The Office of Technology Assessment (OTA) found the disposal of HLRW in domestic land repositories to appear to be technically feasible, if suitable sites were found, and the simplest course to pursue from an institutional standpoint (1). Although domestic political barriers (e.g., siting of facilities) are complex, land-based repositories do not face the international political barriers associated with certain other options (e.g., subseabed disposal, shooting waste into space, or ice sheet disposal). In particular, a domestic repository would afford relatively easier institutional control in coordinating responsible agencies than would an international repository.

While mandating the development of land-based repositories, Section 222 of NWPA specified that research on other disposal options be continued. In addition, Section 223 called for funding an expanded program of cooperation and technical assistance with nonnuclear weapon states in the fields of spent fuel and disposal for fiscal years 1984 to 1989. Because the NWPA strictly commits the United States to developing a land-based geologic repository, alternative technologies are not available for the first United States repository unless unforeseen problems are incurred in siting such a repository. The development of alternative technologies, therefore, provides a type of "back-up" policy (2).

Subseabed disposal involves the emplacement of packaged waste beneath the ocean floor, within the thick clay sediments that cover large areas of the deep mid-oceanic regions. Most scientists consider these thick sediments, which have been geologically undisturbed for millions of years, to be relatively stable and uniform environments; the geologic structures underlying the sediments are less well-known. These regions are generally extensive and therefore could potentially be suitable for the disposal of large quantities of HLRW. They also offer potential environmental advantages in that they lack significant mineral or biological resources and are unlikely to be subject to human activity. The major technical disadvantages associated with subseabed disposal that have emerged to date involve added risks from ocean transportation accidents, the difficulty of waste retrieval (if that became necessary) and some remaining scientific uncertainties (e.g., whether the sediment will fill in sufficiently behind an emplaced penetrator to isolate the waste.)

From an international perspective, subseabed disposal may be the only viable option available to many small and developing countries. The other primary options -- disposal on land, reprocessing of their own HLRW, or shipment to other countries for disposal or reprocessing, may not be feasible for different reasons. Many countries lack land areas suitable for a geologic repository, or cannot afford to properly develop a land-based repository or reprocessing facility. They also may find it difficult to locate another country willing to accept their HLRW for reprocessing or disposal. In addition, reprocessing still yields a high-level radioactive waste byproduct; one such byproduct is plutonium, which is of nuclear nonproliferation concern in that it can be used to produce nuclear weapons.

The major institutional disadvantages of subseabed disposal are the complex international arrangements that would be required for its development and use. The international legal status of the concept would need clarification, standards and regulations would have to be developed, and at least one acceptable disposal site would have to be selected. Because many nations disagree with the use of the ocean for any radioactive waste disposal, it is unclear whether these institutional problems could be overcome. However, it is clear that demonstration of the scientific feasibility of the concept is a prerequisite for any attempt to resolve the institutional problems.

Cooperative international research is being conducted by the Seabed Working Group (SWG), under the auspices of the international Nuclear Energy Agency, a faction of the Organization for Economic Cooperation and Development. Eleven nations, plus the Commission of the European Communities, are involved in this effort.

## DESCRIPTION OF THE SUBSEABED REPOSITORY DISPOSAL SYSTEM

The subseabed disposal system is a multibarrier containment concept, designed to effectively prevent radionuclides from migrating out of the waste and into the ocean environment and eventually to humans. HLRW would first be placed in canisters for transport from the reactor and storage sites to a port facility. The canisters would be prepared at the port for the burial procedure, and then transported by ship at least 200 miles offshore to a preselected deep-ocean site (at least 5000 meters deep) for actual burial.

Once at the site, canisters would be emplaced by an appropriate method approximately 30 meters below the seafloor, into the thick (greater than 350 meters) clay sediments characteristic of the mid-ocean regions. Possible emplacement methods include free-falling penetrators, a booster mechanism to propel the canisters, or lowering of the canisters into drilled holes.

Subseabed disposal, like land disposal, is designed to minimize the release of radionuclides into the environment. The solid form of the waste, the canister, and the clay sediment are expected to form multiple barriers to slow the migration of radionuclides. If radionuclides escape to the ocean floor, ocean water would dilute them and delay them from reaching humans.

During the emplacement procedure, monitoring would be conducted to ensure that the operation proceeded correctly. Subsequent monitoring would be conducted to assess the success of the multiple barriers. The research program contends that retrieval of canisters would be technically feasible, but would be prohibitively expensive except for safety reasons.

## SCIENTIFIC AND ENVIRONMENTAL FACTORS THAT MAY MAKE SUBSEABED DISPOSAL ATTRACTIVE

Certain deep mid-ocean regions are considered potentially appropriate HLRW disposal sites for several reasons (3). These regions are located far from the edges of the Earth's tectonic plates, which are areas of frequent earthquake and volcanic activity, and thus they have been geologically undisturbed for a million years or more (3). One site selection requirement is that scientists must be able to document that the site has been geologically stable for 4 to 5 million years.

The chemical and physical characteristics of deep-sea clay sediments appear to offer several potential advantages; these conclusions are based primarily on modeling and lab research and must be further evaluated with field research. First, the chemical nature of the sediments is such that the majority of radionuclides that escape from waste packages are expected to bind tightly to clay particles and remain within the sediment, rather than migrating up to the ocean floor (4,5). Second, the physical nature of these sediments is expected to result in the quick sealing of any cracks or voids caused by a geologic or other disturbance (6). Third, the very small and uniform sediment grains fit tightly together and retard water movement between the grains, thus acting to further slow the migration of escaped radionuclides. Finally, surrounding sediment and ocean waters would act to absorb any heat emitted by the waste.

Since the sediments in a region are relatively uniform and stable, test results conducted at one location within an abyssal site would be valid for the entire site (another site selection requirement is that a site to be at least 100,000 square kilometers). In contrast, prospective land-based sites would be more difficult to characterize, because their geologic and groundwater patterns vary greatly over relatively short distances (7). Thus site selection might be easier in the subseabed than on land. In addition, because of a subseabed site's large size, any one site in the subseabed could have a significantly larger capacity than any one site on land (2).

## SCIENTIFIC, ENVIRONMENTAL, AND TECHNICAL FACTORS THAT MAY MAKE SUBSEABED DISPOSAL UNATTRACTIVE

### Site Characterization Uncertainties

One major uncertainty is whether the hole created by a penetrator puncturing and entering the ocean floor will thoroughly close behind the penetrator. If sediments displaced in the wake of the penetrator do not seal tightly behind it, radionuclides escaping from the waste form and canister will have easier access to ocean waters. Preliminary calculations from models suggest that the sediment will collapse to fill the hole, but field tests in both shallow and deep water are needed to validate this conclusion (8).

Another uncertainty is the effect that convection will have on the surrounding sediment and potentially on bottom-dwelling organisms. Convection is caused by heat generated by the waste in the canisters. Model predictions, laboratory measurements, and laboratory-scale tests suggest that canister temperature will peak about 3 years after emplacement; the maximum canister temperature should be 250°C and extend to no more than 0.8 meters from the canister. Models predict that the temperature should drop to below 100°C within 40 years (9). Additional experimentation is needed to test the validity of various assumptions used in the models' calculations.

Finally, it is uncertain what effect porewater advection will have on transporting radionuclides that have escaped from waste canisters up to the ocean floor. Porewater advection is the process by which porewater moves between the grains of the sediment; the more tightly the grains are bound together, the lower the rate of porewater advection. To determine the porewater advection rates for sediments in potential disposal sites, chemical analysis of sediment cores need to be conducted.

Risk of Transportation Accidents

The total risk of a transportation accident could be greater for subseabed disposal than for land disposal, for the following reasons. The risks of an accident occurring during the land transportation component would probably be roughly the same, for transport to a port facility (for subsequent subseabed disposal) or for transport to a land-based repository. However, one important difference associated with the subseabed option is that canisters probably would be transported to a port facility located in a highly populated district. An additional important risk factor for subseabed disposal relates to the ocean transportation component. Once the canisters reach a port facility, additional transport by ship (a distance of hundreds of miles) is required for subseabed disposal.

This comparison of accident risks is applicable to nations that would host a land repository, but not for nations that already ship their waste by sea to other countries for reprocessing or disposal. In the case of such nations that routinely ship their HLRW by sea, the risks of transportation accidents may already be as great as the risks associated with subseabed disposal.

Retrievability of Waste Canisters

The subseabed disposal research program has not thoroughly analyzed the feasibility of retrieving waste canisters at sea. The program contends that current technologies are adequate to locate waste canisters emplaced within the subseabed, remine the repository site, and recover the canisters (10). Nonetheless, such operations could be exceedingly difficult, and the routine costs of retrievability could be prohibitively high. Consequently, retrieving waste canisters in the deep ocean would likely occur only if the environment and public health were in jeopardy.

Retrievability from a land-based repository could also be difficult. The Nuclear Regulatory Commission's (NRC's) regulation (Title 10 of Code of Federal Regulation Part 60.111(b)) for land-based repositories requires that HLRW in such a repository be retrievable for about the same amount of time as was necessary to fill the repository -- an estimated 50 years. After that time the repository shafts would be backfilled, and if retrievability was then found necessary the shafts would have to be remined. The National Research Council's Board on Radioactive Waste Management believes that waste retrieval would be difficult, costly, and potentially dangerous (11). In particular, the Board warns that radioactive decay would cause high temperatures that could affect the waste package, the surrounding rock, and the repository rooms.

POTENTIAL FOR EXPOSURE AFTER DISPOSAL

The subseabed disposal program has attempted to model the risks of human exposure to radionuclides released during normal repository operations and from transportation accidents. These models suggest that exposure to humans from properly emplaced waste would be between 500,00 and 100,000 times less than exposure from natural background radiation (12), while exposure to humans in a worst-case ocean transportation accident could be up to seven times greater than exposure from natural background radiation (13).

To be considered politically acceptable, subseabed disposal would have to meet specified safety standards or criteria. Presumably, risk estimates from domestic modeling research would have to be compared to internationally established standards. However, no such radiological safety criteria have yet been developed that directly apply to subseabed disposal of HLRW. If compared to the Environmental Protection Agency's (EPA's) land disposal safety standards; modeling results suggest that the risk of exposure from subseabed disposal would be approximately 100 times below these land standards (12).

Risk of Exposure Under Normal Condition

Even when wastes are properly emplaced, there are several pathways by which humans could be exposed to radionuclides released from a subseabed repository, including exposure to contaminated water or consumption of contaminated organisms. However, estimated exposure rates are low for several reasons. In general, human exposure to these organisms and waters should be minimal for the foreseeable future, because potential repository sites are remote from fishing grounds, are more than 200 miles offshore, and are far from other human activities such as shipping lanes and mining. In addition, many radionuclides that eventually migrate through the sediment and into the water would be returned to the sediment by bonding with particles falling from higher levels of the water column (e.g., planktonic and other organic debris). Finally, the density of deep-sea organisms is 100 to 1,000 times less than the density of organisms in shallow coastal waters (13), and few deep-sea organisms are links in food chains that lead to humans.

Another pathway that could be more important, and which is not well understood, involves radionuclides being physically transported by ocean processes to the continental slope. In this region, human activities are more frequent and various vertical transport mechanisms and common food chain processes also could in turn transport radionuclides to surface waters.

Future research would be designed to address information gaps on poorly understood biological pathways by which radionuclides might be transported. For example, the ability of bottom-dwelling organisms to disturb porewater held within sediment, thus exposing radionuclides to ocean water and more mobile organisms, is poorly understood. Other poorly understood biological factors are bottom-dwelling community structure and metabolism, the biology of deepsea mobile scavengers, and the biology of organisms that inhabit midwater regions (9). More research is also needed to determine the background concentrations of radionuclides in fish and the pathways to fish and humans.

Risk of Exposure Under Accident Conditions

Results from models developed by the subseabed disposal research program for a worst-case accident scenario -- one in which a ship sinks in coastal waters without the recovery of any canisters -- suggest that the dose to a maximally exposed individual would be seven times greater than the dose received from natural background radiation. Maximum dose to nearby marine organisms is estimated to be six times greater than the natural background dose (13). If canister recovery techniques are possible, as contended by the research program, such canisters would be recovered and exposure doses would therefore be much less than those indicated above.

## LEGAL FRAMEWORK AFFECTING THE SUBSEABED CONCEPT

### United States Legislation

No legislation directly addresses subseabed disposal, primarily because current laws governing the use and protection of the marine environment were written before subseabed disposal was seriously considered. The two Federal laws with jurisdiction over subseabed disposal are the Nuclear Waste Policy Act (NWPA) (Public Law 97-425) and the Marine Protection, Research, and Sanctuaries Act (MPRSA) (Public Law 92-532), also known as the Ocean Dumping Act.

With respect to alternatives to a land-based repository, Section 222 of NWPA calls for continuing and accelerating a program of research and development of alternative means and technologies for the permanent disposal of HLRW. Subseabed disposal is the only alternative that was being seriously studied; since funding for it has been terminated, Section 222 is no longer being fulfilled.

Section 223 of NWPA could also affect the subseabed disposal option, since it establishes a policy of U.S. cooperation with nonnuclear weapons nations in the disposal and storage of spent fuel, for the purpose of nonproliferation. A subseabed repository under international control would be consistent with this policy.

The Ocean Dumping Act currently prohibits ocean dumping of HLRW by banning its transport from the the United States with the intention of dumping. The act, however, does not expressly define emplacement under the seabed as dumping.

### International Legal Framework

The London Dumping Convention (LDC) is the primary international agreement governing the implementation of the subseabed disposal concept. The LDC expressly prohibits ocean dumping of HLRW but defines "dumping" as "any deliberate disposal at sea of wastes or other matter from vessels, platforms, or other man-made structures at sea." As in the case of the U.S. Ocean Dumping Act, it is unclear whether the LDC would consider the emplacement of waste under the seafloor to be "dumping".

Delegations of signatory nations attempted to *clarify* the LDC's dumping definition by convening a group of legal experts in December 1983. These experts reported to convention members at the LDC's Eighth Consultative Meeting in February 1984. A majority bloc of nations at this meeting concluded that subseabed disposal of HLRW is prohibited, while a minority bloc of nations (including the United States) concluded that the LDC does not have jurisdiction over subseabed disposal and, therefore, such disposal is permitted. At the end of the meeting, a U.S.-sponsored resolution calling for further study of subseabed disposal was endorsed. Convention members agreed that no subseabed disposal should take place until the scientific feasibility and environmental acceptability of such disposal were proven, and until an appropriate regulatory mechanism was established. They also agreed that the LDC should be the appropriate vehicle for establishing such a mechanism.

There are eleven nations that have nuclear capability, yet are not signatories to the LDC. If one of these nations decided to use the subseabed for HLRW disposal, there is currently no legal recourse to prohibit such disposal. Several of these nations (e.g., Taiwan and Korea) have not chosen a disposal alternative for their HLRW.

The United Nations Conference on the Law of the Sea III (UNCLOS) was an international conference that produced the Convention on the Law of the Sea. The convention could also claim jurisdiction over subseabed disposal of HLRW if it ever enters into force; currently it lacks sufficient signatories. Moreover, even if the convention was in force, the United States is not a signatory. With respect to nations that are signatories, article 141 of the convention would permit the use of the seabed for peaceful purposes, which could be interpreted as giving signatories jurisdiction to develop a subseabed repository. The convention also establishes the International Sea-Bed Authority, of which all signatories of the convention are members. The role of the Authority is to organize and control activities in the "Area"; the "Area" is defined as "the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction." The Authority could also potentially assert jurisdiction over the emplacement of waste into the subseabed.

Pollution control treaties, international statements of environmental principles, and general principles of international conduct may also apply to the subseabed case. These principles impose a standard of care or duty when using the world's oceans.

## INTERNATIONAL IMPLICATIONS OF SUBSEABED DISPOSAL

### HLRW Disposal Options Available to Individual Nations

Many countries, both developed and developing, have nuclear reactors and hence must contend with HLRW. Only four basic options are potentially available for the management of HLRW: 1) disposal in a domestic land-based repository, 2) reprocessing in a domestic facility, 3) shipment to other nations for reprocessing or land disposal, or 4) disposal in the subseabed. Of the above management options, reprocessing is the only one that is not permanent, in that it generates a radioactive byproduct that still must subsequently be managed. HLRW can also continue to be stored, but storage is generally considered a temporary, rather than a final, disposal solution (1). For the reasons outlined below, subseabed disposal of HLRW could be a preferable disposal option for many countries.

The land-based disposal option may not be viable for many small and developing nations. Land-based repositories may be environmentally infeasible in nations that are subject to earthquakes or are geologically complex. Repositories built under these conditions would have a greater risk of excessive releases of radionuclides, resulting in environmental and human exposure to radiation.

Economic and institutional factors also could constrain development of land-based repositories. Many nations with small nuclear power programs (e.g., the Philippines) probably would be unable to support a land-based repository program. Such nations generally cannot afford to spend the billions of dollars that are needed to develop a land-based repository.

An important institutional constraint is the potential variability of standards and enforcement procedures between nations. The Director of the International Atomic Energy Agency is said to have acknowledged the potential problem of having numerous small sites operating at different safety levels, and to have stressed the importance of large, properly designed and operated repositories (14).

As an alternative, some countries could choose to ship their HLRW to a foreign country for disposal or storage. This may be difficult, however, in many cases; domestic political opposition may arise because of increasing the risk of transportation accidents and because of increasing the total volume of waste which the receiving country must manage. For example, suggestions that the United States accept limited quantities of foreign spent fuel for interim storage have been rejected by Congress (15; also, a provision to permit 100 tons of foreign commercial spent fuel to be stored in the United States was removed from the final version of the NWPA). There are some exceptions -- the Soviet Union accepts spent fuel from its allies for disposal (16,15), and China has expressed interest in storing West Germany's spent fuel (17).

A country could also choose to reprocess their waste or ship it to a foreign country for reprocessing. Reprocessing, however, is practiced by few countries and may not increase due to political and economic constraints. Reprocessing is also a nuclear nonproliferation concern in that one of the byproducts of the process is plutonium which can be used in the production of nuclear weapons. Disposal in subseabed or land-based repositories could reduce the amount of spent fuel available for reprocessing.

## Institutional Constraints on Subseabed Disposal

If a subseabed repository is to be developed under international auspices, a number of difficult institutional barriers must be overcome. The concept must be internationally approved as a legal disposal option for HLRW; an international regulatory framework must be developed; international standards and monitoring mechanisms for subseabed disposal need to be established; and agreement must be reached among interested nations on the selection of a site. As mentioned in the previous section, a nation that is not a signatory of international conventions with jurisdiction over the oceans could proceed in using the subseabed for disposing of HLRW.

Even if all involved countries abide by the appropriate international conventions, the institutional barriers listed above will eventually need to be overcome. Before attempting to overcome these barriers, however, the scientific feasibility of the concept still remains to be determined. The major institutional factor influencing the possibility of such a determination is funding. The United States has supported approximately half of the international research on subseabed disposal in the past, but made the determination in its 1987 budget to end its support. In response, the other nations of the Nuclear Energy Agency's Subseabed Working Group (SWG) have greatly reduced or terminated their research programs. Much data were lost because of this determination, in that instruments already emplaced on the ocean floor will not be recovered and data from multiyear long experiments terminated midstream will be of little use. Based on the data that were collected thus far, a report on the scientific and environmental feasibility of the concept will be published this summer by the SWG. If the United States decides in the future to resume its funding of the program, several countries may do likewise; however, the Netherlands and the Commission of the European Communities have decided to end their membership with the SWG.

## Conclusion

By resuming support for research on the subseabed disposal concept, the United States could help its allies develop a viable option for their HLRW, and provide itself with a supplemental option to deep-geologic land disposal. Several international institutional hurdles exist to developing a subseabed repository, but resolution of these is unlikely until after the disposal concept is found to be scientifically and technically feasible. Research staff estimate that about 7 years of research, funded at the 1986 budget level, will be needed to complete the scientific and environmental feasibility phase. While this work is ongoing, some effort could also be started to analyze the institutional constraints of subseabed disposal.

## REFERENCES

1. U.S. Congress, Office of Technology Assessment, "Managing the Nation's Commercial High-Level Radioactive Waste," OTA-0-171, Washington: U.S. Government Printing Office (1985).

2. U.S. Congress, Office of Technology Assessment, "Staff Paper on Subseabed Disposal of High-Level Radioactive Waste," Washington (May 1986).

3. C.D. Hollister, D.R. Anderson, and G.R. Heath, "Subseabed Disposal of Nuclear Waste," *Science*, 213, 1321-1326 (1981).

4. L.H. Brush, "Subseabed Radionuclide Migration Studies and Preliminary Repository Design Concepts," *The Technology of High-Level Nuclear Waste Disposal*, Hofmann, P.L. (ed.), U.S. Department of Energy Technical Information Center, 2, 287-294 (1984).

5. F.S. Schreiner, S. Fried, and A.M. Friedman, "Measurement of Radionuclide Diffusion in Ocean Floor Sediment and Clay," *Nuclear Technology*, 59, 429-438 (1982).

6. C.H. Karnes, P.R. Dawson, and A.J. Silva, "Sediment Mechanical Response Due to Emplacement of a Waste Canister," *Marine Geotechnology*, 5(3-4), 379-401 (1984).

7. U.S. Geological Survey (USGS), "Geologic Disposal of High-Level Radioactive Waste - Earth Science Perspectus," circular 779 (1978).

8. J.R.F. Burdett and C.H. Karnes (eds.), "Report on the Sixth Interim Meeting of the Seabed Working Group's Engineering Studies Task Group," Rome, Italy, October 7-11, 1985, ISMES SpA. (1985).

9. Sandia National Laboratories, "The Subseabed Disposal Program: 1983 Status Report," SAND83-1387 (October 1983).

10. D.R. Anderson, Sandia National Laboratories, personal communication at OTA *Workshop on Subseabed Disposal of High Level Radioactive Waste*, September 4, 1985, Washington (1985).

11. National Research Council, "A Study of the Isolation System for Geologic Disposal of Radioactive Wastes," Washington, National Academy Press (1983).

12. M.F. Kaplan, C.M. Koplik, and R.D. Klett, "Preliminary Post-Emplacement Safety Analysis of the Subseabed Disposal of High-Level Nuclear Waste," SAND83-7106, Sandia National Laboratories (1984).

13. M.F. Kaplan, R.D. Klett, C.M. Koplik, and D.A. Ensminger, "Radiological Protection Options for Subseabed High-Level Waste Disposal," SAND84-0548, Sandia National Laboratories (March 1985).

14. *Nuclear Waste News*, 5(39), 249, (1985).

15. J.N. Barkenbus, A.M. Weinberg, and M. Alonso, "Storing the World's Spent Nuclear Fuel," *Bulletin of Atomic Scientists*, (November 1985).

16. J. Diehl, "Eastern Europeans Placing Emphasis on Nuclear Power," *The Washington Post*, (December 17, 1985).

17. D. Fishlock, "German Waste to the Gobi," *The Energy Daily*, (September 11, 1985).