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**Subseabed Radioactive Waste Disposal
Feasibility Program: Ocean Engineering
Challenges for the 80's**

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Daniel M. Talbert

Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department
of Energy under Contract DE-AC04-76DP00789

Printed November 1980

Sandia National Laboratories

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Printed in the United States of America

Available from
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5285 Port Royal Road
Springfield, VA 22161

NTIS price codes

Printed copy: \$6.00

Microfiche copy: A01

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Printed November 1980

UC-70

SUBSEABED RADIOACTIVE WASTE DISPOSAL FEASIBILITY PROGRAM:

OCEAN ENGINEERING CHALLENGES FOR THE 80's

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Abstract

The objective of the Subseabed Disposal Program is to assess the feasibility of disposing of high-level radioactive wastes or spent fuel in suitable geologic formations beneath the deep ocean floor. The program is entering a phase which will address engineering feasibility. While the current phase of the program to determine the scientific and environmental feasibility of the concept is not yet complete, activities to assess the engineering aspects are being initiated in parallel to facilitate the development of the concept on a time scale commensurate with related programs both in the United States and abroad. It is anticipated that engineering aspects will become the central focus of the program during the early 80's and will continue so through the establishment of a pilot-plant level activity which could occur by the mid-90's.

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SUBSEABED RADIOACTIVE WASTE DISPOSAL FEASIBILITY PROGRAM:

OCEAN ENGINEERING CHALLENGES FOR THE 80's

Introduction

Sandia National Laboratories is engaged in a program whose primary objective is to assess the scientific, environmental, engineering, and economic feasibility of disposing of appropriately solidified high-level radioactive wastes (HLW) and/or repackaged spent nuclear reactor fuel in suitable geologic formations under the world's oceans. A secondary objective is to develop and maintain a capability to assess other ocean disposal programs for nuclear waste, whether national or international.

This assessment of geologic disposal of radioactive waste beneath the deep ocean floor is part of the Department of Energy (DOE) National Waste Terminal Storage (NWTS) Program. The overall goals of the NWTS Program are to identify and develop technologies that will provide a high degree of assurance that existing and future radioactive wastes can be isolated from the biosphere in a safe, environmentally acceptable manner and to provide necessary facilities to achieve this isolation.

The Subseabed Disposal Program (SDP) is a multi-institutional multi-disciplinary study investigating the feasibility

of disposal within subseabed geologic formations. The bases of this study are as follows: (a) approximately 72% of the earth's surface is covered by oceans, and this large area should not be neglected in our search for disposal sites; (b) large portions of the seabed are among the least accessible areas of the world and display low potential for economic exploitation by mankind; (c) there are thousands of square kilometers of seafloor which are mid-plate located and appear to be extremely stable geologically, have been totally depositional (as distinct from continental regions which are primarily erosional), and show no signs of having been adversely affected by millions of years of climatic changes; (d) many deep sea sediments display a great affinity for the constituent ions of radioactive waste and show an ability to immobilize chemically these ions; and (e) the disposal of radioactive waste may ultimately be an international problem, and one of the few remaining international areas are the world's oceans.^{1,2,3}

Using the above bases and considering present knowledge of midplate and continental trailing-edge regions of the oceans, the SDP has been working to provide the information needed to assess the viability of subseabed disposal and to develop any required new engineering capabilities.⁴⁻⁹

At present, attention in the SDP is focused on unlithified deep-sea sediments as candidate media for containment of radionuclides from solidified radioactive HLW. Deep sea

clays that form a large portion of marine sediments have a number of properties that make them attractive:

1. They are extremely fine-grained (most particles are less than three microns in diameter) and consequently have a low permeability, so that the rate of water migration (natural or induced) is very low;
2. They have very large surface areas per unit volume, an important attribute when combined with the ability of the clays to extract (sorb) cations from solutions;
3. Their strength is relatively low, and thus may facilitate subsurface emplacement of waste containers; and
4. They are in a plastic state, do not fracture if disturbed, and tend to flow or "heal" if disrupted.

Program Structure

A multi-year Subseabed Program Plan¹⁰ was issued in January 1980. It outlines in some detail the current SDP's and planned activities. The plan is governed by the consciousness that, even though our understanding of deep ocean sedimentary geologic formations indicates that they may be repository candidates, much additional specific research and development is needed before the feasibility of the concept can be considered to have been demonstrated.

The SDP is currently structured as a four phase program concluding in 2000. During Phase I (concluded in 1976)

the objective was to determine, in a preliminary fashion, the technical and environmental feasibility of the seabed disposal concept on the basis of collected historical data. Phase II (concluding in 1985) was begun in 1975 before the conclusion of Phase I. During Phase II major objectives are to acquire new oceanographic and effects data needed to supplement the Phase I data base establishing that the deep sediments in isolated regions of the ocean floor are an effective barrier to the dispersal of radionuclides from suitably emplaced waste.

If nothing is found during Phase II that would eliminate the concept from further consideration, Phase III (concluding in 1990) will assess the engineering aspects of handling and emplacement of HLW or spent fuel into the chosen geologic sites beneath the ocean floor. If Phase III is successfully completed and nothing is identified which would eliminate the concept, Phase IV (1991-2000) may be implemented and will demonstrate the capabilities of the concept through development of all necessary systems on a pilot plant level for emplacement of waste containers.

At the end of each phase of the program, a review is made and concept feasibility is assessed. This assessment requires both internal and external reviews. Following each of these reviews, a comprehensive report is prepared summarizing the results of that phase. If results indicate that the concept is unacceptable, the program will be terminated and emphasis thereafter will be placed on

demonstrating this unacceptability to other nations which are considering using the seabed for HLW disposal.

Background

The basic assumptions of the program are summarized in the following statements:

1. There exists a system of definable natural barriers that will provide the required containment of waste constituents.
2. A system of man-made barriers can be constructed which will insure the integrity of the waste form for the at least an order of magnitude greater than the half-life of the radionuclides of interest.
3. Summation of the containment times provided by the natural and man-made components of the barrier system will be at least an order of magnitude greater than the half-life of the radionuclides of interest.
4. Since the required isolation time is much longer than any man-made experiment, the attributes of each component of the barrier system must be adequately known so that a credible prediction of barrier system integrity can be made.

To compare the rates of decay of constituents of radioactive waste against the rates of migration of the

nuclides toward mankind, a formalism based on a set of sequential barriers to that release has been adopted. This formalism, a multiple-barrier concept developed by the SDP in 1974,^{5,7} is essentially a system of barriers composed of the waste form, the waste container, any controlled modification of the emplacement media, and the subseafloor emplacement media. This multiple-barrier concept is the foundation upon which the Subseabed Disposal Program is built. The task of the program is to determine whether any submarine geologic formation can contain radioactive waste long enough for it to decay to innocuous levels.

During the first year of this program, 1974, generic ocean areas were identified for consideration for seabed disposal concepts, and initial investigations were undertaken to evaluate early thoughts by program participants. From this first year came results and conclusions, based upon evaluation of collected historical data, preliminary analytical calculations, and initial new data derived from field work, that the water column (the mass of water extending from the seabed to the surface) should not be considered a primary barrier or an emplacement medium for HLW.

Program emphasis during the second year shifted from the water column to the characterization of midplate/midgyre sediments, their natural processes, and processes that are altered or imposed by the presence of radioactive wastes. Further analysis of available data, including supplemented

historical data and new laboratory and field information, reinforced the initial impression that the water column was unsuitable for consideration as a disposal medium. Peer reviews of the program found that conclusion to be technically sound.

Many results from the second year of research proved to be the beginnings of complex investigations that must be completed to allow realistic assessment of ocean-bottom sediment as a disposal medium and a primary barrier to the migration of radionuclides. During 1976, emphasis was divided between the continuing collection of data with which to characterize the midplate/midgyre sediment cover, initial laboratory investigations into the ion-exchange capabilities of the clay sediments, and analytical and modeling efforts to define the near-waste thermal environment.

The acquisition of a long, large-diameter core from a generic study area of the central North Pacific provided samples of a major portion of the sediment column for geotechnical, chemical, and microbiological laboratory analyses, gave a firsthand look at the geologic history of the region, and provided an opportunity to correlate remotely acquired geophysical data with the realities of the geologic structure. Analysis of these data indicated long-term stability of the region and produced no surprises or anomalies that would preclude use of the sediment column as a disposal medium. Initial laboratory work with samples of abyssal red

clays and selected ions that might be expected to result from dissolution of waste showed a high affinity of the clays for the ions, suggesting very favorable ion-exchange properties for the deep-sea sediments.

The broad spectrum of research investigations begun in 1976 continued in 1977, the fourth year of the program. The activities focused on (1) development of an analytical capability to assess ion transport through seabed media; (2) development of an analytical and numerical capability to analyze transient and steady-state fluid flow and heat transfer in porous media; (3) development of computer models to evaluate sediment column response to emplacement and heat burden; (4) initial development of biological transfer model to address potential paths and rates of ion transport; (5) an extensive laboratory program to evaluate sediment sorption with respect to single-specie ions and competition provided by waste constituents; (6) characterization of sediment properties to establish initial conditions and develop a long-term predictive environment model of the sediments; (7) initial investigations into the chemistry and waste canister, waste form, pore water, and sediment interactions near the emplaced waste; (8) continued characterization of the geochemical and geotechnical properties of deep-sea clay sediments; (9) initial laboratory investigations into the effects of high temperatures on geochemical and geotechnical properties of sediments; (10) development of an in-situ heat transfer field experiment to obtain quantitative

information on thermal processes and material properties and initial design of various hardware subsystems and deployment/recovery methods; (11) corrosion studies to evaluate candidate canister materials; (12) assessment of a variety of potential canister overpack materials for relative costs and economic impact; (13) a synthesis of existing western North Atlantic geological and geophysical data and an initial evaluation of a potential western North Atlantic study area; (14) compilation of an extensive geological and geophysical data base for the North Pacific and selection of areas for more detailed study based on current site-suitability guidelines; (15) initiation of a joint study with the National Science Foundation to develop a Long Coring Facility to enable acquisition of high-quality deep sea sediment cores; and (16) development of an international program and participation in the International Seabed Working Group.

The attention of the SDP remains focused on the waste form and canister for short-term (several hundred years) containment and on the sediments for long-term containment. Data thus far suggest that normally slow diffusion of cations through the highly impermeable deep-sea clay is further reduced substantially by the sorptive properties of clay sediments. In addition, the low permeability of the clay strongly inhibits thermally driven convection of pore water. Provided that the trends in the data acquired to date continue, there is room for cautious optimism with respect to technical feasibility of this disposal option.

Future Challenges

Some of the general areas of uncertainty which exist and for which more data and investigation are required include (1) effects of the density and pressure changes of pore waters caused by the heat from the canister; (2) capacity of the sediment to retain its original strength, permeability, and sorptive properties after emplacement of a canister; (3) geochemical interactions between the sediments and the waste materials; (4) reliability of emplacement and consequences of failure to emplace properly; (5) consequences of transport of the wastes back to the ocean floor; (6) safety of transporting the waste by land to a port, loading it onto a ship, and sailing to the disposal site; (7) quantitative assessment of the costs, risks, and benefits of the system; (8) legal constraints imposed by domestic environmental legislation and international law and agreements; and (9) public acceptance of the concept.

A significant number of items enumerated above involve engineering activities: instrumentation development, equipment design and development to enable acquisition of needed samples; systems development and cost analyses; and conceptual design, development, fabrication, and extensive testing of emplacement techniques, handling systems, ship systems, port facilities, and monitoring systems.

As previously mentioned, Phase III of the SDP is currently scheduled to conclude in 1990 with an assessment of the engineering feasibility of the subseabed disposal concept. While the current phase of the program to determine the scientific and environmental feasibility of the concept is not yet complete, activities to assess the engineering aspects are being initiated to facilitate development on a time scale commensurate with other related programs both in the United States and abroad. It is anticipated that these engineering aspects will become the central focus of the program during the early 80's and will continue so through the establishment of a pilot-plant level activity which could occur by the mid-90's.

Design requirements for handling, transportation, port facilities, deployment, monitoring, and salvage will naturally be driven by the selected method of subseabed emplacement. However, the emplacement method cannot be chosen independently of the other aspects of the system and, consequently, a significant system engineering effort is envisioned.

A number of emplacement alternatives are currently being considered at a preliminary conceptual level. Concepts currently deemed worthy of further effort fall into three general categories: penetrator, punch-in, and drilled-hole. Variations of these three span a large spectrum and it is anticipated that more than one technique will be found to be acceptable based on the scientifically derived criteria for emplacement.

Early evaluation of the relative practicality of the various concepts is important to meet development, construction, and operation milestones. In addition, engineering evaluations that will merit further scientific investigation.

Two base-case scenarios for emplaced waste canisters have been established: one each for the North Pacific and western North Atlantic oceans. These two base cases are shown in Figure 1. The North Pacific is characterized, in contrast to the western North Atlantic, by generally deeper water, lower rates of sedimentation and associated thinner sediment thickness, and greater areal extent of acceptable sediments.

Figure 1
Subseabed Disposal Program base-case scenarios
for emplaced radioactive waste containers

These basic differences between the two oceans have led to the two different emplaced waste canister configurations shown in Figure 1. The generally thin sediment cover of the Pacific is probably suitable for only a single container in the vertical dimension, while the much thicker sediments available in the Atlantic may well be amenable to a multiple container configuration in a vertical column. A thin sediment layer in the North Pacific is compensated for by the known wide horizontal coherence of these sediments, and the potential exists for developing a disposal site over a greater areal extent than is probably possible or feasible for the smaller, more congested, and less horizontally coherent Atlantic.

Given the above two scenarios, a number of penetrator emplacement concepts (Figure 2) and a drilled-hole scenario (Figure 3) have evolved. A punch-in concept, although appearing less feasible at this time, could be similar to the rotary drilled concept and may be applicable to burial shallower than that for the drilled-hole.

The penetrator concepts fall into two groups: those characterized by a free-fall mode (scenarios 1, 3, and 4 of Figure 2) and those requiring boosting (scenarios 2, 4, and 5 of Figure 2) using either conventional propellants or the ambient hydrostatic pressure.

The "drilled-hole" emplacement concept is envisioned as a multiphase operation as shown in Figure 3: (1) establish the emplacement hole, (2) emplace a canister at the end of

Figure 2
Subseabed Disposal Program sediment penetrator
emplacement concepts

Figure 3
Subseabed Disposal Program drilled-hole
emplacement concept

the drill pipe, (3) withdraw the drill pipe a specified distance, (4) backfill with local material and reconsolidate, (5) repeat steps two, three, and four the required number of times for the specific hole location, (6) withdraw, backfill, and reconsolidate the sediments above the last canister. The emplacement site would then be left with a reentry cone and any other required monuments and instrumentation.

While it is apparent that a number of advantages and disadvantages are readily enumerable with respect to each of the concepts shown in Figures 2 and 3, it is far too early in this initial stage of this program phase to dismiss any plausible concept. These ideas are starting points for addressing preliminary conceptual designs and the multitude of interfaces that will ultimately be identified between the major systems involved.

The shore-based handling, transportation, and port facilities for transshipment of properly packaged waste to the transport ship will be a complex system driven by such considerations as the land transportation system, port facility location, interim storage requirements, storage shielding and cooling requirements, transfer rates to match system through-put requirements, canister designs for transshipment if different from land transport, and methods of transfer to the transport ship. Each of these system elements will require detailed definition of numerous alternative engineering concepts and careful trade-off studies leading to the selection of system configuration.

Similarly, the ship and salvage subsystems present an extensive array of design considerations, and some of the most challenging trade-off studies will probably exist in the definition of concepts and the subsequent development of these stages of this program.

Potential monitoring requirements fall into a number of categories: long-term test and pre-operational engineering development, pre-operational site characterization, route position monitoring, surveillance during scheduled operations, routine post-operations surveillance, and emergency monitoring necessitated by accident or system failure. While actual data requirements for the various monitoring modes may be a number of years away (awaiting promulgation by various national and international agencies), it appears reasonable at this time to assume that requirements will probably evolve over a period of time and instrumentation requirements will ultimately be a subset of those developed during engineering development and proof-of-concept stages of this program.

It is envisioned that during emplacement development and long-term tests as much relevant data as possible will be collected. This data collection will necessitate in-place instrumentation in a demanding environment and will require development of emplacement techniques, periodic maintenance, data retrieval, and safeguarding and verification of authenticity of transmissions.

Concluding Comments

While a large technology base for the various subsystems discussed above does exist as a consequence of programs related to the Deep Sea Drilling Project, the development of the GLOMAR EXPLORER, the extensive offshore drilling industry, the newly evolving ocean mining ventures, the field of terradynamics and earth penetrators and subsequent marine sediment penetrators, and the Japan/United Kingdom transport ships for spent nuclear fuel, it only provides points of departure for the development of the total, complex, integrated system that will ultimately be required.

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