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The Third International Seabed High-Level Waste Disposal Assessment Workshop Albuquerque, New Mexico, February 6-7, 1978; A Report to the NEA Radioactive Waste Management Committee

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THE THIRD INTERNATIONAL SEABED HIGH-LEVEL WASTE DISPOSAL ASSESSMENT WORKSHOP ALBUQUERQUE, NEW MEXICO, FEBRUARY 6-7, 1978; A REPORT TO THE NEA RADIOACTIVE WASTE MANAGEMENT COMMITTEE

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ABSTRACT

The task groups of the Third International Workshop were staffed by scientists from the attending countries. Reviews of the progress of programs within each nation were given and plans for cooperative task group workshops, data interchanges, newsletters, ocean cruises, sample exchanges, and critical laboratory and field measurements were coordinated. Although a considerable amount of work remains to be done to assure safety and feasibility, no technical or environmental reasons were identified that would preclude the disposal of radioactive wastes beneath the ocean floor.

ACKNOWLEDGMENT

The editor thanks the workshop participants for the cooperation which made preparation of this report possible.

The editor is especially grateful to the participants from England, France, Canada, the United States, CED, and NEA (see Appendix I), and for the letter outline from Japan, as well as for the information exchange, and the formation of an international cooperative research and development program for assessing the feasibility of seabed disposal of high-level waste.

The interest shown and the advice given by a number of scientists and engineers of Sandia Laboratories is gratefully acknowledged.

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WASTE DISPOSAL ASSESSMENT WORKSHOP
ALBUQUERQUE, NEW MEXICO, FEBRUARY 6-7, 1978;
A REPORT TO THE NEA RADIOACTIVE WASTE MANAGEMENT COMMITTEE

BACKGROUND

At the October 6-7, 1975 session of the Radioactive Waste Management Committee of the Nuclear Energy Agency (NEA)*, held in Paris, it was decided that workshops should be organized to determine interest in, and the nature and scope of possible international cooperative activities in the field of high-level waste disposal. A geologic option which showed promise, on the basis of ongoing US studies, was emplacement in the ocean floor. The Committee therefore decided that an international workshop should be organized to examine the research and development required to assess the technical and environmental feasibility of using the geologic formations beneath the ocean floor as a repository for high-level waste. The First International Seabed High-Level Waste Disposal Assessment Workshop was organized by the USA and held in Woods Hole, MA, on February 16-20, 1976. A report of the meeting was submitted to the NEA Committee. The Committee suggested that since seabed disposal of high-level waste was a highly sensitive subject but looked sufficiently promising to warrant further investigation, interested member countries should plan on meeting again in approximately one year for a status report and program review.

*The Nuclear Energy Agency is an international body affiliated with the Organization for Economic Cooperation and Development, a group formed to facilitate operations of the European Common Market. Both the NEA and the OECD are based in Paris.

Accordingly, in March 1977, the USA hosted the Second Workshop in Washington, DC. All NEA member nations were again invited. Four nations attended - USA, UK, France, and Japan. From this meeting came an informal written agreement that member nations would cooperate on the research and development (R&D) needed to better evaluate the feasibility and acceptability of seabed disposal of high-level waste. A letter report outlining the areas of cooperation and an organizational structure for a Seabed Working Group (SWG) was sent to the NEA. The Chairman of the SWG would come from the USA (currently Glenn Boyer, DOE-ECT), with an executive committee made up of a senior member from each participating country. Each participating country would have a member on each task group, with one member of each group acting as lead correspondent.

In February 1978, the USA hosted the Third International Seabed High-Level Waste Disposal Assessment Workshop in Albuquerque, New Mexico. In attendance were representatives from the four countries identified earlier, and a representative from Canada. (A list of attendees is provided as Appendix I.) During the two-day meeting, reviews and updates of the individual national programs were presented to the assembly, after which the task groups met to formulate detailed plans for R&D in their areas of interest. A letter report was prepared by Glenn Boyer and sent to NEA (Appendix II).

The report of this Albuquerque meeting, which follows, was prepared by the Workshop for the NEA Radioactive Waste Management Committee. It includes individual task group R&D plans, a summary of the programs of member nations, and a list of areas of cooperation and planned R&D.

WORKSHOP ACTIVITIES

After an introductory session, summaries of the activities of each participating nation over the past year were given. The Workshop was then divided into seven task groups and an executive section to accomplish the following:

1. Develop an R&D program for each task group.
2. Identify relevant current research within each nation.
3. Develop a plan for expanding current and future cooperative international research.

In the following pages are presented the information developed at the meeting, the results of the task and executive group meetings, and the names and addresses of SWG participants.

THE INTERNATIONAL SEABED PROGRAM

The structure of the SWG and the five participating member nations can be seen in Appendix I.

Since Canada only recently joined the SWG, a full complement of task members had not been identified at this writing; however, ocean science task members were to be identified by the end of April 1978.

Japan did not send a delegation to SWG this year, but in their letter of regrets (Appendix III) they state that they are supporting studies related to certain ocean science task groups and would like to participate in these areas.

The SWG recommended that Dr. David Deese, Harvard University (US) be asked to contact individuals within the various participating countries in relation to the international legal and political aspects of seabed disposal of high-level waste or spent fuel, and to keep the SWG apprised of accomplishments.

Many task group members cited the need for an information exchange more rapid than is allowed by an annual meeting. Several task groups suggested mail stops within each country for rapid information exchange, or a task group newsletter. A SWG newsletter was suggested to better facilitate coordination between task groups, the rapid dissemination of information, and complete and permanent documentation of SWG activities. This newsletter will consist of inputs from each task group member and will be compiled by D. R. Anderson for distribution to the SWG membership. A list of suggested areas of cooperation within each task group follows:

System Analysis Task Group

- Provide an overview by means of a complete system analysis; identify requirement and input needs from other task groups.
- Prepare a complete seabed disposal system analysis model.
- Plan a group meeting for the Spring of 1978 in Ispra, Italy.

Physical Oceanography Task Group
(formerly Water Column Task Group)

- Provide for increased exchange of information about ongoing physical oceanographic programs.
- Initiate new studies of mutual interest.
- Areas of cooperation include:
  - a. Development of oceanographic models;
  - b. NEADS - (North East Atlantic Dynamics Study) - a water-sampling program;
  - c. EUROMODE - (a planned Anglo-French eddy study using float tracking; and
  - d. GEOSECS - (an existing eddy study using tracers).
- Participate in task group workshops.

Canister Task Group

- Review and exchange data on material corrosion.
- Develop new testing techniques for deep sea conditions.

- Exchange data on materials under test and evaluate testing environments.

- Exchange concepts for sorptive barriers or sacrificial materials.

Waste Form Task Group

- Encourage use of standard ISO waste characterization tests by all investigators.

- Develop similar characterization tests for hydrothermal studies.

- Exchange samples of various waste forms.

- Use unique high-pressure/temperature facilities at Sandia Laboratories.

- Consider joint large-scale in-situ tests.

- Develop and maintain reference materials and publications library.

Biology Task Group

- Expand areas of joint R&D (France - US).

- Develop understanding of role of deposit feeders in movement of radionuclides out of sediments.

- Develop understanding of the physics and chemistry of radionuclides in sediments (UK - US).

- Identify ecological and biological laboratories in each nation and encourage data interchange.

Sediment and Rock Task Group

- Encourage collaboration and data exchange between sea disposal task groups and investigators of geologic disposal on land.

- Exchange sorption data already acquired.

- Exchange sediment samples.

- Compare different material transport models.

- Design and operate joint large-scale laboratory verification experiments.

Site Selection Task Group

- Exchange available track chart data.
- Acquire lateral acoustic data on several study sites.
- Develop the necessary techniques for, and acquire in-situ acoustic properties.
- Continue to compile and look for hiatuses within sediments and rock.
- Work with the French in the Atlantic on two study sites using the research vessel RESOLUTION.

SYSTEM ANALYSIS TASK GROUP REPORT

PARTICIPANTS

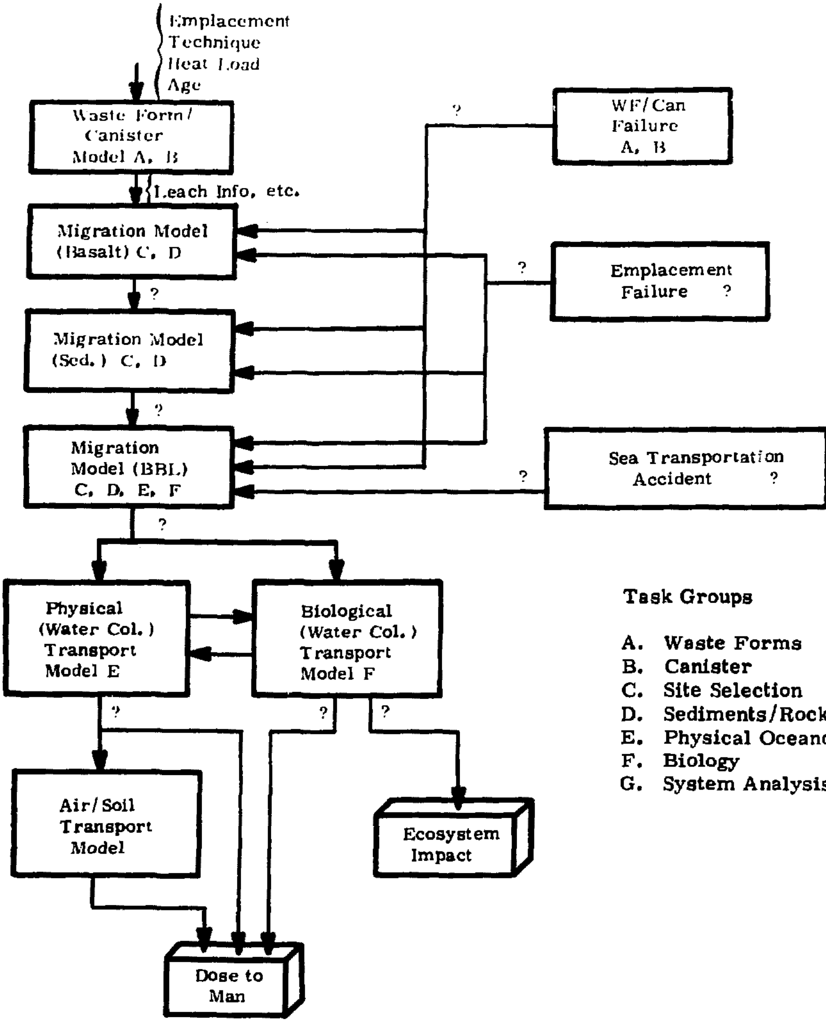
G. Webb, United Kingdom (Chairman)
D. Talbert, United States
N. Murray, CEC
G. de Marsily, France

INTRODUCTION

System analysis provides an overview of the entire problem structure and of interactions between various problem elements. A major responsibility of the System Analysis Task Group is to ensure that other task groups have identified all assessment requirements and are producing the necessary parameters to feed into the complete system. This is done by an iterative process in which a preliminary analysis and a sensitivity analysis are used to identify the parameters and data of most importance. These studies will form the basis on which the Seabed Working Group can direct overall programs of the task groups. The work of the other task groups should then be focused on these parameters and data so that improved results can be fed back into the overall system model. The process is repeated until the predictions of the system model achieve the required precision and confidence.

RESEARCH AND DEVELOPMENT PLAN

The task group devoted much of its time to discussion of methods of characterizing the overall problem. It was not possible to finish this in the time available at this workshop but the task group will continue the discussion at the summer meeting. Figure 1 shows the problem breakdown into subsystem models and interaction with other task groups. The boxes



Task Groups

A. Waste Forms
B. Canister
C. Site Selection
D. Sediments/Rock
E. Physical Oceanography
F. Biology
G. System Analysis

Figure 1. Modular Structure of Seabed Disposal Problem

in Figure 1 do not represent particular mathematical techniques or sets of techniques; these will depend on the formulation of the subsystem model. This is a preliminary attempt, and considerably more effort will be needed to define the inputs, outputs, parameters, and data requirements of each set of models. The system described in Figure 1 is a deterministic model corresponding to normal operation of the system, and will result in a predicted normal impact on man and the ecosystem. Accident assessment will require a combination of probabilistic and deterministic models. These will be developed separately and may be combined at a later stage. The task group decided to consider only accidents specific to the seabed option, such as those at the port facility during sea transport and emplacement. Accidents during waste processing, intermediate storage, and land transport are therefore excluded.

CURRENT RESEARCH ACTIVITIES

No information has been accumulated at this time.

FUTURE COOPERATIVE RESEARCH

The mechanism for carrying out this process uses models for the various subsections of the problem. The models may be developed by the System Analysis Task Group or by other task groups; in the latter case it is the job of the System Analysis Task Group to ensure that the inputs, outputs, parameters, and model forms are compatible with other models used.

No complete system analysis model for the problem has been developed in any of the participating countries. Some member countries plan to start developing such a complete model; it appears beneficial for all parties to cooperate in these developments. This does not imply that one unified model must be developed but that the different techniques used should be discussed and understood. For these reasons a separate meeting of the System Analysis Task Group will be held before the next SWG meeting.

Technical areas that do not appear to be adequately covered by existing task groups include emplacement and transportation. These areas are being addressed by individual countries but are not being internationally coordinated through the SWG.

Thus far the task group has restricted itself to technical aspects of the analysis, but a complete problem description should include legal, political, and administrative aspects. It appears that no SWG Task Group is addressing these aspects of the international program.

CANISTER TASK GROUP REPORT

PARTICIPANTS

N. Magnani, United States (Chairman)
A. Corbet, United Kingdom
L. Grall, France
J. Braithwaite, United States

INTRODUCTION

The task group feels that in addition to developing a canister for the containment of high-level wastes on or in the seabed, its charter also includes the development of new concepts for other engineered barriers. These could be sorbents, sacrificial materials, coatings, etc., in addition to canisters. Because of similarities between the types of canister problems associated with both geologic and seabed disposal, the group recommends that observers from countries with geologic disposal programs (for example FRG and Sweden) be invited to Canister Task Group meetings.

Limitations imposed by canister materials on canister lifetimes were discussed. A 1000-year life for a canister on the seabed might be achievable. Archaeological evidence is encouraging in this respect. However, for times in excess of 100 years there is much uncertainty for even the best materials. Because of the elevated temperatures associated with seabed placement, more severe material problems are anticipated. Accurate electrochemical corrosion data cannot presently be obtained above ~300°C. Therefore, this temperature sets an upper limit for long term predictability of low corrosion rate processes. Long canister life may be achievable at this temperature and possibly at higher temperatures, but a great deal of laboratory work will be required to prove it.

RESEARCH AND DEVELOPMENT PLAN

The canister program outline prepared by D. R. Anderson, Sandia Laboratories, in 1977, was revised by the task group as follows:

I. Environment - Identification of environment in which canister may be placed, both in and on the seabed:

A. Physical environment

1. Temperature
2. Internal and external pressure
3. Material flow
4. Changes in environment with time and heat

B. Chemical environment

1. Radiolysis products
2. Major and trace elements (Fe, Mg, H_2, CO_2, Cl, SO_4, S)
   a. pH change
   b. Competitive ion interactions
   c. Oxidation potential
   d. Organics
3. Sacrificial material (cask protection)

C. Biological environment

1. Chemicals produced by biota
2. Biological forms generating a physical crevice
3. Temperature effect (e.g., insulation)
4. Synergistic effects of combinations of above.

II. Corrosion Studies - Time periods of interest for these experiments include the period of high heat production (~100 years) and the period required for decay of the main fission products (~1000 years). Experiments should include canister material corrosion studies as well as those required to demonstrate reliability of closure mechanics (joints, heads, seals, crimps, valves, etc.). The objective of these studies is to predict the rate of exposure of the waste form to the environment. The study should include the following compatibility regimes as well as the testing methodology:

A. Compatibility regimes

1. Waste form - canister compatibility
2. Geologic environment - canister compatibility
3. Canister-canister or canister-liner compatibility

B. Types of corrosion

1. General
2. Pit or crevice
3. Stress corrosion
4. Hydrogen embrittlement
5. Galvanic

C. Corrosion testing

1. Electrochemical
2. Compatibility

III. Design - Many aspects of canister design for in the seabed should be initiated as soon as possible. Modeling expertise is needed throughout the study. Development of appropriate modeling capabilities should begin immediately.

A. Pressure compensation designs

B. Canister closure designs

C. Fabrication and filling methods

D. Model development

E. Handling considerations

1. Transportation
2. Emplacement
3. Retrievability after emplacement
4. Retrievability after accident
   a. From ship on surface
   b. From sunken ship
   c. From bottom

F. Storage

1. At fabrication site
2. At dockside

G. Prototype testing and model verification

H. Monitoring capabilities

I. Material availability and cost

J. Other engineered barriers
   1. Sacrificial materials
   2. Sorbents
   3. Coatings

IV. Canister Construction - In this area not much if anything should be done until the seabed barrier has been more adequately demonstrated and the required design criteria and parameters passed down from the thermo-mechanical response studies for specific geologic formations (heat load, size, radiation load, etc.). Quality assurance guidelines can be developed. A brief outline follows:

A. Identify critical criteria required for the geologic formation (heat load, size, radiation)

B. Develop a quality assurance methodology

Corrosion was determined to be the most important problem area related to canister development, and two important areas for corrosion research were identified. New techniques must be developed for the study of very slow corrosion phenomena. The techniques must be very sensitive in addition to being accurate. Techniques must also be developed to provide for early detection of localized corrosion phenomena such as pitting, crevice attack, and stress corrosion cracking.

A brief description of the canister work planned or underway in each represented country follows. Japan was not represented and has stated that it is not interested in participating in a cooperative program for high-level waste canister development.

CURRENT RESEARCH

United States

In the corrosion program at Sandia Laboratories, an attempt is being made to identify the most cost-effective materials that can be used to construct a waste canister or waste canister overpack. The main selection criterion is corrosion resistance, with the goal of finding materials which will remain unbreached for 50 to 100 years in the buried subsea sediment environment. No research presently is addressing canister design or waste-form/canister compatibility.

The major accomplishment of the past year was the construction of a laboratory in which the heated subseabed environment can be simulated. Included are autoclaves in which time-efficient electrochemical measurements can be made. Also, some preliminary corrosion data on a variety of alloys at 4°, 25°, and 90°C and 8000 psi in sea water and sea sediments have been collected.

Presently, the US effort is concentrated on corrosion caused by the external environment, excluding radiation effects. Five alloys, each representing a different expected corrosion response, are being studied. These include: 1018 carbon steel, 304L stainless steel, Carpenter 20Cb3 stainless steel, Inconel 600, and the titanium alloy, Ticade 12. Long-term compatibility tests in hot (250°C) sea water and deep-sea sediments are underway. Direct-current electrochemical polarization measurements are being made to evaluate effects of temperature, oxidation potential, pressure, and solution chemistry on corrosion response of the above alloys. After two or three candidate materials are selected and other testing facilities developed, experimentation will be expanded to consider the very important ways in which corrosion is effected by stress, radiation, sensitization, joining techniques, etc.

France

The aim of the French program is to establish reliable, sensitive, and accurate methods, mainly based on electrochemical systems, of detecting and measuring very slow corrosion phenomena. These must include impedance measurement, pitting-potential measurements, low-strain rate testing, accurate general corrosion rate measurements, detection of localized phenomena such as pitting or cracking and crevice effects, and, eventually, galvanic effects.

The first step will be at moderate temperature (≤100°C). A second step will focus on higher temperatures in autoclave conditions under 300°C.

Experimental work is planned to begin during 1978, depending on funding.

United Kingdom

The work content of the UK program is still essentially that given in the summary dated March 3, 1977, attached to Dr. H. Glauberman's letter dated March 14, 1977. A brief outline of current activities follows:

I. Canister Material Properties

A. Creep Laws - Additional creep tests are being carried out on specimens of Incoloy alloy 800. This work will supplement IAEA-SM-207/3, in that particular attention has been paid to ascertaining the history of the specimens.

B. Corrosion - Simple immersion tests in various types of water (e.g., salt, pure, etc.) have been carried out with Incoloy alloy 800 weld test plates after they had been subjected to the glass-making thermal cycle. No corrosion has been detected.

A systematic theoretical and practical program of corrosion work in support of HARVEST* is in hand.

C. Evidence of Durability - Archaeological evidence of 1000-year durability of materials found buried in various soil conditions is being assembled. This may have some relevance to assessing the compatibility of the canister with sediments. It appears that chalk is very benign but that gravel and certain types of clay can be most detrimental.

II. Physical Properties of HARVEST Glasses - Physical data pertinent to stress-strain modeling for the HARVEST canister have been determined for two glass formulations. These include strain rate, thermal expansion, thermal conductivity, infrared spectral absorption coefficients, specific heat and elastic moduli.

III. Modeling of Thermal and Mechanical Conditions - Computations have been performed using the FISPIN IV and FISP PT programs to predict heat generation rates in waste arising from fuels having a variety of irradiation histories, for periods up to 10^8 years. In general, there is fair agreement between these programs for the early years. FISPIN IV and ORIGEN show agreement within an order of magnitude over the complete range. Only limited use has been made of UNCLE (a general multidimensional master program) for predicting stress and creep, since the program is still under development and running times can be long.

Some thermal stress studies have been done by a postgraduate student at London University (Peruvian Navy First Lieutenant Jose J. Dellepiane Massa) using GORDA which is based on CREEPA, a well-tested program in use at Imperial College to predict residual stresses in thick-walled cylinders.

More systematic work is planned using the expertise of the Windscale Nuclear Power Development Laboratory of the UKAEA in modeling irradiated fuel behaviour to match PIE information.

*A method for vitrifying HLW.

IV. <u>Fabrication</u> - A full-scale canister has been manufactured from the prime candidate material Incoloy alloy 800 in conformity with a specially prepared high-quality specification (BNFL SPEC NO. P72151A). The canister was made without undue difficulty and a complete record of materials and procedures employed is available. Weld prep Type A required modification to allow the initial TIG root run to be made. Few weld flaws were found during fabrication and the ones that fell outside the specification were successfully repaired (see Table I).

TABLE I

Darchem Engineering Limited - Aycliffe

<u>Nature of Canister Weld Flaws</u>

L1	1 inclusion approx. 1/8" 1 inclusion approx. 3/16" + 3/64" gas pore
L2	1 pipe (1/16") 1 crack 1/4"
C1	2 pores (1/16") at 1/2" centres 1 pipe (1/16") 1 tungsten 1/16" 1 pore 1/16"
C2	2 small pores 1/32" at 1/8" centres 2 inclusions 1/16" long 1 pore 1/16" 1 inclusion 1/16" 1 inclusion 1/16" 1 pore 3/64"
C3	1 inclusion 1/16" 1 inclusion 1/16"

Total of 6 acceptable gas pores 1/64" dia.
Total welding length approx. 40.0 ft

The program for examining the canister before and after glass making has been drawn up. Dimensional changes will be determined by the Hickson Platen Gun technique as well as by linear measurements.

A smaller 4-inch diameter vessel has also been successfully fabricated to the same specification and filled with simulated glassified HLW for sawing trials.

A program of development work is in hand at the Springfields Nuclear Power Development Laboratory of the UKAEA for remotely sealing canisters after they have been filled with glassified HLW.

Technical consultations have been held with the UK Copper Development Association on the welding of copper and copper alloys in a highly active environment. No insuperable problems are foreseen in developing suitable weld designs and techniques.

Technical consultations have been held with contractors who have in the past successfully incorporated cast lead shielding into BNFL irradiated fuel flasks (casks). Enough is known of the technology of lead casting to specify the techniques and conditions for completely encasing primary canisters in void-free lead.

V. Canister Performance - Four canisters have been used in support of HARVEST development in the AERE Harwell pilot plant (Table II). The first canister was 24 in. diameter, of Type 321 stainless steel for plant commissioning trials. Details of the other three and their performance to date are given in Table II.

After each inactive glass making run the canister is emptied for reuse by unplugging a drain nozzle and remelting the glass. The circumferential weld area attaching the base to the cylindrical barrel is then checked for cracks by a dye penetrant technique.

TABLE II

Harvest Vessels Used in Harwell Pilot Plant

Vessel No. 2 18" cast HK 40, flat base Immaculate 5 (25/20)
Vessel No. 3 18" cast HK 40, flat base Immaculate 5 (25/20)
Vessel No. 4 18" cast HK 40, dished end Incoloy 800.

Vessel	Total No. of Heating Cycles	Total Hours Above 1000°C	Comments
2	22	139	Taken out of service when delamination cracks appeared in base weld.
3	15	124	Taken out of service when transverse cracks appeared in base weld.
4	33	519*	Still in service.

*This figure refers to hours above 900°C. The advent of vessel No. 4 coincided with the change from glass M22, which requires a working temperature of 1050°C, to glass M9, which requires a working temperature of 950°C. There is some diametral expansion of Vessel No. 4 up to 0.060 in., i.e., 0.3% since new.

The superior performance attributed to the revised geometry of Vessel 4 base can be appreciated since no cracks are detectable after 33 heating cycles and 519 hours service above 900°C.

A replica of the Windscale small-scale active pilot plant for HARVEST development is in service, processing very faithful simulants of highly active liquor concentrate (HLLW). The plant uses the actual rising level glass-making process as envisaged for use in the full-scale demonstration plant. The canisters used in the plant are 4 inches in diameter and the height of glass fill is 10 inches.

The canister material currently employed is the wrought version of HK 40 (Type 310 SS), but Incoloy alloy 800 will be used in the future.

Canisters have been sectioned after having been used for glass making and the glass/canister interface checked for any wall attack by known embrittling elements such as tellurium, using electron-beam microprobe analysis. No signs of attack have been detected.

VI. Summary of Canister Studies in the Uk - The main UK work in this area has been for the purpose of evaluating and selecting candidate canister materials for the vitrification and subsequent engineered pond storage of HLW. Experimental work has been done and more is programmed for determining creep laws, cyclic high-temperature oxidation, and corrosion in pond water of materials after appropriate heating/cooling schedules. Computer codes have used these data for stress and creep analyses. The materials have been both parent metal and welded specimens. Some of the input for the mathematical modeling of canister behaviour is coming from the work on waste characterization, e.g., vitrified waste "viscosity" and Young's moduli measurements from 1100°C down to ambient. A full-scale canister of 18-in. diameter, fabricated from the prime candidate material Incoloy-800 and to the high-quality specifications considered necessary for HLW containment, is due for delivery within three months. It will be used in inactive vitrification trials to compare actual canister behaviour with that predicted from mathematical modeling. Funds are allocated for the procurement of similar additional prototype containers in support of the FINGAL/HARVEST project. Computer codes are being employed for predicting thermal and mechanical conditions under equilibrium and transient conditions. These codes include UNCLE (a general multidimensional master program), FISPIN (a program for predicting the yield of fission products plus heavy elements together with their associated decay heat), and HEATRAN for heat transfer. This program allows material properties to vary with temperature and position for many types of boundary conditions (including boundaries within the matrix) such as thermal radiation and reradiation.

The archaeological evidence for longevity of metals in sea water has been reviewed (BNFL Report 314(R)) and any new evidence will be reviewed as it becomes available. Design studies for packages based on these evidences will be carried out.

The BNFL budget for 1977/78 includes a sum of £50,000 for work on prototype HLW disposal packages. The objectives of this work have yet to be determined in detail; e.g., should a prototype package be dumped into the ocean to establish whether the rapid rate of pressure change jeopardizes its integrity?

Discussions have been held with the UK National Engineering Laboratory (NEL) to determine where their offshore technology expertise can be employed to the best advantage. NEL has been invited to submit proposals for reviewing methods of canister burial, their status, limitations, and costs. They are directed to give most consideration to self-burying techniques which they have developed in the past, i.e., those involving fluidization and percussion which will complement the U.S. work on free-fall penetrometers and rotary drilling.

NEL has also been invited to submit proposals for the design of a structure to contain HLW canisters deposited on the seabed.* The purposes of such a structure are:

1. To prevent heat-emitting wastes from sinking into the sediments too quickly and becoming overheated.
2. To provide easy relocation of the waste for periodic environmental monitoring, inspection, and recovery, if necessary, during the demonstration phase of on-the-seabed disposal.
3. To reduce considerably the probability of disposed waste being inadvertently recovered.

*Two concepts (on or in the seabed) are being pursued at this time in different countries. The US and France are considering the concept of in the seabed only. Research in the other area is of value, however, when the consequences of an accident at sea are addressed.

The UK program on vitrified HLW characterization includes a facility for storing the canister and its associated waste under a variety of conditions with or without artificial flaws in the canister, and then a comprehensive examination including leach-testing using a variety of leachants. Particular attention will be paid to the canister/waste interface to establish compatibility, etc. Preliminary work has already been carried out in support of this program with accurate inactive HLW simulants. Part of this facility will be available in 1978 and the remainder in 1980.*

Part of the HARVEST project for HLW vitrification includes the development of canister-sealing methods and sealed canister decontamination and inspection procedures. These are all necessary precursors to the eventual disposal of HLW containing canisters if system analyses confirm that the relatively short-lived radionuclides are the most significant in terms of radiological hazard and that the container/package system can mitigate the consequences of disposal and accident situations to acceptable levels.

The other area of work which could be relevant to the container is the glazing of plutonium contaminated incinerator ash. R&D has been in hand in the field for some time.

FUTURE COOPERATIVE RESEARCH

The study of corrosion was identified as an area for cooperation during the coming year. Pertinent information already exists which should be exchanged. Development of new testing techniques was identified as another area where cooperation will be beneficial. The group also agreed to exchange information on materials being evaluated and on testing

*Capital cost of equipping this facility, which is housed in two existing caves, is £ 3.1 million.

environments used in the various programs. Attempts will also be made to evaluate materials selected by other countries in each country's facilities when requested.

In the area of new engineering barrier concepts it was agreed to exchange new ideas for discussion and to use members of the task group as a pipeline to disseminate the information.

WASTE FORM TASK GROUP REPORT

PARTICIPANTS

K. Johnstone, United States (Chairman)
J. Krumhansl, United States (Co-Chairman)
K. D. B. Johnson, United Kingdom
P.E. Pottier, France

INTRODUCTION

The Waste Form Task Group had the objective of defining an integrated program plan pertaining to the disposal of nuclear waste on and in the seabed. The program plan includes:

1. An outline detailing the scope of relevent research activities and materials,
2. A compilation of existing programs bearing on the disposal of high-level waste on the sea floor,
3. Identification of areas where cooperation between the various task groups would be necessary, and
4. Assignment of priorities to research activities.

RESEARCH AND DEVELOPMENT PLAN

The group attempted to develop an outline covering the entire scope of the problem. A draft outline had been circulated among group members before the meeting and it served as the focus of effort while the group was assembled. The outline was initially evaluated with respect to completeness, relevance, and clarity. Next, individual topics were assigned priorities according to their importance, which was determined by unanimous agreement (after discussion) among members. In the outline below, the ranking number is shown in parentheses (1, 2, or 3), with 1 the highest priority. Each country was associated with the topics it is currently studying or planning to study.

A number of the topics were noted which overlap those of other working groups. In these cases information from other groups to properly plan our experiments is needed or a joint effort between groups is necessary to adequately attack the problem. These areas of common interest should be topics of discussion between the various working groups in the future.

The waste form program outline is as follows:

I. Environment - Identification of the environment in which the waste form will be placed on or in the seabed.

A. Physical environment.

1. Temperature

a. In the waste itself (1) UK, Fr, US
b. In adjacent sediments (3)

2. Pressure (3)

3. Radiation Fields (α, β, γ, η)

a. In the waste (2)
b. Outside the waste (2)
c. Overall (2)

B. Chemical environment

1. Chemistry of interstitial water in sediments

a. Radiolysis products (1) UK, US (Fr)
b. pH and redox environments (1) US, (UK, Fr)
c. Major element concentrations (1) US
d. Trace element concentrations (3)
e. Organic compounds if any (2)

2. Sediment - silicates/organics/sulfides

a. Radiation damage (2)
b. Phase changes (2)
c. Redox reactions (2)
d. Precipitation of new phases (2)

3. Sacrificial material (cask and/or waste form protection) (2)

C. Biological environment

1. Chemicals produced by biologic activity which will attack the waste (2)

2. Modeling of biologic activity (3)

3. Synergistic effects of heat, radiation, biologic activity (2)

II. <u>Definition of Waste Form</u>

A. Glasses, ceramics, cemented materials, others (bitumen, concrete, plastics, calcines, metal matrix, coated particles)

1. Composition

a. Radionuclides (1) UK, US
b. Others (cladding, inerts, reprocessing poisons) (1) UK, US, (Fr)
c. Homogeneity (1) Fr, US, UK

B. Fabrication method (2)

C. Canister composition (3)

D. Canister design

1. Waste form temperature modification designs (2)

2. Waste form internal strain (2)

III. <u>Stability of Waste Form</u>

A. Thermal stability

1. Devitrification (glasses)

a. Compound identification (1) Fr, UK, US
b. Waste form (1) UK, US, (Fr)

2. Isotope migration within the waste form (coalescence) (2)

3. Radionuclide volatilization - transportation accident (3)

B. Irradiation stability

1. Synergism with temperature to accelerate devitrification (1) Fr, UK, US

2. Radiation damage (defects) (1) Fr, UK, US

3. Transmutation (decay) effects (crystalline materials) (1) US

4. Gas generation, migration (2)

5. Stored energy (2)

6. Annealing rates (2)

C. Chemical durability (leaching, dissolution, conversion)

1. Waste form durability in high pressure hydrothermal environment (all subtopics, see I.A).

   a. Temperature effects; Fr, UK, US (1)
   b. Pressure effects; US, J (1)
   c. Time; Fr, UK, US (2)
   d. Waste form composition; Fr, UK, US (2)
   e. Stored energy due to fabrication; US (3)
   f. Particle size; UK (3)
   g. Water/waste ratio; US (2)
   h. Water pH, particularly as a function of time and temperature; Fr, UK, US (1)
   i. Water composition; how it is affected by canister corrosion products and sediment types; Fr, UK, US (1)
   j. Radiation effects on sea water; oxidation potential; US, UK (1)

2. Identification of leaching mechanisms

   a. Model development (1) UK, US
   b. Development of leaching inhibitors (1)

3. Waste form/geologic interactions (2)

4. Simulated versus full scale test evaluation (2) UK, Fr, US

IV. <u>Failure Modes</u> - Identification of failure modes arising from changes in waste form.

A. Thermal effects

1. Stresses in the glass (1) UK, Fr, US

2. Devitrification products (1) UK, Fr, US

3. Pre-emplacement history of canister (2)

B. Pressure

1. Stresses placed on canister and waste by deployment in the deep sea (3)

C. Radiation Field

1. Helium generation (3)

2. Stored energy (2)

3. Decay effects (2)

D. Interaction with the environment immediately adjacent to the canister

1. Waste leaching

a. Definition of acceptable leach rates and optimization of waste composition to the criteria for seabed disposal (1) US, Fr, UK

b. Determination on the basis of half-life which elements are of concern (3)

c. Relationship between texture of altered waste and possible failure modes (2)

2. Local redistribution of elements

a. Failure through unacceptable local thermal loadings (2)

b. As a boundary condition for long distance transport of radionuclides (2)

CURRENT RESEARCH

United States

The objective of the US solidification program is to provide waste forms with maximal radionuclide retention. Although the US is considering a variety of low-melting-point glasses, cement-like materials, and ceramic matrix forms for isolation of wastes from specialized chemical processes, it seems probable that any high-level commercial waste would be isolated in a borosilicate glass similar to that being developed at Battelle-Northwest Laboratories. In addition to work being done in conjunction with waste-form development, the US has several programs related specifically to the concerns of the Seabed Program. Battelle-Northwest and Sandia Laboratories have programs underway to determine the leachability of borosilicate glass waste at elevated temperatures and pressures, and Sandia is also concerned with effects of heat and radiation on the composition of fluids in contact with the waste. A more detailed report of specific research areas of concern to the US may be found in the Working Outline.

United Kingdom

The broad goal of the UK program is to understand the combined effects of alpha, beta, and gamma radiation, heat, pH, and chemical composition of leach solutions so that data can be fed into a complete model of activity migration back to man. At present the concentration is upon borosilicate glass of the type being developed for HARVEST. Ideally, several other media, particularly cements, also will be investigated. Nothing is planned for bitumen, and little for plastic materials.

Recent conclusions are:

1. The combined effects of alpha, beta, and gamma radiation and heat do not greatly affect leach rates.
2. Temperature and pH do affect leach rates.
3. Dimensional changes are small enough not to put severe stresses on canisters.

4. Gas release is significant but pressures likely to be generated are modest and will not endanger containment.

5. Stored energy due to radiation is unlikely to be a hazard or to affect greatly the behavior of the glass.

6. Lithium addition can improve thermal conductivity with not too great a sacrifice in other properties.

7. There is insufficient understanding of leaching mechanisms to permit good extrapolation from short leach tests to very long-term dissolution of glasses. Long-term rates are probably over-estimated.

8. Physical properties have been measured (viscosity, external expansion, thermal conductivity, specific heat, elastic moduli).

9. Good large-scale manufacture gives uniform glasses with properties similar to those of small-scale samples, but this needs to be carefully controlled.

10. Examination of FINGAL glass block stored for 15 years suggests that very little has happened to the material (though specific activity was insufficient to reach the axial temperature expected for HARVEST systems).

In the future we should:

1. Attempt to show that glass will remain massive and not change to a high-surface area form.

2. Make maximum use of European Economic Community cooperative programs.

3. Pay more attention to leaching by sea water saturated with sediment species (does sediment absorb and draw out activity from glass?)

France

I. Goals - At present in France, waste is stored in surface repositories (in or out of trenches).

A. Future waste storage

1. Continental geological formations (granite, clay, salt mines) - Site selection work is under way.

2. Seabed - Only deep burial is considered. France intends to use this method mainly for high-alpha-activity wastes. The burial of glasses is also a goal.

B. Waste form

1. For nonliquid HLW (probably without separation of actinides) - The only materials are glasses.

2. For other HLW (hulls for example) - The choice between concrete or a metal matrix has not been made.

3. For low-level wastes - The solidifying material is bitumen, plastics, or concrete.

II. Experiments Related to Seabed Program - Many experiments may be used that are not strictly oriented toward sea disposal.

A. For glasses - Experiments are conducted at Marcoule in conjunction with other European laboratories (Harwell, Hans Meitner Inst. (Berlin)). Status is as follows.

1. Leaching - France is in charge of block leaching about 1 liter each) with measurement of the total leaching rate and the specific leaching rate of ^{137}Cs, ^{90}Sr, ^{144}Ce, and ^{106}Ru. For alpha transuranics, using tap water, the parameters considered important by Harwell and HMI are:

Temperature effects
Annealing
Structural stability
Alpha-ray effects

B. For other solid media

1. Bitumen - Studies conducted at Cadarache include all effects at normal temperature and pressure; at Marcoule, leach-is done with tap water and sea water on 200-liter blocks.

2. Concrete - For the near future (1978 and following years) experiments will be undertaken to define the limits of alpha contents acceptable for bitumen and plastics (internal effects with transuranics). Some experiments on blocks (with concrete shielding) are conducted in Saclay, but only tap water is used. No sea water tests are programmed.

3. Plastics - Experiments using Pu and Am will be conducted mainly in Cadarache in the future. At the present time results are available from Grenoble for resistance to leaching in pure and tap water, and sea water.

NOTE: Disposal of concentrated alpha wastes (e.g., $^{241}AmO_2$) is not foreseen. These will be stored in special containers for potential uses.

FUTURE COOPERATIVE RESEARCH

A number of factors were considered in the assignment of priorities to the different research activities. Since the manufacturer of the waste will be able to supply relevant data concerning waste composition, such matters were not assigned the highest priority. In other instances it was determined that although existing data were far from complete, they were adequate to place limits on possible waste responses; hence, research in these areas was also assigned a lower priority. It was concluded that the chemical durability of waste at elevated temperatures in solutions of low pH was the matter most in need of immediate investigation.

During discussions in the Waste Form Task Group a number of areas were identified where international cooperation would foreshorten the process of assessing whether a particular waste form was compatible with disposal on or in the seabed. Standard ISO waste characterization tests should be used where applicable, and similar procedures may be developed for use under hydrothermal conditions. It was also agreed that samples of various waste materials should be exchanged and that common use of some experimental facilities should be considered. Interest was also expressed in cooperating on large-scale in situ tests. Finally, it was agreed to exchange relevant publications as they become available.

During the plenary summary session it was stressed that although all wastes are important and should be considered at some time, for the initial phase of the program, efforts should be concentrated on high-level wastes. In France work is beginning on the development of alpha waste forms.

SEDIMENT TASK GROUP REPORT

PARTICIPANTS

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C. E. Hickox - United States
G. de Marsily - France

INTRODUCTION

The sediment forms the primary barrier for long-lived radionuclides. Wastes must therefore be buried satisfactorily in sediments which will remain stable over a very long period of time. The adsorptive and hydraulic characteristics of these must remain unchanged even under the combined effects of heat and radiation from the wastes. Again, there must be no short-circuit paths for the transport of radionuclides to the sea above; resulting, for example, from disruption of sediment by the emplacement technique used, the heat evolved, or biological activities in the sediment.

RESEARCH AND DEVELOPMENT PLAN

Sediment studies must include the following:

1. Studies of the chemistry of long-lived radionuclides in the sea-water/sediment system, and measurements of the distribution of radionuclides between sediments and sea water.

2. The chemical stability of sediments under the heat evolved from the waste form in the first few years after emplacement.

3. The mechanisms of heat transfer in sediments, so that canister temperature can be predicted.

4. The physical and 'engineering' properties of typical sediments so that emplacement techniques can be developed and the long-term fate of the canister predicted, as well as the possible bulk movement of sediments as a result of thermal convective flow.

5. The development of suitable mathematical models for Items 1 to 4.

CURRENT RESEARCH

United States

Most of the proposed program listed in Item 4 above is underway in the United States, mainly at Sandia Laboratories and the University of Rhode Island.

Extensive small-scale laboratory tests are in progress, larger scale pilot plant experiments are being developed, and in situ trials are planned. Mathematical models are being developed for the temperature field around buried canisters, and for the prediction of fluid flow and nuclide migration in sediments.

Much of the work on heat transport, nuclide adsorption, etc. in rocks, which is part of the geological disposal program, is relevant to sea disposal also.

France

Although there is at present no seabed sediment program, work being carried out under the geologic disposal program is relevant, in particular, to mathematical models being developed for heat transfer and nuclide migration predictions.

United Kingdom

No experimental work is in progress on deep ocean sediments, but measurements on the uptake of radionuclides by shallow sea sediments will be applied to studies on deep sediments. A mathematical model of heat transport properties of deep ocean sediments has been developed and is being refined. This work is being carried out by a team also involved in similar studies on geologic disposal and much of the experimental work of the latter is relevant to sea disposal.

Canada

No seabed studies are in progress in Canada but proposals have been made to set up a study of the effects caused by the degradation of biological material in sediments. The degradation products might change the chemical nature of radionuclides and thus alter their sorption characteristics.

FUTURE COOPERATIVE RESEARCH

Collaboration between various countries is possible now in some areas. There should also be internal collaboration within each country between those involved in geologic disposal and smaller teams concerned with seabed disposal.

The following specific areas of international collaboration can be identified (there are undoubtedly others):

1. Exchange of sorption and other chemical and physical data, including information on the chemistry of radionuclides in the sediment/sea water environment.

2. Exchange of sediment samples.

3. Comparison of different mathematical transport models.

4. Determination of the design and objectives of large-scale laboratory experiments, e.g., heat flux modeling, since these are expensive to set up and operate. (It would be better to have complementary rather than duplicate experiments).

Collaboration should be possible on carrying out large-scale laboratory as well as in situ experiments, e.g., heat transfer measurements and the use of monitoring tests planned to be used at the NEA low-level seabed disposal site in the North Atlantic.

Although low-level sea disposal of waste is sanctioned and carried out regularly, there is a continuous need for updating present hazard assessments. It may be possible to use observations planned at the NEA site to obtain data on the in situ uptake of radionuclides in sediments, which might be of interest in connection with high-level disposal studies. For example, it might be possible to identify drums of known radioactive content on the seabed and to sample and analyze the surrounding sediments.

It was agreed to nominate 'post boxes' in each country to serve as centers for data exchange. They are:

D. R. Anderson	Division 5336 Sandia Laboratories Albuquerque, NM 87185, USA
G. R. Heath Sediments and Rock	Graduate School of Oceanography University of Rhode Island Narragansett Bay Campus Narragansett, Rhode Island 02882, USA
J. B. Lewis Sediments and Rock	Building 175 Chemistry Technology Division, AERE Harwell, Didcot Oxon, United Kingdom
G. de Marsily System Analysis	Centre d'Information Geologique Ecole des Mines de Paris 35 Rue St. Honore 77305 Fontainebleau, France

H. Hotta | Japan Marine Science and Technology Center (JAMSTEC)
Natsushima-Cho
Yokosuka 237 Japan

G. Vilks | Bedford Institute of Oceanography
Darmouth, Nova Scotia, Canada

PHYSICAL OCEANOGRAPHY TASK GROUP REPORT

PARTICIPANTS

H. W. Hill, United Kingdom (Chairman)
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F. Madelain, France

INTRODUCTION

The name of this group was changed from the Water Column Task Group to the Physical Oceanography Task Group (POTAGE). We recommend that an over-all R&D plan of the following type be formulated to focus the research necessary to allow sensible decisions to be made on the feasibility of ocean disposal of HLW. Approximately 15 years lead time will be required for the physical oceanography research necessary to evaluate suitable dumping sites. This work can be divided into two phases: a 2- to 5-year exploratory period, followed by a subsequent period of site specific experimental work.

RESEARCH AND DEVELOPMENT PLAN

Some general activities are needed to supplement all programs. They are:

1. Complete a literature search
2. Begin a review of existing data and expertise to determine relevancy to the deep-sea disposal program, e.g., of modeling, geochemical tracers, current meters, and float track inventories.
3. Explore the possibility of work related to the seabed program being added to on-going or planned oceanographic programs.
4. Identify interactions between physical, geological, geochemical, and biological oceanographic studies.

5. Organize a workshop of invited specialist oceanographers to assess the implications of state-of-the-art physical ocean-ography and to plan, in detail, an internationally coordinated work program, probably to be held in the US in late 1978 or early 1979).

The physical oceanography research and development plan outline is as follows:

I. Nature of the Problem -- It is necessary to establish the probability of occurrence of various concentrations in space and time from a specified source function at a designated source site. The nature of the space-time scales used in averaging dispersion requires consideration, as do transient mechanisms. Gross (coarse) equilibrium statistics are not sufficient, and the final equilibrium may not be a uniformly mixed state.

II. Relevant Physical Processes --

A. Benthic boundary layer (BBL) mechanisms

B. Horizontal transport mechanisms (scales; diffusion, advection)

C. Vertical transport mechanisms (general and site-specific)

D. Breachment mechanisms; upward pathways after horizontal displacement from source.

1. Effects associated with topography, islands, shelves, coasts.

2. Overturning, deep water formation, and sloped isopycnal transports.

3. Mechanisms that could occur after movement part way up the water column.

III. Interface of Physical Oceanographic Processes With Other Processes --

A. Biological, geochemical, sediments, etc.

B. Capture by III-A process, secondary source or recycling process.

C. Join on-going or planned research projects in other areas with physical oceanography add-ons.

IV. Assessment and Use of Existing Data and Knowledge --

A. Tracers, models, historical data, implications of state-of-the-art knowledge for this special purpose.

B. Explore existing and planned programs for add-on activity.

C. Workshop of experts to accomplish IV and develop US plans.

V. Modeling --

A. Let present models serve as pilot studies for special questions.

B. Dispersal of radionuclides from numerical experiments in existing models (process, gyre and world ocean model-dependent results).

C. Analytical and numerical modeling of special processes (source dependence, averaging, topography, boundaries).

D. Benthic boundary layer (BBL) modeling (coupled to models of type V-B).

E. Site-specific local process model (see VI below).

VI. Field Program - Potential Elements --

A. Site exploration; statistical & descriptive geography (current meters with deep conductivity, temperature, density (CTD) for BBL characterization (1-2 yr)).

B. Specific site testing (intense effort (1 yr); variety of measurements).

C. Site monitoring and related activity

1. Measurement program designed, or results of VI-B, 0-10 yr.

2. Horizontal extension of descriptions.

D. Tracer studies; existing plus releases.

E. Process experiments and explorations.

1. BBL

2. Horizontal dispersion; SOFAR float cloud with autonomous listening station.

3. Vertical

4. Exploratory observations to identify breachment mechanisms and pathways; general plus site-specific.

F. Model verification as results of A-E become available.

G. Special measurements associated with III.

NOTES: (1) Immediate work could include VI-A, VI-E-1, and possibly E-2.

(2) Because site evaluation will take 12 to 15 yrs, should work back from desired disposal time to get a start time for scientic research.

VII. Longer Time Considerations --

A. Shifts of current systems, deep water formation processes and locations, etc.

B. Identify climate related ocean-air research.

CURRENT RESEARCH

Current research was catagorized by task and by sponsoring nation. This was summarized as follows:

I. By Task --

A. Model studies

1. General circulation models

2. Process studies, e.g, models of boundary layer horizontal dispersion, etc

B. Additions to NEADS locations

C. Float tracking around current meter arrays at NEADS locations. For an example of the type of experiment planned, see EUROMODE 1979: a planned Anglo-French float-tracking eddy study.

D. BBL studies (CTD, sediment studies, and bottom currents).

E. Feasibility of radioactive ion releases (tritium) in relation to other track studies.

F. Exploration of physical pathways and breaching mechanisms.

G. Long-term (12 months) float tracking using acoustic listening stations. Two or more exercises over period 1984-85.

II. By Nation --

A. France - Literature search

B. United States of America - Development of a water-column research program

C. United Kingdom - Some general circulation model development and associated current-meter deployment.

Considerable relevant oceanographic research not specifically related to SWG, but which could be useful to the seabed programs is being carried out in all five countries concerned in SWG. For additional details see UK progress report (Appendix IV).

FUTURE COOPERATIVE RESEARCH

Areas where future cooperation research would be desirable include the following:

1. Model development

2. Additional NEADS locations

3. EUROMODE; a planned Anglo-French float-tracking eddy study at NEADS sites (7 - Fr and either 5 or 6 - UK) in August and September 1979.

4. GEOSECS study to coordinate tracer work relevant to the Seabed Program (Shephard, UK, to go to Lamont-Doherty to work with Broecker, beginning August 1978.)

5. Workshop (to be planned)

6. National task groups should be established to coordinate, via POTAGE, national oceanographic programs related to SWG.

BIOLOGY TASK GROUP REPORT

PARTICIPANTS

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M. J. Holden, United Kingdom (by correspondence)

INTRODUCTION

Recognizing that communication is an important aspect of international cooperation, the Biology Task Group spent some time on methods of fostering and sustaining communication. Three actions were recommended: (1) the dissemination of a task group newsletter; (2) an annual review of biological problems with radioactive wastes in the oceans and of progress toward their solution; (3) an annual presentation of formal papers at each International Meeting of the Biology Task Group. In addition, the group discussed current research in each nation and identified some areas for future cooperative research.

The Biology Task Group suggests that a newsletter be prepared and mailed twice each year (June 1 and December 1). Each group member will prepare his part of the newsletter and send it to all other Biology Task Group members; to Ferruccio Gera; and to the SWG (Hotta, Barbreau, Vilks, Johnson, Boyer, and Anderson). The following suggested format for the newsletter is not to be construed as immutable:

Newsletter Format

1. General direction of studies (name of nation) on seabed disposal and related topics.
2. Scientific publications of interest (references, reprints, or preprints).
3. Newspaper and popular magazine articles.

4. Scientific meetings of interest to radioactive waste management and radioecology (announcements or summaries).

5. Availability of samples or sampling opportunities.

6. Miscellaneous remarks.

Biological problems related to the seabed disposal of radioactive wastes were delineated in the Report for the Radioactive Waste Management Committee on the First International Workshop on Seabed Disposal of High-Level Wastes, Woods Hole, Massachusetts, February 16-20, 1976, which has the Sandia Laboratories report number SAND76-0224. The Seabed Task Group recommended that an annual review be made of the research proposed in that report. The review should identify the biological problems that have been solved, that are approaching solution, that are being neglected, and that have been only recently identified. Belot and Yayanos attempted this review, but such an evaluation can be done only by the entire Biology Task Group.

Each year at the International Meeting of the SWG each member of the Biology Task Group should present a formal paper summarizing his nation's activities and showing how these activities address seabed disposal strategies. The Task Group Chairman would then summarize the activities in writing for the minutes of the meeting.

RESEARCH AND DEVELOPMENT PLAN

None identified.

CURRENT RESEARCH

France

Current work emphasizes the intertidal zone and includes:

1. Determining the role of deposit feeders in the movement of radionuclides out of sediments.

2. Studying the physical chemistry of radionuclides in sediments.

United Kingdom

Current work, summarized from letter of M. J. Holden, Lowestoft, and from IOS Report by A. Rice includes the following:

1. Have identified cephalopods to be important in deep water food chains and to be a potential food resource for man, and are encouraging the study of their population biology with opening-closing nets.

2. Studying samples collected to 4,000-m depth with discrete depth-sampling nets in the search for vertical biological transport of radionuclides.

3. Investigating relationships between the benthos and the water column with the use of nonquantitative samples and photography.

4. Studying mobile bottom fauna with traps and time-lapse cameras.

United States

Work in the US includes the following:

1. Determining and analyzing the structure of abyssal benthic communities with box corer samples and photography.

2. Studying the population biology of amphipods with trapping and tagging-recapture techniques.

3. Describing the structure of the water column ecosystem.

4. Investigating the factors regulating the state-of-the-water-column ecosystem.

5. Estimating the fisheries potential at possible disposal sites.

6. Determining the food energy transfer rates through the deep-sea food web.

7. Determining the food energy transfer rates through deep-sea benthic and pelagic animals.

8. Determining the value for the rates of deep-sea microbial processes.

9. Determining the rates of metabolic processes in deep sea animals kept in the laboratory under deep sea conditions.

10. Beginning radiosensitivity studies of deep-sea microbes.

FUTURE COOPERATIVE RESEARCH

France - United States

It was proposed that France and the US cooperate in determining (1) the role of deposit feeders in the movement of radionuclides out of sediments and (2) the physical chemistry of radionuclides in sediments.

United Kingdom - United States

Water column ecologists from each nation should be identified and mechanisms of potential cooperation sought.

SITE SELECTION TASK GROUP REPORT

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D. A. Deese, United States

INTRODUCTION

The Site Selection Task Group had the objective of defining an integrated international program plan for selecting sites within the North Pacific or Atlantic oceans for future study. The four main steps in the program are to:

1. Obtain provisional suitability criteria for subseabed disposal sites from other task groups.

2. Determine the location of suitable generic study areas in the deep seabed.

3. Ensure that generic study areas are in geologically stable regions.

4. Select study areas and test them by means of detailed scientific and engineering investigations; e.g., tests for vertical and horizontal coherence.

These tasks may involve a literature search for all available data on study areas, the identification of additional data needs, and recomendations for field programs required to obtain new data.

The above tasks may have to be performed a number of times in the process of finding the best possible study areas and potential disposal sites.

RESEARCH AND DEVELOPMENT PLAN

Research and development plan outlines were developed for each participating nation. They are as follows:

Canada

I. 1977: Vilks initiated discussions with SWG participants at WHOI in December. Funds were identified for Bedford Institute for 1978-1979, and arra. ·ements are being reviewed.

II. 1978: Supply all information on hand (e.g., survey data for North Atlantic); establish plans for field work in 1979.

III. 1979: Begin cooperative work in the North Atlantic; identify specific problems whose solution will be within our capabilities by 1980.

IV. 1980: Concentrate on acquiring the following:

A. bathymetry sediment thickness, continuity of acoustic reflectors within unconsolidated sediments

B. acoustic properties of sediments (i.e., core analysis versus acousticsignals):

C. sediment core analysis (e.g., biostratigraphy, lithostratigraphy);

D. geochemical and BBL information.

These plans reflect our capabilities at the moment. They do not yet take into account other capabilities available at Bedford Institute of Oceanography.

United States

I. 1977 and Beyond

A. Establish site suitability criteria

1. Sediment thickness >100 m
2. Fine-grained oxidized sediment
3. Stable tectonic setting
4. Away from western boundaries of basins
5. Away from continental margins--potential resource interference

B. Assign responsibilities for assessing N. Pacific and N. Atlantic for possible study sites

1. N. Pacific - Hayes (LDGO), Hollister (WHOI)
2. W. N. Atlantic - Tucholke (LDGO), Laine (URI), Hollister (WHOI)
3. E. N. Atlantic - Lancelot (Fr.), Hollister (WHOI), Laughton (UK). Other SWG members to be assigned.

II. 1978

A. Identify new study sites

1. N. Pacific - West of Emperor Seamounts?
2. W. Atlantic - Bermuda Rise?
3. E. Atlantic - East of Great Meteor Seamount?

B. Examine all historical data from new study sites

III. 1978-79 Prepare proposals for confirmatory field programs

IV. 1979-80 Mount oceanographic expeditions

VI. 1982 Assess feasibility on basis of site suitability criteria

France

I. 1978 France will undertake a preliminary study based on existing data. Essentially, this represents an inventory of available data and an assessment of the state-of-the-art in four domains:

A. Physical Oceanography - Develop an understanding of deep circulation in the Northeastern Atlantic. Begin needed instrumentation development.

B. Geology - Identify the extent of and characterize sediment types in the North Atlantic; measure the ion exchange capacity of sediments; characterize the interstitial environment for each sediment type.

C. Chemistry - Characterize chemical parameters acting at the BBL.

D. Biology - Characterize some typical benthic assemblages, including quantities and roles.

II. 1979-1980 - Based on previously acquired data and provided French authorities decide to proceed along the proposed lines, CNEXO will undertake specific research work on the topics described above. Detailed research programs will be coordinated internationally to avoid duplication of effort. Fifteen days of ship time are anticipated for 1979; 30 to 60 days for 1980. Ship time will be provided in order of:

A. test methodology,

B. acquiring nonexisting specific data.

CURRENT RESEARCH

United States

I. 1978: Collection of historical data on sediment thickness and sub-bottom (basement rock) roughness will be completed for both the Eastern and Western North Atlantic. Prospective sites for further study will be identified. One French and two US cruises are slated to map and collect sediment samples in a possible future study site in the Northwestern Atlantic. The collection of similar historical data for the North Pacific will be initiated, with completion expected in 1979.

II. 1979: Historical data collection for the North Pacific will be completed and sites identified for further study. If possible, mapping cruises will be scheduled for the more promising of the identified sites. Detailed site-ranking criteria will be developed to supplement the already developed exclusion criteria. A combination of the two sets of criteria will then be used to identify and rank the areas in the North Atlantic and North Pacific which show promise as possible repositories.

III. 1980 and Beyond: Refinemente ranking criteria and acquisition of data on the chosen study sites will allow choice of the best sites. Deep Tow sub-bottom profiling of the more promising sites will be completed along with acquisition of the cores for actual material studies. From these will come estimates on lateral and vertical coherence of the sediment column, as well as estimates of the extent of the natural barriers (sediment, the benthic boundary layer, and the water column).

France

I. CNEXO (Centre National pour l' Exploration des Oceans) -- In 1978, the main effort will be focused in two areas: (1) Develop an understanding of physical, chemical, and mineralogical characteristics of sedimentary layers, particularly of upper layers where living organisms play an important role; (2) Develop an understanding of deep oceanic currents and their role in erosion and diffusion phenomena. This effort can be further broken down into:

A. Geology - Drilling data of the International Program for Ocean Drilling (IPOD) will be analyzed, particularly those concerning deep oceanic sedimentary deposits, to define types of formations in which waste storage could be contemplated. For identifying these formations, the following criteria will be used:

Stability and erosion sensitivity.

Reactivity and ion-exchange capacity.

Porosity and permeability.

B. Chemistry - Available data will be synthesized to determine parameters playing a role in exchanges between interstitial water, water immediately above the bottom, and the mineral matrix. The thermodynamic and kinetic aspects will be studied.

C. Biology - The study will relate to the biocenoses of the most representative benthic organisms. Particular attention will be paid to biochemical aspects, to the temperature of metabolism and nature of the enzyme,and to processes which control transport from mineral matter to living matter. In the first stage the analysis will focus mainly on microbitic phenomena.

D. Physics of the Oceanic Environment - Available data on deep oceanic currents will be collected in an area in the North Atlantic between 50° and 20° N latitude, the Mid-Atlantic Ridge and the European continental shelf.

E. General Instrumentation - The lack of available instrumentation in the scientific fields considered above will be investigated. Investigation will be made of the problems of obtaining large-diameter cores, developing devices for obtaining geotechnical samples at great depth, developing of techniques for measuring in-situ parameters, and making laboratory measurements (chemistry and biology) under high pressure.

II. Laboratorie de Radio Ecologique de la Hague -- Studies have been made concerning shallow water and coastal sediments, which could easily be extended in the near future to include deep sediments as follows:

A. Adsorption of heavy metals by sediments.

B. Movement of heavy metals from sediments to interstitial water.

C. Transport of heavy metals from sediments to bottom feeders.

III. IFP Program -- Early in 1978, a bibliographic review of the most recent synthetic data and publications dealing with North Atlantic submarine geology was completed by the French Petroleum Institute of Geological Research on behalf of CEA. The area of study extends from the equatorial fracture zones to Ireland. The purpose of the review was to delineate areas of possible interest for seabed waste disposal. The reviewers were interested in collecting data from the following fields:

Physiography
Bathymetry
Sea-bottom geology
Seismicity
Volcanism
Heat flow
Sedimentary thickness at basement
Basement topography
Stratigraphy

General distribution and lateral coherence of sedimentary layer

Mechanical characteristics of sediments

Mineable substances

Bottom currents and turbidity currents

The purpose of this bibliographic review is to draw attention to some North Atlantic areas that look particularly stable from ocean-ographic, structural, and sedimentary points of view. These areas seem to fulfill the basic conditions for selection of a seabed waste disposal site. Such areas are present (at approximately 3000 m) on both sides of the mid-oceanic ridge between the axis of maximum depth (AMD) and the lower part of the ridge's flanks.

Many data, however, are still lacking (or exist only in poor quality) in these areas, and additional work should be performed in different fields, such as high resolution seismics, coring, and quantitative studies of sedimentary series (mineralogy, geochemistry, soil mechanics).

During 1978, 1500 km of seismic profiling will be performed with the IFP's seismic vessel RESOLUTION. The "mini-flexichoc" high-resolution technique designed by IFP's laboratory will be used for this seismic work.

Multiple coverage and appropriate processing will be used when necessary in order to collect precise data on acoustic properties (e,g., acoustic impedance) of sedimentary cover and basement, and vertical and lateral coherence of sedimentary sequences.

Generic study areas are still under consideration, pending the receipt of complementary data from SWG workshop participants.

FUTURE COOPERATIVE RESEARCH

It is planned to exchange track charts between AMD and 3-km isopleth on each side of the Mid-Atlantic Ridge (including the Bermuda Rise). These track charts will be at a scale of 1 in./deg of longitude and should extend from 0° to 50° N. Track notation is to be noted in 2-hour ticks, with 24-hour marks, with a date. The charts should differentiate between bathymetry, seismic profiles, multibeam, stacked array, 3.5 kHz, and navigation technique. Station information will be included.

All existing isopleth maps for the North Atlantic should be brought to a cruise-planning* workshop at Lamont-Doherty Geological Observatory on 27 March 1978. New generic study sites in the Atlantic will be identified at this meeting.

All cruise plans will be compiled and coordinated. Any ship-time to be dedicated to the SWG should be sent to Dr.Hollister (WHOI) as soon as possible for distribution to SWG member nations.

The internal acoustic structure in the upper 100 m will be measured at Atlantic study sites in 1978. The best equipment for the task is the French IFP "mini-flexichoc".

The internal acoustic structure in the first 50 m will be measured. The best equipment for this is the 3.5-kHz pinger with the Giant Corer. The most logical ships and times are the KNORR (US) or HUDSON (Canada) in MPG-Atlantic in 1982.

By combining the Giant Corer with Deep Tow from the KNORR and the HUDSON, an understanding of vertical and horizontal coherence of sediments can be acquired.

---

*Fifteen days of ship-time with France's RESOLUTION are available in May and June 1978.

Acoustic properties at the Western Atlantic study site will be acquired with the HUDSON, the KNORR, and possibly the CHARCOT (France) in 1980.

Regional microphysiography (e.g., faulting) in the Atlantic will be determined with GLORIA side-scan sonar and SEABEAM.

Thermal isopleth maps of the Atlantic will be developed to identify anomalies in which significant changes in permeability and thermal conductivity could be related.

All historical data will be collected and measurements of pertinent geotechnical properties will be started.

Joint Canada-US stratigraphy capability will be developed. In zeolitic clays, stratigraphy has to be done with fish teeth and palynology. At present only the US is doing this type of research.

APPENDIX I

WORKSHOP PARTICIPANTS

United States

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France

Name	Address	Phone No.
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Ferruccio Gera Executive Committee	OECD Nuclear Energy Agency 38 Blvd. Suchet 75016 Paris, FRANCE	524-96-58 (Telex) 630 668

Commission of European Communities

Murray Nicholas Biology Sediments & Rock	Commission of European Communities Joint Research Centre Ispra Establishment 21020-Ispra Varese, ITALY	332-78-0271 (Telex) 380 42/ 380 58 EURATOM

APPENDIX II

DOE LETTER REPORT TO NEA

COPY

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Department of Energy
Washington, DC 20545

February 27, 1978

Mr. J. P. Olivier
Nuclear Energy Agency
38, Boulevard Suchet
75016 Paris, France

Dear Mr. Olivier:

Enclosed is a report to the NEA Radioactive Waste Management Committee (RWMC) on the third international workshop on seabed disposal of high-level radioactive waste held on February 6-7, 1978, in Albuquerque, New Mexico.

The NEA-RWMC members from Canada, France, United Kingdom, and the United States were represented through the Seabed Working Group (SWG). Japan was not represented, but submitted a position paper on Seabed Disposal and expressed continued interest in participating with other countries in the Seabed Working Group.

Specific areas of cooperation were identified by the SWG Task Groups and coordination of joint projects was planned. Sandia Laboratories will issue a detailed report of the meeting.

Sincerely,

/s/D. Glenn Boyer
U.S. Member, Seabed Working Group

/s/Alex Perge
U.S. Representative to NEA-RWMC

Enclosure:
As stated

cc: J. Coady, Canada
Y. Sousselier, France
M. Ishizuka, Japan
K. Johnson, UK
All Participants

REPORT TO THE NEA RADIOACTIVE
WASTE MANAGEMENT COMMITTEE (NEA/RWMC)

The Seabed Working Group (SWG), a subgroup of the RWMC of the NEA, and its Task Groups met in Albuquerque, New Mexico, on February 6-7, 1978. The meeting was attended by representatives from Canada, France, UK, US and NEA. Also in attendance was an observer from the JRC EURATOM, Ispra. No Japanese representatives were present, but a letter was sent expressing their regret for not being able to attend, stressing Japan's continued interest in the SWG, and briefly summarizing the Japanese research activities over the past year in the field of sea disposal of radioactive wastes.

The objective of the meeting was to continue and strengthen international cooperation in the area of seabed disposal of high-level radioactive waste.

The composition of the various Task Groups under the SWG is shown in Figure 1. The members of the Task Groups will serve as national correspondents for future cooperation, coordination and exchange of information within each technical work area. The general objectives of the Task Group efforts in promoting cooperation are outlined in Figure 2. Additional activities in specific areas can be proposed by the Task Group members.

It was emphasized that the overall objective of the SWG is to harmonize ongoing programs aimed at assessing the environmental and technical feasibility of radioactive waste disposal into the seabed in order to achieve a more economical and complete coverage of the required scientific effort. The results of the cooperative activities will be made available to all participants and can be made available to other NEA member countries on request. The Task Group leaders will be responsible to assure that information is distributed to all other Task Group members with copies to the SWG members and the NEA Secretariat.

Any countries with programs in the area of seabed disposal would be welcomed and are encouraged to join the SWG, simply by informing the NEA secretariat, through their members of the RWMC.

The RWMC will be kept informed of the progress of work in the framework of the SWG through the issuance of letter reports following meetings of the SWG. Such reports will include references to the technical information developed.

The SWG will meet again in approximately one year's time to survey the progress accomplished and to plan further work. March 5-7, 1979, has been tentatively selected as the date of the next meeting. The location will be determined in due course.

The US member of the SWG will continue to act as informal chairman. It is understood the NEA requirements for meetings and groups may require an NEA secretariat be assigned.

A full report on the Third Annual Seabed Working Group will be prepared and issued by Sandia Laboratories. Annex I gives a summary of the areas of cooperation identified by each Task Group.

Canada	G. Vilks
Japan	H. Hotta
France	A. Barbreau
UK	K.D.B. Johnson
US	D. Glenn Boyer
NEA	F. Gera

Task Group	Canada	Japan	France	UK	US
Physical Ocean	Needler	Hotta*	Madelain	Hill	Robinson
Canister	-	Emura	Grall	Corbet	Magnani
Waste Form	-	-	Pottier	Marples	Johnstone
Biology	Mills	Hotta*	Belot	Holden	Yayanos
Sediments & Rock	Wangerski	Hotta*	Salle	Lewis	Heath
Site Criteria	Keen/Piper	Hotta	Barbreau	Laughton	Hollister
System Analysis	-	Hotta*	de Marsily	Webb	Talbert

*Acting Capacity

Figure 1. NEA-Radioactive Waste Management Committee Seabed Working Group

- Provide forms for discussion, assessment of progress, and planning of future efforts;
- Encourage and coordinate cooperative cruises and experiments among the member nations including sharing of ship time between experimenters from different nations;
- Share facilities and test equipment;
- Exchange information;
- Maintain cognizance of international policy issues.

Figure 2. Objectives of the Seabed Working Group and Its Task Groups

ANNEX I

Summary of Task Group Areas of Cooperation

<u>System Analysis Task Group</u>

- Provide an overview of a complete system analysis; identify requirement and input needs from other Task Groups.
- Prepare a complete Seabed Disposal System Analysis model.
- A group meeting is planned for the Spring of 1978 in Ispra, Italy.

<u>Physical Oceanography Task Group</u>
(formerly Water Column Task Group)

- Provide for increased exchange of information from ongoing physical oceanographic programs.
- Initiate new studies of mutual interest.
- Areas of cooperation include:

  a. Development of oceanographic models;

  b. NEADS - North Atlantic water sampling study;

  c. EUROMODE - a planned Anglo-French float-tracking eddy study; and

  d. GEOSECS - an existing study using tracers.

- Participate in task group workshops.

<u>Canister Task Group</u>

- Review and exchange existing data on materials corrosion.
- Develop new testing techniques for deep sea conditions.
- Exchange data on materials under test and evaluate testing environments.
- Exchange concepts for sorptive barriers on sacrificial materials.

<u>Waste Form Task Group</u>

- All investigators should use standard ISO waste characterization tests.

- Develop similar characteristic test for hydrothermal studies.
- Exchange samples of the various waste forms.
- Use unique high pressure - temperature facilities at Sandia Laboratories.
- Consider joint large-scale in situ tests.
- Develop and maintain reference materials and publications library.

Biology Task Group

- Expand the areas of joint Research and Development.

  (France - US)

- Develop an understanding of the role of deposit feeders in the movement of radionuclides out of the sediments
- Develop an understanding of the physics and chemistry of radionuclides in the sediments.

  (UK - US)

- Identify the ecological and biological laboratories in each nation and encourage data interchange.

Sediment and Rock Task Group

- Encourage collaboration and exchange of data between sea disposal task groups and investigators of geologic disposal on land.
- Exchange of sorption data already acquired.
- Exchange of sediment samples.
- Comparison of different materials transport models.
- Design and operate joint large-scale laboratory verification experiments.

Site Selection Task Group

- Exchange available track chart data.
- Acquire lateral acoustic data on several study sites.
- Develop the necessary techniques and acquire in situ acoustic properties.

- Continue to compile and look for hiatuses within the sediment and rock.
- Work with the French in the Atlantic on two study sites using the R/V RESOLUTION.

APPENDIX III

POSITION PAPER OF JAPAN

COPY COPY

Hiroshi Hotta
Japan Marine Science and Technology Center (JAMSTEC)*

Satoru Emura
Power Reactor and Nuclear Fuel Development Corporation (PNC)**

Makoto Takahashi
Science and Technology Agency (STA)***

January 26, 1978

Position Paper of Japanese Seabed Disposal Program

1. Because of limited budget and resources and of heavy commitment of experts to their planned works in 1977, little progress has been achieved [in the seabed program]. At present [the] seabed disposal program constitutes only a small part [of] R&D program in the field of waste management in Japan.

2. In view of the fact that [the] geological disposal program has been gaining momentum and seabed disposal is considered as an alternative in [the] 21st century and therefore Japanese experts believe that [the] seabed disposal program should be carried out [on] a reasonable scale. Experts are also reluctant to divide our resources into two parts, namely, geological disposal and seabed disposal. Present oceanographic research for the preparation of sea dumping of low-level radioactive wastes in the North Pacific is believed to provide useful information on [the] water column and ecology in the deep ocean.

3. Following the evaluation of the state of the art of waste management technology in Japan, we reached the conclusion that less active contribution to the cooperation in the framework of SWG could be made in the fields of waste form and canister. On the other hand Japan will be

able to contribute actively in the field of water column, ecology and sediments on the basis of our oceanographic research.

4. This oceanographic research in the western part of the North Pacific has been carried out since 1972, with a total budget of $1,500,000 (US), in order to accumulate oceanographic data to be used for the hazard evaluation of the sea dumping of low-level radioactive wastes, involving the following national organizations;

Meteorological Agency and Meteorological Research Institute: deep water current, [and] diffusion coefficients in the deep sea

Fishery Agency: ecology, fishing resources

Since this program is quite successful in spite of limited budget and resources, it is believed that this program should be expanded to cover subject areas for the seabed disposal program.

5. JAMSTEC has also been involved in the low-level sea dumping program in order to develop a system to evaluate mechanical impact on containers [dropped] on the bottom. Therefore, JAMSTEC may have a partial concern with the seabed disposal program in collaboration with PNC.

6. Since PNC has played an important role in establishment of waste management system with cooperation of JAERI, PNC has been funded by [the] Ministry of Finance [at] about $200,000 (US) for promoting [the] seabed disposal program in FY 1978 starting from next April. The budget must be, of course, approved by the Diet. It is planned that this budget will be [primarily] used for study on [a] system analysis with a view to identifying items on which we should preferentially put stress in the beginning stage.

7. Since [the] main emphases are placed on sea dumping of low-level radioactive wastes in Japan, we are reluctant to launch [a] comprehensive international cooperation program. It may be visible to the public and consequently stir up the public debate on use of [the] sea. This may delay

[the] Japanese sea dumping program of low-level radioactive wastes. Therefore, it is preferable for us to retain [the] cooperative program at the present scale for the time being, namely, [limited to] exchange of information and coordination of national programs of participating countries in SWG. In this respect it is useful for us to identify instrumentation for oceanographic research and methods to evaluate data obtained through national programs.

8. We know that US authorities are interested in setting up an official cooperative relation with Japan and other countries in the field of waste management [with the hope that], its implementation may lead to joint evaluation of [the] seabed disposal program.

- - - - -

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APPENDIX IV

PAPERS PRESENTED DURING MEETING

1. Temperature Field Around a Buried Canister
2. Morphology, Structure and Sediments of the North Atlantic.
3. Progress Report - Harwell, UK Relating to the Vitrification and Disposal of High-Level Waste.
4. High-Level Nuclear Waste Canister UK Progress Report.
5. Progress in Exploring the Oceanographic Option for Disposal of High-Level Radioactive Waste on the Seabed.
6. Preliminary Analysis of Deep-Water Movements in the Eastern North Atlantic.
7. MAFF Plans for Water Column Research.

TEMPERATURE FIELD AROUND A BURIED CANISTER

Introduction

The research on deep ocean disposal of highly radioactive waste at the UKAEA Harwell Laboratory, has been concentrated on defining the range of temperature which the waste and the disposal region might experience. This paper describes briefly the development of the mathematical model which will be used, initially, for study of the temperature field around a heat emitting waste canister, emplaced in a typical ocean bed sediment. The model was based on thermal conduction from a single cylinder of waste and was formulated and solved numerically. The following description covers the formulation, numerical implementation, and preliminary analysis of the sensitivity of predictions to various parameters. Also included is a brief discussion of the technical requirements which are already foreseen as being of major importance in evaluation of emplacement in deep ocean sediments as an option for final disposal of radioactive waste.

Formulation of the Mathematical Model

The following assumptions were made in establishing the model:

The waste form is a HARVEST block, containing 25% by weight of high level waste, in a canister of high corrosion resistance.

The heat source is cylindrical, of finite length and provides a heat flux into the ocean bed sediment which decays with time.

The heat source term is defined for a given reactor fuel burn-up and reprocessing specification and depends on the mass of waste in the canister.

The heat flux is distributed uniformly over the surface area of the canister.

The emplacement medium is sea-water saturated sediment and is treated as a purely conducting medium. Neglect of convective heat transfer will result in conservative temperature field predictions in the sense that temperature may be somewhat high, but earlier work at the Sandia Laboratories indicates that this effect is negligible for low-permeability sediments.(1)

The sediment is assumed to be homogeneous and isotropic in porosity and their properties.

The sediment properties are assumed to be independent of temperature.

In the absence of experimental data, the thermal conductivity and heat capacity of saturated sediment are calculated from the separate solid and fluid properties.

The ocean bed is assumed to remain an isothermal boundary at its initial temperature before waste emplacement.

The heat transport within the waste and canister is excluded from the model since the canister is represented as a cylindrical source of prescribed heat flux.

The narrow cores of sediment extending from the lower end of the cylinder to the lower boundary of the simulation region and from the upper end of the cylinder to the ocean bed have been excluded from the simulation region. This was done to avoid numerical singularity problems at the upper and lower edges of the canister.

The basic model equation is that for thermal conduction in a solid with an isothermal boundary condition at the ocean bed and zero heat flux across the lower, outer radial, and inner radial boundaries except across the canister wall where the heat flux is a prescribed function of time. An initial condition of uniform temperature was assumed.

The model equations can be solved numerically for various values of the parameters involving cylinder geometry, the burial time delay (time from reprocessing to burial) and depth of burial in order to obtain temperature profiles in space and temperatures at selected points as a function of time. The parameters describing sediment thermal properties and initial heat source intensity are contained in the scaling factors used to derive the dimensionless variables. The heat source function was derived for Magnox reactor fuel with a burn-up of 4000 MWd/tonne at a rating of 2.72 MW/tonne. Fuel reprocessing is assumed to occur one year after removal from the reactor with 1% loss of radionuclides and 99.9% removal of uranium and plutonium. Data for the sum of the alpha, beta and gamma heating as a function of time after reprocessing were interpolated, using spline functions, to give the heat source.

Numerical Implementation

A finite difference technique was selected to solve the set of equations. A conservative method of forming the finite difference approximations was used to minimize the truncation error which can be a problem at small radii near the cylinder. Time integration was carried out by means of the explicit method for cases where simulation was terminated soon after the peak temperature at the canister wall had been achieved. For longer simulations an alternating direction implicit technique was used without iteration.

The computer codes were tested for accuracy by comparing results after a long simulation time with those of a steady state diffusive transport program code, by comparing the results in the middle plane of the region with the analytical solution for an infinitely long cylinder of finite radius, and by computing a cumulative energy balance on the simulation region. Results from all three tests were satisfactory. Convergence testing showed that an error of about 3% is present at the grid spacing of .2 x .2 units used for most of the simulations. An additional error of about 5% is present in the long time simulations executed with a time step of .2 units.

A check of the effect of distance from the heat source to the outer and lower boundaries showed that if eight cylinder lengths below the canister and eight cylinder lengths away from the canister were used, the rise in temperature at these boundaries was less than 0.5°C after four time units of simulation. This was adequate for the shorter simulation. Longer simulation with high level heat sources may require these to be moved further away to keep their influence on the temperature field negligible.

Pilot Sensitivity Analysis

A small set of pilot cases was run in order to identify the sensitivity of the peak temperatures to the various parameters of the system. A table of base case parameters appears below. (These are NOT seen as final design values.)

Sediment Porosity	.5	
Sea Water Density	1045	$kg/3^3$
Sediment Particle Density	2800	kg/m^3
Heat Capacity of Sea Water	3.	kjoules/kg C
Heat Capacity of Sediment Particles	.84	kjoules/kg C
Thermal Conductivity of the Saturated Sediment	2.3×10^4	kjoules/m yr C
Initial Temperature	2	C
Cylinder Radius	.225	m
Cylinder Length	2	m
Thickness of Canister Wall	.05	m
Initial Heat Flux at time of Reprocessing	2.6×10^8	$kjoules/m^2$ yr
Time between Reprocessing and Burial	60	yr
Burial Depth	2	m

The above values lead to the following calculated parameters:

Effective Heat Capacity of the Saturated Sediment	3.2×10^3	$kjoules/m^3$ C
Thermal Diffusivity of the Saturated Sediment	7.0	m^2/yr

In these sensitivity tests the computed peak temperature occurred on the cylinder wall at 0.8 - 1.0 m up from the cylinder bottom. Figure 1 shows the variation of peak temperature with burial depth (i.e., depth to top of canister). The value for zero burial depth is somewhat artificial since conduction of heat through the canister waste and cladding has been neglected. The results show that peak temperature is not very sensitive to burial depth and this is consistent with the low thermal conductivity of the medium relative to the heat flux applied.

Figure 2 shows the variation of peak temperature with time delay of burial (i.e., time between reprocessing and waste burial). Delaying the time of burial can significantly reduce the peak temperaure at the cost of long term interim storage of the waste canisters.

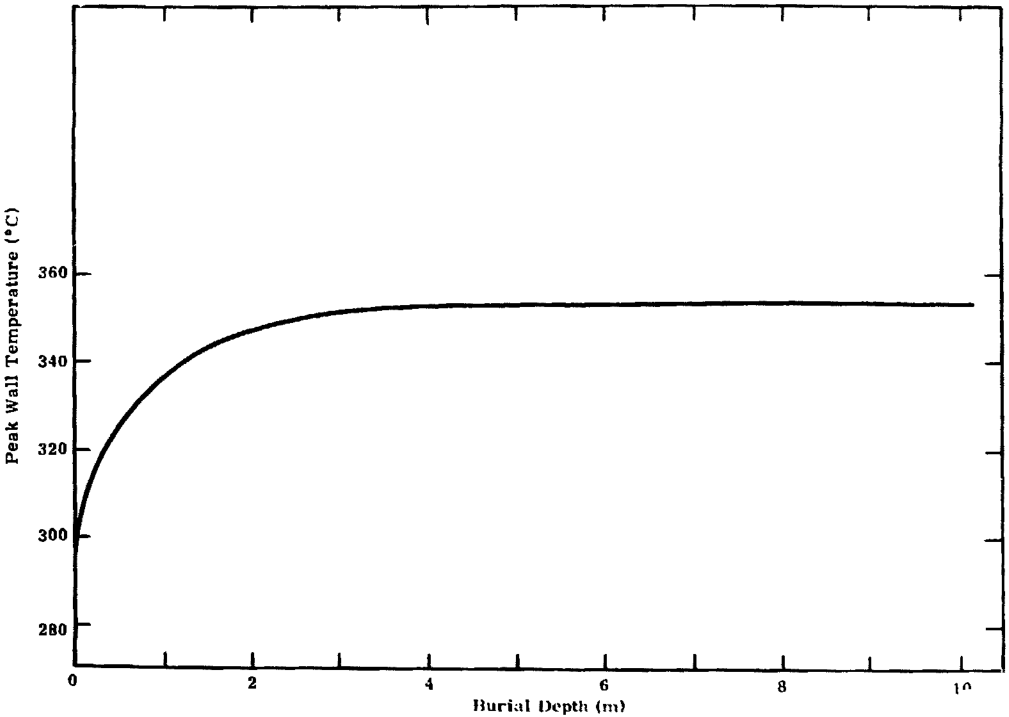
Peak Wall Temperature (°C)
360
340
320
300
280
0
2
4
6
8
Burial Depth (m)

Figure 1

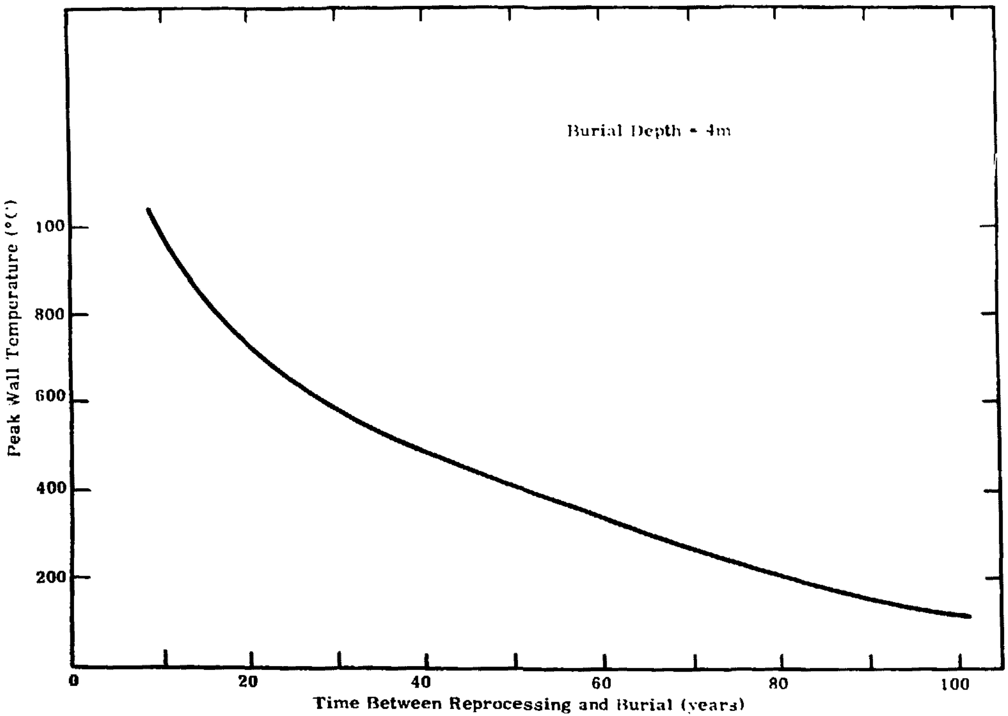
Burial Depth = 4m
Peak Wall Temperature (°C)
100
800
600
400
200
0
20
40
60
80
100
Time Between Reprocessing and Burial (years)

Figure 2

Figure 3 shows the variation of peak temperature with cylinder geometry. Changing the length to diameter ratio of the canister while keeping the volume and waste content constant gives a modest variation of peak wall temperatures. Longer, thinner canisters have a lower heat flux because of the increase in surface area.

Peak wall temperatures were calculated with maximum and minimum reported values for sediment thermal conductivity. The change in thermal conductivity, by a factor of 5, changed the peak temperature by a factor of 2.6 which implies that the thermal properties of the sediments will need to be measured to within a factor of 2, or better, in order to be able to evaluate peak temperatures to within 25%.

The peak temperature is a linear function of the initial waste content of the canister. Halving the initial waste charge halves the peak temperature rise over the initial temperature level. This is the most effective way of controlling the peak temperature since the initial heat flux is the parameter to which the system is most sensitive.

In all cases considered in this sensitivity study the time taken to reach peak temperature fell within the range 0.5 to 2 years after burial (Figure 4).

Calculations, using the base case parameters, predict a peak temperature in the region of 350°C. Although direct comparison is difficult, the results of this parameter sensitivity analysis are consistent with those obtained at the Sandia Laboratories.[2]

Further analyses will be concerned with selection of the peak temperature limiting criterion and the various possible design and disposal strategies required to comply with it.

A few long term simulation calculations have been made to determine the time necessary for the temperature field to return to nearly pre-burial conditions. Figure 5 is a plot of the temperature vs time at .8 m up from the cylinder bottom where the computed peak temperature occurs. About 110 years is required for the temperature to return to 10°C with the base case parameters and heat source function employed. This result is somewhat pessimistic because the lower and outer radial boundary did influence the temperature field slightly.

Conclusions

A simple numerical model of thermal conduction has been implemented and used for preliminary sensitivity analyses of the physical system of a single canister of radioactive waste buried in the deep ocean bed sediments. Once the limiting temperature criteria are selected, the model will aid specification of canister design and operational policy.

The sensitivity of the computed peak temperature to the various parameters decreased in the following order: The initial heat flux, the time delay between fuel reprocessing and burial, the saturated sediment thermal properties, the canister geometry, and the depth of burial. (The initial heat flux is a function of the initial charge of waste and of the canister geometry.)

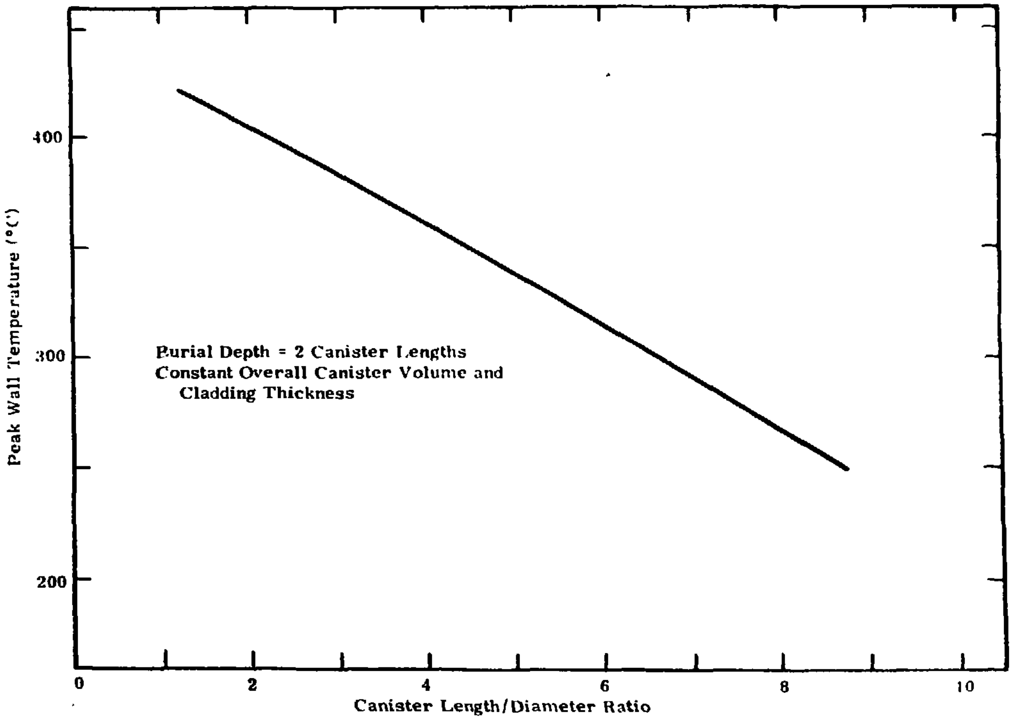
Peak Wall Temperature (°C)
400
300
200
0
2
4
6
8
10
Canister Length/Diameter Ratio
Burial Depth = 2 Canister Lengths
Constant Overall Canister Volume and
Cladding Thickness

Figure 3

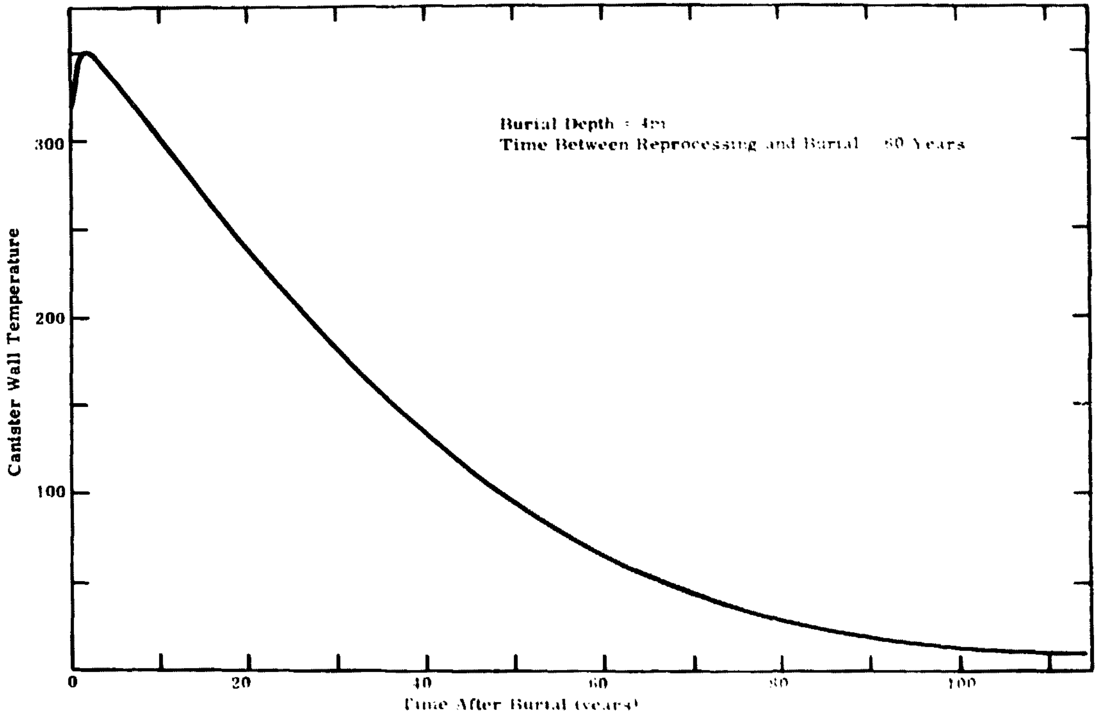
Burial Depth = 4m
Time Between Reprocessing and Burial 60 Years
Canister Wall Temperature
300
200
100
0
20
40
60
80
100
Time After Burial (years)

Figure 4

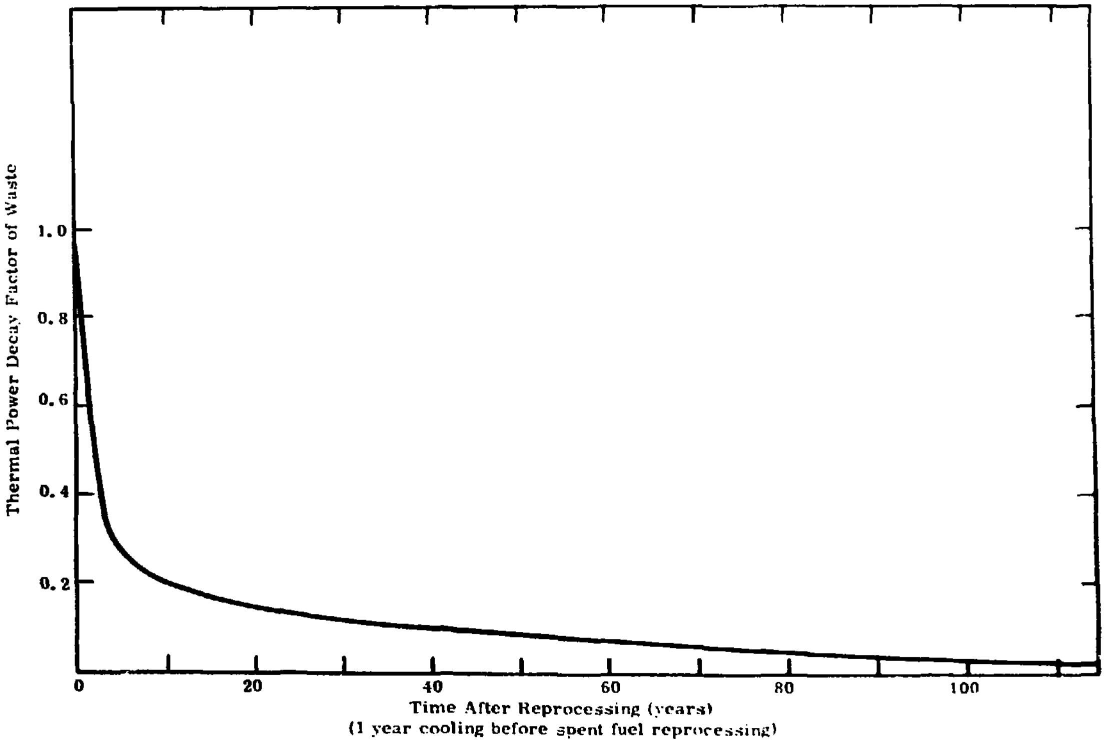
Thermal Power Decay Factor of Waste
1.0
0.8
0.6
0.4
0.2
0
20
40
60
80
100
Time After Reprocessing (years)
(1 year cooling before spent fuel reprocessing)

Figure 5

For the base case parameter values for a HARVEST type canister containing 25% by weight of waste and with a 50-year delay after burial, temperatures of the order of 350°C are reached at the canister wall within the first two years after burial.

Although direct comparison is difficult, the results of this study are consistent with those obtained at the Sandia Laboratories.

Future Requirements

The work described above relates specifically to a sediment which is porous, rigid and of very low permeability. If, in the future, it is found that sediment, in a candidate site for waste disposal, has a permeability which is high enough to influence the temperature field by permitting significant fluid convections, then an extension of the present temperature field model will be necessary. If, however, at the emplacement depth achieved by a simple penetrometer, the sediment is not rigid but is in the nature of a semi-liquid ooze then convection, fluidisation or buoyant disruption of the medium may be possible. In this situation, a completely restructured model would be required and, clearly, the resulting temperature field would be quite different from that of the rigid sediment.

On the assumption that canister integrity is maintained until fission product activity and thermal effects have entirely decayed the importance of understanding the mechanical and thermal properties of the sediment lies in allowing realistic prediction of the temperature history of the emplacement region and also of the depth of canister penetration into the ocean floor. The sorption capacity of the sediment which probably depends on its thermal history as well as its chemical characteristics, is a controlling factor in radionuclide migration. Also, emplacement depth defines the migration distance for release to the ocean so these items of information will be vital in the study of radionuclide release to the ocean after breaking of the canister containment. It has not yet been determined which criteria will set the limit of peak temperature in the emplacement region. Possible limits include the melting point of vitrified waste (~300°C) or its devitrification temperature, the melting point of sediment minerals (~1300°C), the melting point of the outer cladding alloy (~1500°C), the melting point of lead (~300°C) if a composite clad is employed or, most likely, the temperature at which canister corrosion becomes unacceptable (~200°C?).[3]

If, after a study of the sediment sorption characteristics under realistic thermal history and environmental conditions, it is found that radionuclides could be released at a rate shown to be unacceptable by oceanographic and radiobiological studies then it would be necessary to modify one or more stages of the assumed waste disposal procedure. Amongst the various options are the following:

(a) Selection of another site with more suitable sediment characteristics.

(b) Reduction of the waste concentration in the canister and, perhaps, removal of actinides.

(c) Development of a new conditioned waste form with lower leachability.

(d) Increased interim storage time before emplacement.

(e) Emplacement of waste in hole drilled into lithified sediment or crusted rock underlying the ocean bed.

It is premature to speculate on the ultimate procedure for deep ocean disposal but, clearly, the overall costs of radioactive waste disposal are going to be extremely dependent on the degree to which the above options are exercised. In order that a realistic assessment of costs may be made, for comparison with other disposal options, it is imperative that candidate disposal sites be identified without delay. (The general requirements of such sites have been discussed at length elsewhere and will not be repeated here.) Only after such identification will it be possible to obtain the information on mechanical, thermal and chemical properties of sediment which is necessary for a confident assessment of feasibility and costs.

References

(1) Hickox CE and Watts HA "Steady Thermal Convection from a Concentrated Source in Porous Medium". SAND-76-0562, Sandia Laboratories, Albuquerque, New Mexico, November 1976.

(2) Talbert DM ed. "Seabed Disposal Program Annual Report - Part II - January-December 1976". SAND-77-1270, Sandia Laboratories, Albuquerque, New Mexico, October 1977. Appendix K.

(3) Heath GR. "Barriers to Radioactive Waste Migration". Oceanus, 20, 4, 26 (1977).

INSTITUT FRANCAIS DU PETROLE

DIVISION GEOLOGIE - JW/CP -

Le 2 Fevrier 1978

MORPHOLOGY, STRUCTURE AND SEDIMENTS
OF THE NORTH - ATLANTIC

Summary

The review of the most recent papers and the most synthetic available studies, allow us to sketch the main morphologic, structural and sedimentary features of the North-Atlantic. The North-Atlantic ocean is considered in this study between the equatorial fracture zones and Iceland, outside the marginal seas (Gulf of Mexico, Caribbean Sea, etc...). We should notice first that the density of available data is very irregular, i.e. some areas are very well known, whereas others were scarcely surveyed. Therefore, regional mapping of a given phenomenon has not the same precision in different areas.

Before describing the present setting of the North-Atlantic, it seems useful to remind briefly its genesis and evolution according to plate tectonics concepts. The North-Atlantic was born some 200 MY ago (Permo-Triassic), when ancient continent "Pangaea" broke apart. The oceanic opening began first between the Equator and the Azores area. It extended up to the present Labrador Sea at the beginning of the Cretaceous (135 MY). At the Paleocene (60 MY) the opening stopped in the Labrador sea and shifted eastwards, separating Norway from Greenland. So, the first stages of oceanic opening gradually migrated towards the north from Jurassic to Paleocene, resulting presently in different physiographic structural and sedimentary characteristics of each area.

Physiography - Bathymetry: The North-Atlantic has an area of about 15,000,000 sqm and a mean depth of 2150 fm (3900 m). The maximum depth is 3750 fm (6500 m) (except the Puerto-Rico trench which belongs to the Caribbean system). The most striking feature is the symmetry of its margins with respect to a northerly-trending median ridge called the mid-atlantic-ridge. Hence, the deepest areas are not located in the middle part of the ocean but along two parallel belts, extending 600 to 1000 miles off the Coast. These are called "oceanic basins" and they are more or less divided into several sub-basins by submarine highs and ridges. Some of these highs raise above sea level into islands or archipelagoes related either to the mid-atlantic-ridge (Azores, Iceland) or to other volcanic highs (Bermuda, Canary Is, Cape Verde Is, Madeira). Two bathymetric contour lines seem of particular structural significance: the 200 m line which broadly delineates continental shelves, and the 4000 m line which corresponds on the continental margin to the outer limit of continental basements and in the middle of the ocean to the mid-atlantic-ridge and other main volcanic highs. We will mention too that the average oceanic depths are shallower in the northern part of the North-Atlantic, that is to say the youngest one.

Morphology. From the continent to the mid-atlantic ridge, five morphologic units are recognized, as a classic sequence on stable margins: the continental shelf is a terrace-like feature of continental origin extending down to the 200 m line; the continental slope is an area of strong sedimentation linking the shelf with oceanic basins; the continental rise has a very gentle slope and a quite thick sedimentary blanket resting on an oceanic-type basement; the abyssal plains are horizontal outer extensions of the continental rises; the mid-atlantic ridge is a complex, strong relief volcanic range, with a thinner and finally discontinuous sedimentary cover towards the crestal area. Other important morphologic features are described either of structural origin (volcanic highs like Bermuda or Cape Verde, fracture zones of the mid-atlantic ridge) or of sedimentary origin (sedimentary ridges, mid-oceanic-canyons) (see plate 2).

Seismicity - Volcanism - Heat flow: Seismicity of the North-Atlantic, which reveals areas of present crustal instability, is restricted to the crestal or rift part of the mid-atlantic ridge and to the main fracture zones, especially the Azores-Gibraltar fracture zone, which separates the African and the Eurasian plates. The remaining North-Atlantic is seismically quiet (except the lesser Antilles Island arc, which belongs to another tectonic system).

Volcanism is present in the North-Atlantic through some islands or archipelagoes (Iceland, Azores, Canary, Cape Verde...) active at historic times. These volcanoes are part of a much greater number of submarine volcanoes located chiefly north of the Bermuda Rise, in the Azores - Canary Madeira area, and south of 30°N. Their heights range from 1 to 4 km above surrounding sea bottom and they average 5 to 20 km in diameter. It is often uneasy to know about their age and their present activity status.

Heat flow from the earth crust has highest values on the mid-atlantic ridge and decreases significantly and regularly towards the continental margins. It represents a first attempt to evaluate the geothermal gradient.

Oceanic basement: Both refraction and reflection seismics and the study of oceanic magnetic anomalies bring information about it. The refraction shows a stratified structure of the basement into four layers of increasing sound velocities, each a few kilometers thick, corresponding to different rock types. The reflection shows a regular deepening of the basement from the crest of the mid-atlantic ridge towards the continental margins, and a very rough topography, mainly on the mid-atlantic ridge, smoothing towards the continents. The age of the oceanic basement, as indicated by the magnetic anomalies correlated with the JOIDES holes, increases from the mid-atlantic ridge (Pliocene) towards the Continental margins (Middle Jurassic), thus reinforcing the hypothesis of ocean spreading since that epoch.

The lithology of the oceanic basement appears from the JOIDES holes as a complex superposition of massive flows, pillow lava, breccia, tuffs interbedded with clayey or calcareous sedimentary layers.

Sedimentary cover: It is reminded first that present marine sediments are classified, according to the origin of the particles they are made of (terrigenous, biogenic, organic, authigenic....) into neretic sediments (mostly terrigenous) and pelagic sediments (mostly fine grained biogenic and terrigenous sediments known as oozes). The importance of dissolution phenomena on calcareous sediments at great depths (CCD) is also emphasized. Outside the continental shelf, these sediments are transported mainly by bottom currents, about which few data are available, by turbidity currents, mainly on the continental and other slopes, and by gravity slidings.

Superficial sediments (the first 10 m) are known from dredging and coring. The samples show, from their grain-size, that silty to clayey sediments prevail between the coast and the continental rise and around some topographic highs, whereas fine-grained clayey sediments prevail in abyssal plains and on the mid-atlantic ridge. Calcimetry, used to measure the amount of calcareous material in the sediments reveals that carbonate percentages increase quite regularly in recent sediments from the coast to the mid-atlantic ridge. It is not surprising if we consider that it is an area of low terrigenous influx, of high organic productivity and of water depth not greater than 4000 m (above CCD). We also noticed the areas without sedimentary cover (rock exposures), the great extension of quaternary ice rafted sediments, and areas where the present rate of deposition is very high (i.e. of rapid burial).

Total thickness of the sedimentary cover in the north-Atlantic is known from reflection seismics and the JOIDES holes. Although available documents are of different origins and qualities, we may assert that the thickest sedimentary series are located under the continental slopes and on the contrary that the thinnest series are to be encountered in the middle of the ocean, on the mid-atlantic ridge. This fact can be explained by the bulk of terrigenous material brought on the continental margins since the first stages of atlantic drifting, whereas only recent biogenic sediments are present on the crest of the mid-atlantic ridge. Local thickness variations are also to be found, related to oceanic fracture zones, volcanic highs...

Age and lithology of the sedimentary cover is given by JOIDES holes. About 80 DSDP holes were drilled in the North Atlantic since 1968, but they are very irregularly distributed. From a stratigraphic point of view, many rock types were cored from present oozes to sandstones, limestones, volcanic rocks,...We observe however, in the whole series a comparable lithologic distribution as for superficial sediments, i.e. predominance of terrigenous facies on slope and rise (mainly on the American side) and predominance of biogenic (grading to argillaceous facies with depth) in abyssal areas. On the mid-atlantic ridge, the sedimentary series is only biogenic (calcareous oozes).

Mechanical properties of the sediments: Sediments found in the North-Atlantic JOIDES holes were classified into three groups: soft, chalky and hard soils. The soft soils, of high water content, low density and low cohesion, correspond to silty and clayey oozes, to biogenic oozes and to sands and turbidites. The evolution of these sediments in depth differs for each type, from geostatic compaction to cementation-dissolution processes. The chalk is a cemented biogenic ooze, half-way between oozes and limestones, characterized by a fragile structure. Hard soils correspond to clays and shales, growing to high cohesion and low water content in depth, and limestones, sandstones, crystalline rocks, owning comparable mechanical characteristics related to their rigid matrix and their porosity-permeability patterns. We should insist on the fact that this classification was based only on 80 wells with heterogeneous sampling, storing and description techniques and that any conclusion for the whole north-Atlantic is hazardous.

Mineral mineable products: Generally speaking, there are three main sources of mineral products in the oceans: products dissolved in sea water, presently exploited in near shore conditions, deep sea sediments, potential source of many metals (such as red clay) and natural concentrates. These are considered either on the shelf (mineral placers, glauconite, phosphorite, sand, gravel, coquina) and beneath it (coal, oil...), or in the deep sea (mainly manganese nodules). In the case of the north-Atlantic, three types of potentially mineable products can be considered beyond the shelf: hydrocarbons in every area where sedimentary thickness exceeds 2000 m, manganese nodules north of the Nares abyssal plain and on the Blake Plateau, phosphorites off northwestern Africa and on the Blake Plateau too.

The conclusion of this brief bibliographic review is to draw our attention to some North-Atlantic areas that look particularly stable from oceanographic, structural and sedimentary points of view. These areas seem to fulfill the basic conditions of selection for a radioactive waste disposal site. Such areas are present off Western Africa, between abyssal plains and the lower flank of the mid-atlantic ridge and in a symmetric position, east of the Nares abyssal plain. However many data are yet missing over these areas and some additional work should be done there, for instance high resolution seismics, coring, bottom current surveys and quantitative studies of the sedimentary series in different fields such as mineralogy, geochemistry, mechanics, etc...

Work in Chemistry Division, AERE, Harwell, UK, Relating to the Vitrification and Disposal of High-Level Waste

1. Programme

This may be summarised under the following headings:

(a) Composition

1. Discovery of glass compositions capable of dissolving past, *current and future arisings of High-Level Waste*. (Note that the waste from Magnox fuel reprocessing contains only about 40% fission product oxides.)

2. Study of the effect of process variables on the reference composition; e.g. excess glass formers, excess waste, variation in the proportions of the inactive constituents of the waste (e.g. Mg, Al).

(b) Crystallisation or devitrification

Study of the crystal species that form in the glasses and the rate at which they do so.

(c) Leaching: Study of the rate of attack of water on the glasses and of the mechanism of this attack. Among the variables studied are:

The effect of temperature between 2 and 100°C.

The effect of the pH of the water.

The leach rate in various natural waters including sea water, surface waters and river water.

It is planned to extend these studies to include the effect of radiation ionisation of the water since any leaching of the real waste storage glasses will be in a high radiation flux.

(d) Radiation Stability.

Study of the effect of electron irradiation, simulating the β/γ radiation.

Study of glasses doped with excess quantities of $^{238}PuO_2$ to simulate the effect of incorporated α-emitters on the glass.

(e) Cooperation with European Commission

The division is taking part in a collaborative programme with Germany and France under which comparative tests of leaching, crystallisation and radiation stability are carried out on suggested glass compositions from the three countries.

2. *Results of relevance to the Seabed Workshop.*

(a) Composition

The composition of the two UK reference glasses in wt.% oxides is:

Code No.	Waste	SiO_2	B_2O_3	Na_2O	Li_2O	Formation Temperature
189	25.3	41.5	21.9	7.7	3.7	950°C
209	25.7	50.9	11.1	8.3	4.0	1050°C

The compositions, including that of the waste, are given in more detail in the attached tables.

(b) Leaching

The leach rates of our two reference glasses in sea water and in distilled water are plotted in the diagram [Figure 1]. The reason for the opposite effect of the salt on the two glasses is not known.

The second diagram [Figure 2] shows the effect of pH - notice the poor durability of the glasses in acid leachants. Leach tests were also carried out with samples in close fitting stainless steel vessels containing only enough water to fill the gap (i.e. the leachant/ sample ratio was <<1). This was intended to simulate the situation in storage or disposal when the container leaks. For glass 189, the leach rate was reduced by about 10x under these conditions, for both distilled and sea water. For glass 209, the leach rate was little affected in sea water and was even increased in distilled water.

(c) Radiation stability

Electron irradiation to doses equivalent to the total β/γ dose that the real glasses will receive has shown no effect on the density or leach rate. At very high dose rates in the electron microscope phase separation occurred in some glasses but this has been shown to be an effect of dose rate and it is not thought that it will be significant in the actual waste glasses.

Samples of glass doped with ^{238}Pu have now accumulated 2.5 x 10^{18} α-disintegrations/gram. This is equivalent to over 10,000 years storage of the actual glass. (Magnox waste contains less of the higher actinides than LWR waste because of the lower burn-up.) No significant changes have been observed in the glass or its density. The leach rate has increased by about 50%. The stored energy after 0.8 x 10^{18} disintegrations per gram was about 90 joules per gram (the exact value depended on the storage temperature).

J.A.C. Marples
Chemistry Division
January 1978

Composition of Code Number 189 Glass

XyOz Component	from Additives	from Waste	wt% Total	Mol %	Atom %	Remarks
SiO_2	41.51		41.51	44.81	13.13	
B_2O_3	21.87		21.87	20.17	11.84	
Al_2O_3		5.03	5.03	3.20	1.90	
Li_2O	3.69		3.69	8.02	4.69	
Na_2O	7.68		7.68	8.02	4.69	
K_2O	–		–	–	–	
Rb_2O		0.10	0.10	0.034	0.020	
Cs_2O		0.76	0.76	0.18	0.10	
MgO		6.23	6.23	10.05	2.94	
CaO		–	–	–	–	
SrO		0.32	0.32	0.20	0.059	
BaO		0.38	0.38	0.16	0.047	
Y_2O_3		0.17	0.17	0.049	0.028	
La_2O_3		0.43	0.43	0.086	0.051	
Pr_6O_{11}		0.42	0.42	0.027	0.047	
Nd_2O_3		1.78	1.78	0.34	0.20	
Sm_2O_3		*	*	*	*	Replaced by Nd_2O_3
Gd_2O_3		*	*	*	*	
CeO_2		0.98	0.98	0.37	0.11	
SnO_2		–	–	–	–	
PbO_2		–	–	–	–	
TiO_2		–	–	–	–	
ZrO_2		1.40	1.40	0.74	0.22	
PO_4		0.23	0.23	0.16	0.049	
As_2O_3		–	–	–	–	
Cr_2O_3		0.55	0.55	0.23	0.14	
MoO_3		1.75	1.75	0.79	0.22	
MnO_3		–	–	–	–	
Fe_2O_3		2.68	2.68	1.09	0.64	
RuO_2		0.67	0.67	0.33	0.096	
Co_2O_3		–	–	–	–	
RhO_2		*	*	*	*	Replaced by PdO
NiO		0.36	0.36	0.31	0.091	
PdO		0.42	0.42	0.22	0.064	
CuO		–	–	–	–	
Ag_2O		–	–	–	–	
ZnO		0.44	0.44	0.35	0.10	
U_3O_8		0.058	0.058	0.0045	0.0040	
SO_4		0.09	0.09	0.058	0.018	
				OXYGEN	58.50	

Composition of Code Number 209 Glass
(UK Glass M22)

XyOz Component	from Additives	from Waste	wt% Total	Mol %	Atom %	Remarks
SiO_2	50.83		50.83	53.99	16.77	
B_2O_3	11.12		11.12	10.07	6.29	
Al_2O_3		5.11	5.11	3.19	1.99	
Li_2O	3.99		3.99	8.48	5.30	
Na_2O	8.30		8.30	8.54	5.32	
K_2O	-		-	-		
Rb_2O		0.11	0.11	0.04	0.02	
Cs_2O		0.77	0.77	0.18	0.11	
MgO		6.34	6.34	10.99	3.12	
CaO		-	-	-	-	
SrO		0.32	0.32	0.20	0.061	
BaO		0.38	0.38	0.16	0.049	
Y_2O_3		0.17	0.17	0.05	0.029	
La_2O_3		0.44	0.44	0.09	0.054	
Pr_6O_{11}		0.43	0.43	0.03	0.051	
Nd_2O_3		1.82	1.82	0.34	0.21	
Sm_2O_3		*	*	*	*	} Replaced by Nd_2O_3
Gd_2O_3		*	*	*	*	}
CeO_2		0.99	0.99	0.37	0.11	
SnO_2		-	-	-	-	
PbO_2		-	-	-	-	
TiO_2		-	-	-	-	
ZrO_2		1.43	1.43	0.74	0.23	
PO_4		0.24	0.24	0.16	0.051	
As_2O_3		-	-	-	-	
Cr_2O_3		0.56	0.56	0.23	0.15	
MoO_3		1.77	1.77	0.78	0.24	
MnO_3		-	-	-	-	
Fe_2O_3		2.73	2.73	1.09	0.68	
RuO_2		0.68	0.68	0.33	0.10	
Co_2O_3		-	-	-	-	
RhO_2		*	*	*	*	} Replaced by PdO
NiO		0.36	0.36	0.31	0.095	
PdO		0.44	0.44	0.23	0.071	
CuO		-	-	-	-	
Ag_2O		-	-	-	-	
ZnO		0.44	0.44	0.34	0.11	
U_3O_8		0.06	0.06	0.005	0.0012	
SO_3		0.10	0.10	0.07	0.019	
			OXYGEN	-	58.76	
				100	100	

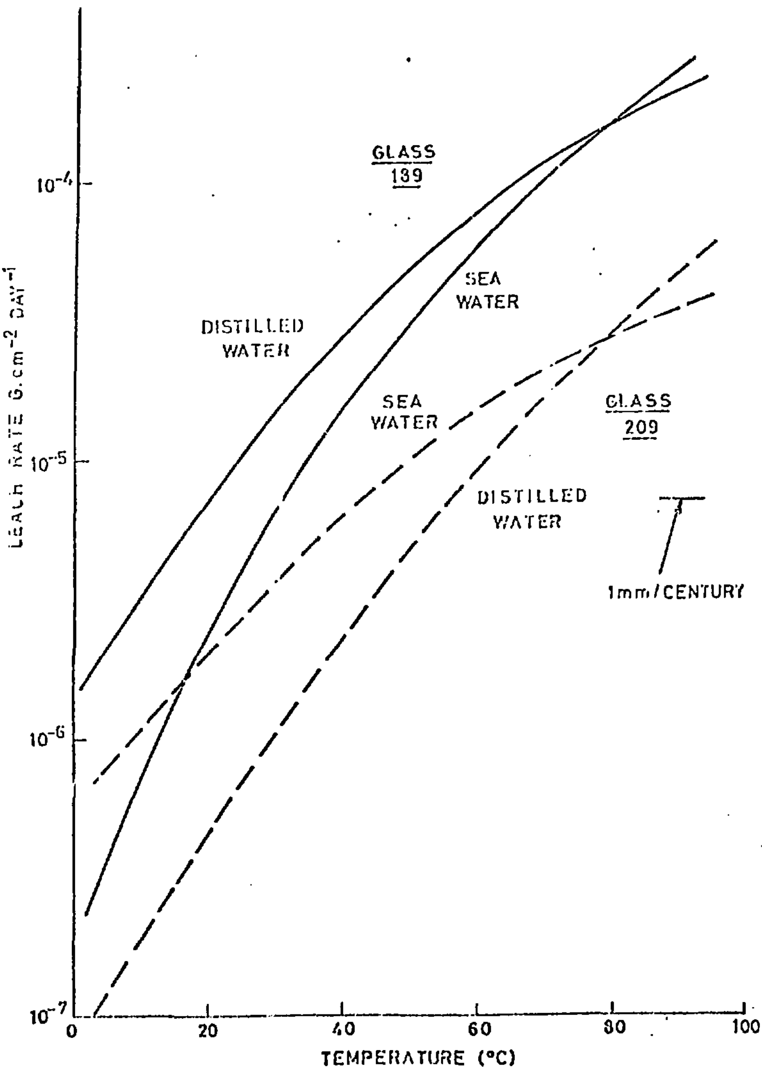

Figure 1. Leach Rates of Glasses 189 and 209 in Sea Water and Distilled Water

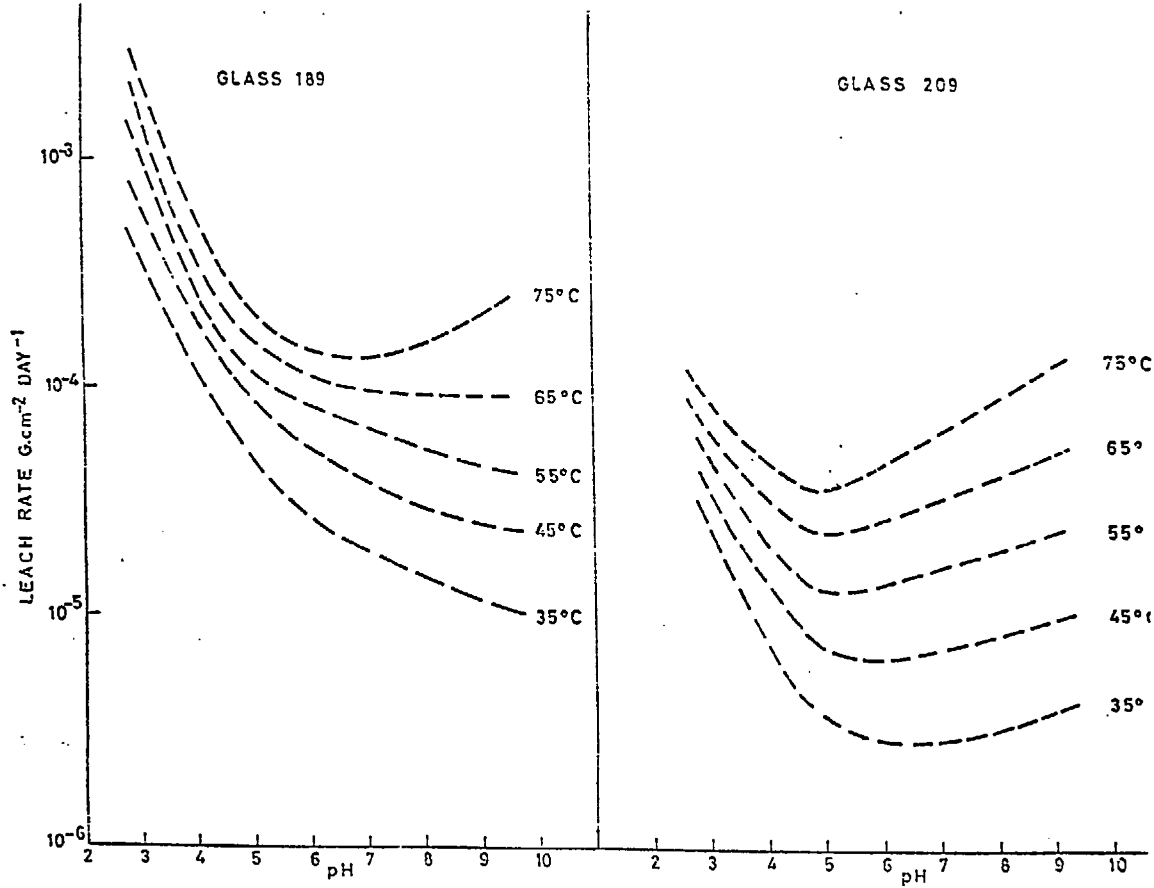

Figure 2. The Effect of pH on the Leach Rates of Glasses 189 and 209

SEABED DISPOSAL 3RD INTERNATIONAL WORKSHOP
ALBUQUERQUE NEW MEXICO USA 6-7 FEBRUARY 1978
HIGH LEVEL NUCLEAR WASTE CANISTER
UK PROGRESS REPORT

GENERAL

1. The work content of the UK programme is still essentially that given in the summary dated March 3, 1977 attached to Dr H Glauberman's letter dated March 14, 1977 (Appendix A).

CANISTER MATERIAL PROPERTIES

2. a. Creep Laws

Additional creep tests are being carried out on specimens of INCOLOY alloy 800. This work will supplement that reported in IAEA-SM-207/3 in that particular attention has been paid to ascertaining the history of the specimens.

3. b. Corrosion

Simple immersion tests in various manifestations of water have been carried out on INCOLOY alloy 800 weld procedure plates after subjecting them to the glass making thermal cycle. No corrosion has been detected.

4. A systematic theoretical and practical programme of corrosion work in support of HARVEST is in hand.

5. c. Evidence of durability

Archaeological evidence for 1000 year durability of materials found buried in various soil conditions is being assembled. This may have some relevance to assessing the compatibility of the canister with sediments. It appears that chalk is very benign but that gravel and certain types of clay can be most detrimental.

PHYSICAL PROPERTIES OF HARVEST GLASSES

6. Physical data pertinent to stress-strain modelling for the HARVEST canister has been determined for two glass formulations. These include strain rate, thermal expansion, thermal conductivity, infra-red spectral absorption co-efficients, specific heat and elastic moduli.

MODELLING OF THERMAL AND MECHANICAL CONDITIONS

7. Computations have been performed for predicting heat generation rates in waste arising from fuels having a variety of irradiation histories for periods up to 10^8 years using the FISPIN IV and FISP PT programs. In general there is a fair agreement between these programs for the early

years. Also FISPIN IV and ORIGEN show agreement within an order of magnitude over the complete range.

8. Only limited use has been made of UNCLE (a general multi-dimensional master program) for predicting stress and creep since it is still under development and running times can be long.

9. Some thermal stress studies have been done by a post-graduate student at London University (First Lieutenant Peruvian Navy Jose J. Dellepiane Massa) using GORDA, which is based on CREEPA, a well tested program in use at Imperial College to predict residual stresses in thick- walled cylinders.

10. More systematic work is planned using the expertise of the Windscale Nuclear Power Development Laboratory of the UKAEA in modelling irradiated fuel behaviour to match PIE information.

FABRICATION

11. A full-scale canister (Drg No. 1NF 54920) has been manufactured from the prime candidate material INCOLOY alloy 800 in conformity to a specially prepared high quality specification (BNFL SPEC NO P72151A).

12. The canister was made without undue difficulty and a complete record of materials and procedures employed is available. Weld prep Type 'A' required modification to allow the initial TIG root run to be made.

13. Only a limited number of weld flaws were found during fabrication and the ones which fell outside the Specification were successfully repaired. See Table I.

14. The programme for examining the canister before and after glass making has been drawn up. Dimensional changes will be determined by the Hickson Platen Gun technique as well as by linear measurements.

15. A smaller 4" diameter vessel has also been successfully fabricated to the same specification and filled with simulated glassified HLW for sawing trials.

16. A programme of development work is in hand at the Springfields Nuclear Power Development Laboratory of the UKAEA for remotely sealing canisters after they have been filled with glassified HLW.

17. Technical consultations have been held with the UK Copper Development Association on the welding of copper and copper alloys in a highly active environment. No insuperable problems are foreseen in developing suitable weld designs and techniques.

18. Technical consultations have been held with contractors who have in the past successfully incorporated cast lead shielding into BNFL irradiated fuel flasks (casks). Enough is known of the technology of lead casting to specify the techniques and conditions for completely investing primary canisters in void-free lead.

CANISTER PERFORMANCE

19. Four canisters have been used in support of HARVEST development in the AERE Harwell pilot plant. The first canister was 24" in diameter of Type 321 SS for plant commissioning trails. Details of the other three and their performance to date are given in Table I.

20. After each inactive glass making run the canister is emptied for reuse by unplugging a drain nozzle and remelting the glass. The circumferential weld area attaching the base to the cylindrical barrel is then checked for cracks by a dye penetrant technique.

21. The superior performance attributed to the revised geometry of Vessel 4 base can be appreciated since no cracks are detectable after 33 heating cycles and 519 hours service above 1000°C.

22. A replica of the Windscale small scale active pilot plant for HARVEST development is in service processing very faithful simulants of highly active liquor concentrate (HLLW). The plant uses the actual rising-level glass making process as envisaged for use in the full scale demonstration plant.

23. The canisters used in the plant are 4" in diameter and the amount of glass made in each is 2-1/2 l.

24. The canister material currently employed is the wrought version of HK 40 (i.e., Type 310 SS) but INCOLOY alloy 800 will be used in the future.

25. Canisters have been sectioned after having been used for glass making and the glass/canister interface checked for any wall attack e.g. by known embrittling elements such as Te (tellurium), using EPMA. No signs of attack have been detected.

D W CORBET
British Nuclear Fuels Limited
Risley

3 February 1978

TABLE I

DARCHEM ENGINEERING LIMITED - AYCLIFFE

L1	1 Inclusion approx. 1/8 1 Inclusion approx. 3/16 ÷ 3/64 Gas Pore
L2	1 Pipe (1/16) 1 Crack 1/4"
C1	2 Pores (1/16) at 1/3" centres 1 Pipe (1/16) 1 Tungsten 1/16 1 Pore 1/16
C2	2 Small Pores 1/32 at 1/8 Centres 2 Inclusions 1/16 long 1 Pore 1/16 1 Inclusion 1/16 1 Inclusion 1/16 1 Pore 3/64
C3	1 Inclusion 1/16 1 Inclusion 1/16

Total of 6 acceptable Gas Pores 1/64 dia.

Total welding length approx. 409'.0"

R. Gray - B.N.F.L.
1st February 1978

TABLE II

HARVEST VESSELS USED IN HARWELL PILOT PLANT

Vessel No. 2 18" cast HK 40, flat base Immaculate 5 (25/20)

Vessel No. 3 18" cast HK 40, flat base Immaculate 5 (25/20)

Vessel No. 4 18" cast HK 40, dished end Incoloy 800.

Vessel	Total No. of heating cycles	Total hours above 1000°C	Comments
2	22	139	Taken out of service when delamination cracks appeared in base weld.
3	15	124	Taken out of service when transverse cracks appeared in base weld.
4	33	519*	Still in service.

*This figure refers to hours above 900°C. The advent of vessel No 4 coincided with the change from glass M22, which required a working temperature of 1050°C, to glass M9 which requires a working temperature of 950°C. There is some diametral expansion of vessel No 4 up to 0.060", i.e. 0.3% since new.

JB MORRIS

31 January 1978.

APPENDIX A

Alan D. W. Corbet
Process Engineering
BNFL, Risley
United Kingdom

March 3, 1977

Canister

The main UK work in this area has been for the purpose of evaluating and selecting candidate canister materials for the vitrification and subsequent engineered pond storage of HLW. Experimental work has been done and more is programmed for determining creep laws, cyclic high temperature oxidation and corrosion in pond water of materials after having experienced appropriate heating/cooling schedules. Computer codes have used this data for stress and creep analyses. The materials have been both parent metal and welded specimens. Some of the input for the mathematical modelling of canister behaviour is coming from the work on waste characterization, e.g., vitrified waste "viscosity" and Young's moduli measurements over the temperature ranges from 1100°C down to ambient temperature. A full scale canister of 18" diameter fabricated from the prime candidate material INCOLOY-800, and to the high quality specifications considered necessary for HLW containment, is due for delivery within three months. It will be used in inactive vitrification trials to compare the actual behaviour of the canister with that predicted from mathematical modelling. Funds are allocated for the procurement of similar additional prototype containers in support of the FINGAL/HARVEST project. Computer codes are being employed for predicting thermal and mechanical conditions under equilibrium and transient conditions. These codes include UNCLE (a general multidimensional master programme), FISPIN (a programme for predicting the yield of fission products plus heavy elements together with their associated decay heat) and HEATRAN for heat transfer which allows material properties to vary with temperature and position and for many types of boundary conditions (including boundaries within the matrix) such as thermal radiation and reradiation.

The archaeological evidence for longevity of metals in sea water has been reviewed (BNFL Report 314 (R)) and any new evidence will be reviewed as it becomes available. Design studies for packages based on these evidences will be carried out.

The BNFL budget for 1977/78 includes a sum of £50,000 for work on prototype HLW disposal packages. The objectives of this work have yet to be determined in detail, e.g., should a prototype package be dumped (into the ocean) so as to establish whether the rapid rate of pressure change jeopardizes its integrity?

Discussions have been held with the UK National Engineering Laboratory (NEL) to determine where their offshore technology expertise can be employed to the best advantage. NEL has been invited to submit proposals for reviewing methods of canister burial, their status, limitations and costs. They are directed to give most consideration to self-burying techniques which they have developed in the past, i.e., those involving fluidization and percussion which will complement the US work on free fall pentrometers and rotary drilling.

NEL has also been invited to submit design proposals for a structure for containing a number of HLW canisters sitting on the seabed. The purposes of such a structure are:

(i) It would prevent heat emitting wastes from sinking into the sediments too quickly and becoming overheated.

(ii) During the demonstration phase of on the seabed disposal the waste could be relocated easily for periodic environmental monitoring, inspection and recovery if necessary.

(iii) It would considerably reduce the probability of disposed waste from being inadvertently recovered.

The UK programme of work on vitrified HLW characterization includes a facility for storing the canister and its associated waste under a variety of conditions, with or without artificial flaws in the canister and then comprehensive examination including leach testing using a variety of leachants. Particular attention will be paid to the canister/waste interface to establish compatibility, etc. Preliminary work has already been carried out in support of this programme with accurate inactive HLW simulants. Part of this facility will be available in 1978 and the remainder in 1980.*

Part of the HARVEST project for HLW vitrification includes the development of canister sealing methods and sealed canister decontamination and inspection procedures. These are all necessary precursors to the eventual disposal of HLW containing canisters if the system analyses confirm that the relatively short-lived radionuclides are the most significant in terms of radiological hazard and that the container/package system can mitigate the consequences of disposal and accident situations to acceptable levels.

The other area of work which could be relevant to 'container' is the glazing of PCM (Plutonium Contaminated Material) incinerator ash. R&D has been in hand in the field for some time.

*Capital cost of equipping this facility, which is housed in two existing caves, is £3.1 million.

INTERNATIONAL WORKSHOP ON SEABED DISPOSAL OF
HIGH LEVEL RADIOACTIVE WASTES,
ALBUQUERQUE, 6-8 FEBRUARY 1978

PROGRESS IN EXPLORING THE OCEANOGRAPHIC OPTION FOR DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTES ON THE SEABED

(A revised and updated version of a paper presented to the Harwell Symposium on Radioactive Waste Management, 2-3 November 1977)

by

H W Hill

Fisheries Laboratory, Lowestoft, UK

INTRODUCTION

The aim of this paper is to report progress since the last Harwell Symposium in November 1976 related to the "on-the-seabed" oceanographic option for disposal of high level waste. Hence the paper should be read in conjunction with the proposal paper presented last year (Ref 1). Progress has been mainly in the field programme but some advances have been made on the associated modelling work. Future plans are also discussed briefly.

FIELD WORK

Work has been carried out in the northeast Atlantic by both RV CIROLANA (MAFF) and RRS DISCOVERY (IOS). During November/December 1976 a full depth current meter mooring was laid at 46°05'N, 17°11'W and three short-term near-bottom moorings (containing only two meters each at 50 m above the bottom and 3700 m from the surface) were deployed around this position within the present NEA low-level dump area. A number of neutrally buoyant floats were tracked through the area for periods up to 17 days. The short-term current meter records and floats appeared to indicate a topographically controlled cyclonic eddy system below 3300 m in the southern part of the area with similar mean residual velocities in the range 1.0-4.7 cm/s at 3300-3700 m, and 1.8-2.7 cm/s in the near-bottom layer (4200-4700 m). Towards the north of the experimental area a float was tracked at a mean velocity of 3.4 cm/s in a northwesterly direction for about 7 days, and two floats released in the centre of the area at depths near the core of the Mediterranean water (1000-1200 m) moved more rapidly westwards at mean speeds of 7.7 and 8.8 cm/s. Two short hydrographic sections were completed across the float tracking area in approximately north-south and east-west directions. The geostrophic velocities calculated from these sections were consistent with the current field indicated by the floats and current meters. It is not supposed that these results, indicating a topographic control of the d eep circulation in the NEA dump area, are characteristic of the area in anything but the very short-term. Even if the apparent topographic control is real, it is likely that in the longer term the circulation will be subject to radical change, for example, through the interaction of transient meso-scale eddies. Indeed preliminary results from the full depth mooring referred to above have already indicated major long period variations at 4000 m depth. However, we do now have both an intensive, albeit in some respects short-term, hydrographic study of the present NEA dump area, and also the potential, nationally, to carry out similar and more comprehensive studies in other areas of the North Atlantic on both RV CIROLANA and RRS DISCOVERY. (A fuller report (Ref 2) of the work outlined above was presented to the International Council for the Exploration of the Sea in September 1977. Copies of this report will be available at the Workshop.)

In a related project IOS have, since November 1976 laid, and are intending to maintain over at least a two-year period, three of the NEADS full depth moorings referred to in Ref 1, as well as extensive associated CTD and float tracking work on a section between 41°N and 42°12'N (Ref 3). Kiel University have also deployed two further NEADS moorings and RV CIROLANA had deployed a mooring at a sixth NEADS site (52°30'N, 17°45'W) plus positioning three moorings in the Gibbs Fracture Zone (52°;10'N, 31°00'W) of the mid-Atlantic Ridge in an attempt to estimate the deep water transport between the east and west basins of the North Atlantic. It is understood that CNEXO (COB) has recently deployed a seventh NEADS mooring at approximately the location shown as site 7 on Figure 1 of Ref 2.

Looking to the future, we already have two cruises planned within MAFF for 1978 which will include further current measurements in the mid-Atlantic Ridge fracture zones, the servicing of the NEADS sites, and float tracking experiments, as well as other hydrographic studies. We have also proposed a programme of studies felt to be required on a world-wide basis to the Water Column Task Group of the International (USA, UK, France and Japan) Seabed Working Group in the hope of encouraging international co-operation at least in the field work involved.

MODELLING WORK

Following the publication of the Shepherd model (Ref 4) (presented here last year) we have some initial steps towards the development of a three dimensional diffusion-advection model of the North Atlantic, along the lines of the Holland and Hirschman model, but over a more extensive area, which would allow us to test various hypotheses about vertical circulation and obtain some feel for the sensitivity of the results to variation of the various input parameters anbd boundary conditions. Clearly the field work within the fracture zones is a necessary corollary of the model development, and together with other current measurements to be obtained, will be used as validation data for the model.

Once we have a reasonably realistic velocity field in 3 dimensions, we plan to carry out diffusion/advection calculations incorporating the effects of radioactive decay, thus allowing us to arrive at concentrations of activity in time and space from specific disposal operations.

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International Council for the Exploration of the Sea

CM 1977/C:11
Hydrography Committee

PRELIMINARY ANALYSIS OF DEEP-WATER MOVEMENTS IN THE EASTERN NORTH ATLANTIC

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ABSTRACT

This paper describes a short-term but intensive study of deep-water movements within a localized area of the eastern Atlantic in November-December 1976. The study area, centred on 46°N 17°W, is the site of an existing disposal area for low-level radioactive waste and incorporates one of the long-term full-depth current meter moorings maintained by the North East Atlantic Dynamics Study (NEADS) Group of SCOR Working Group 34. Morphologically the site takes the form of a re-entrant valley on the northern slopes of the Azores-Biscay Rise. Using both neutrally buoyant floats and near-bottom current meter moorings, the flow in the near-bottom layer was found to be cyclonic around and above this valley with an apparently strong morphological control. The current meter records were dominated by motions close to the local inertial period of 16.5 h and speeds did not exceed 14 cm sec^{-1}. Average speeds of 1.8-2.6 cm sec^{-1} were observed at 50 m above the bottom and 1.0-4.7 cm sec^{-1} at 1000 m above the seabed. The overall mean speeds of 5 neutrally buoyant floats at depths greater than 3000 m ranged from 2.2 to 3.4 cm sec^{-1}. Plans are described for longer-term monitoring of the deep circulation at this site to assess the variability of the mean flow.

INTRODUCTION

The deep current measurements to be described were conducted during RV CIROLANA cruise 10/76 in November-December 1976. As shown in Figure 1, the study area in the eastern Atlantic was centred on 46°N 17°W at the location of an existing dump site for the disposal of radioactive low-level waste. This site is also the location of one of the long-term current meter moorings maintained by the NEADS* Sub-group of SCOR WG 34. Hydrographically (as typified by the Nansen cast from Station 86, Figure 2) North Atlantic Central Water occupies the uppermost 800 m (approximately) of the water column, underlain at 800-1200 m depth by the conspicuous salinity maximum marking the core of Mediterranean Water, and at deeper levels (>2000 m) by the relatively uniform characteristics of North Atlantic Deep and Bottom

*The NEADS network of moorings is shown by triangles in Figure 1.

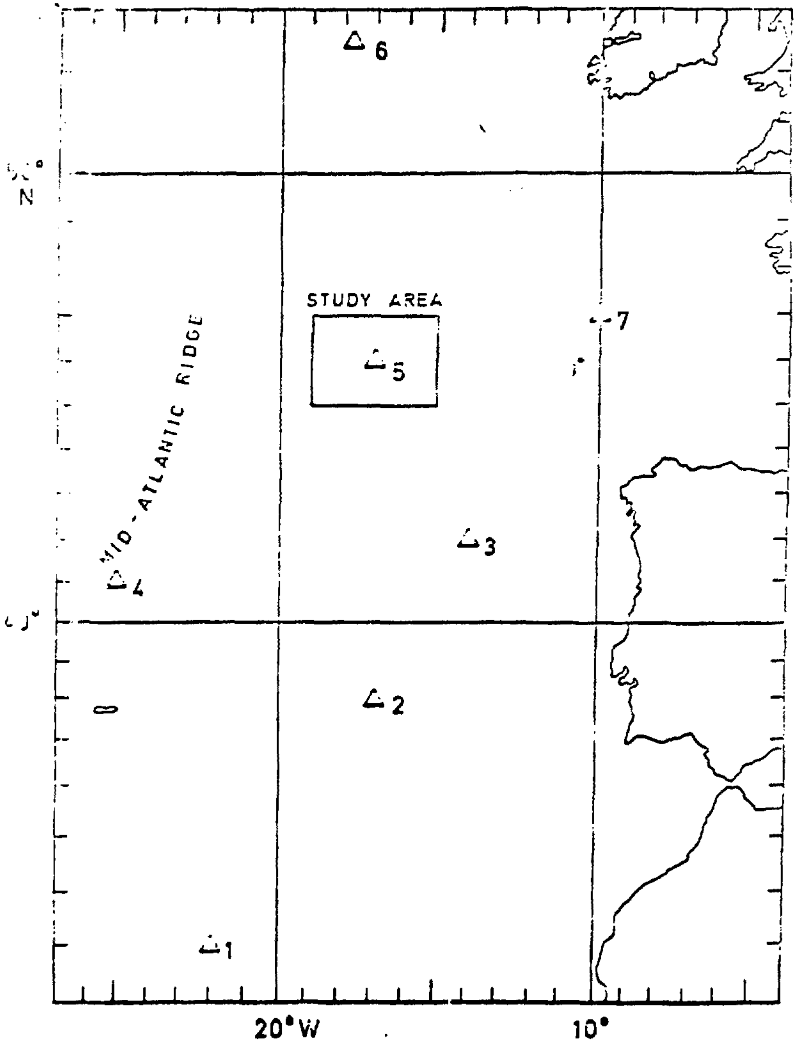


Figure 1 Location chart showing study area and sites of existing NEADS moorings (triangles).

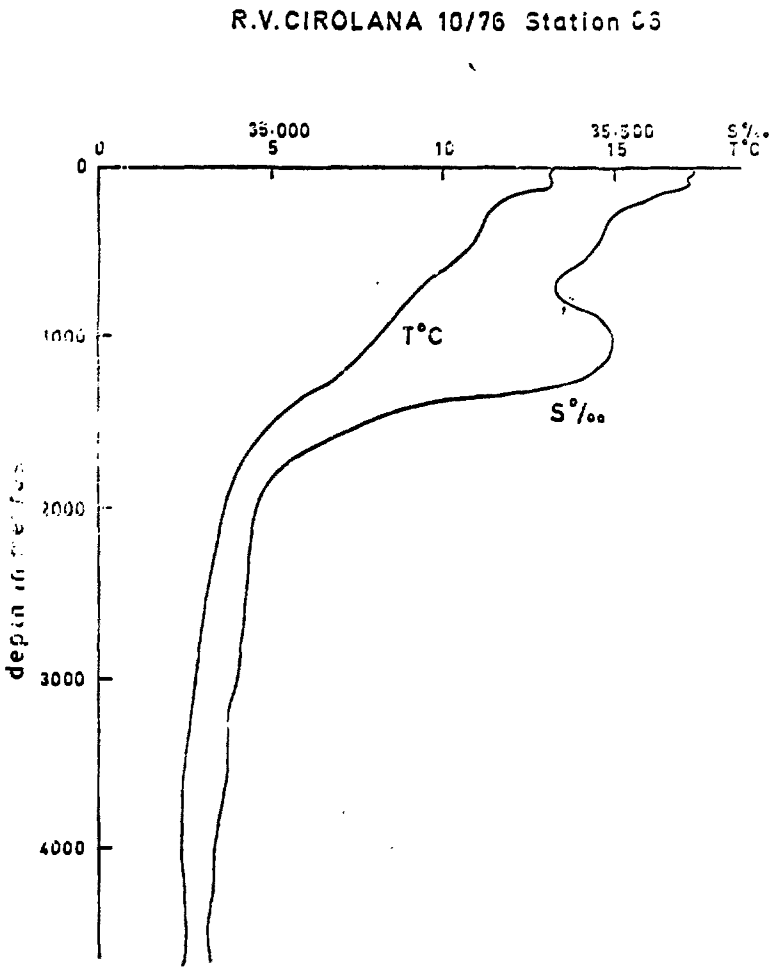


Figure 2 Temperature and salinity profile for Station 86 (46°08'N 17°11'W).

Water. Topographically the study area takes the form of a north-south valley indenting the northern slopes of the Azores-Biscay Rise with a maximum depth exceeding 4750 m and opening northwards on to the Porcupine Abyssal Plain. The detailed bathymetry of the area is shown in Figure 3.

INSTRUMENTATION AND METHODS

Two methods of direct current measurements were employed. First, 9 neutrally buoyant floats were deployed at a variety of depths along a north-south transect through the deepest part of the valley and were tracked by ship for up to 17 days. As detailed in Table 1, two floats were set at 1000-1200 m to describe water movements in the core of the Mediterranean Water, while the remainder were deployed in the deepest part of the water column at depths ranging from 3356 to 4675 m.

During tracking, the position of each float was fixed with reference to three moored acoustic beacons (also shown in Figure 3) whose location had been accurately pre-determined by repeated SATNAV fixes. Where possible float positions were measured 3-4 times per day but the severe weather prevailing for much of the cruise meant that, in practice, fixes had to be made whenever the opportunity arose; during the extreme weather conditions of 5-7 December with gusts exceeding 90 knots, delays of up to 2 days occurred between successive fixes.

These estimates of Lagrangian drift within the central part of the study area were supplemented by current meter observations at three moorings around the perimeter of the valley. The locations of these three moorings (stations 23, 35, and 40) are indicated on Figure 3. At each station the mooring (multiplait) was restricted to the near-bottom layers with two current meters per mooring (modified Aanderaa Model 4 with pressure cases tested to 7000 psi, 10 min sampling interval). In conformity with the depths of the deeper floats, the upper meters were placed to lie in a common horizontal plane 3700 m below the surface while the bottom meter on each mooring was placed 50 m above the seabed. Performance details of these instruments are listed in Table 2.

RESULTS

(a) Floats

The trajectories and depths of the seven successful floats are summarized against the local bathymetry in Figure 3. As illustrated, the floats at 1000 and 1172 m in the core of the Mediterranean Water moved rather directly toward the west or north-west at overall mean speeds of 7.7 and 8.8 cm sec^{-1}, and were evidently isolated from the sense of the drift in deeper layers. The deeper floats were apparently constrained by the bottom topography to follow a cyclonic path around the central valley area at lower overall mean speeds ranging from 2.2 to 3.4 cm sec^{-1}. In the case of the

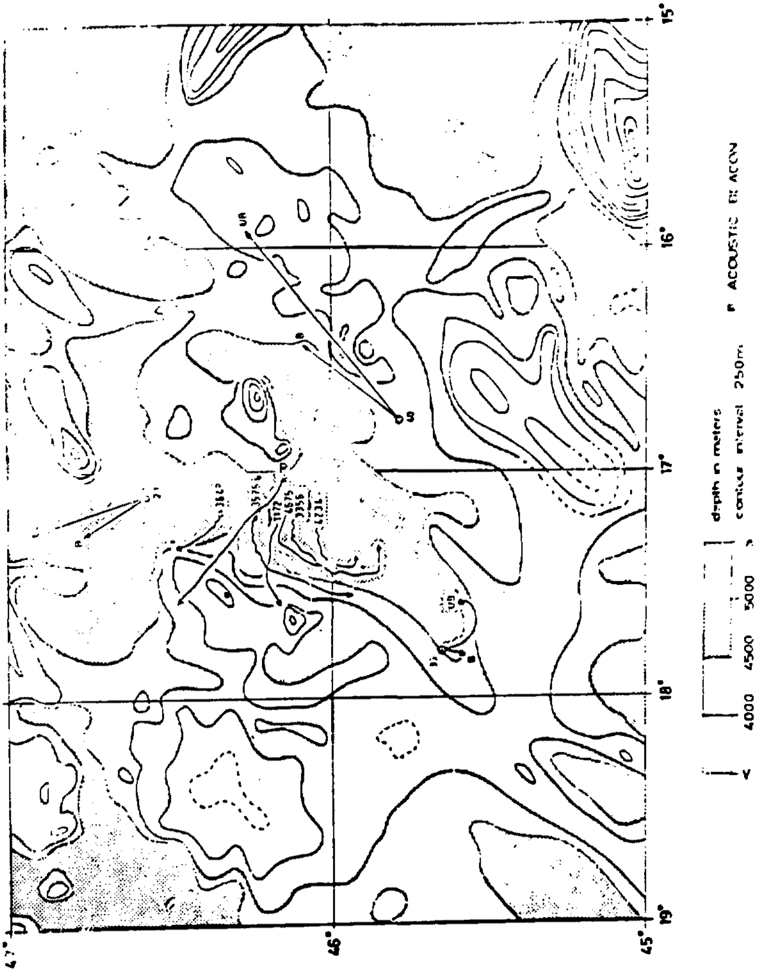


Figure 3 Bathymetry of study area (m) together with paths of neutrally-buoyant floats at the listed depths (m) and progressive vector diagrams for bottom (B) and upper bottom (UB) current meters at Stations 23, 35 and 40.

TABLE 1

Float release and recovery positions, CIROLANA cruise 10/76

Channel	Planned depth (m)	Actual depth (m)	Release time	Position		Recovery time	Position		Duration of tracking	Mean speed (cm/sec)*
7	3350	3356	0207/19 Nov	46°06'N	17°12'W	1210/ 5 Dec	45°52'N	17°21'W	16d 10h	3.3
8	4700	on bottom	1619/20 Nov	46 02	17 14	1230/22 Nov	46 02	17 14	-	-
9	3700	3576	1813/20 Nov	46 14	17 11	0928/ 8 Dec	45 58	17 33	17d 15h	2.8
11	3700	3648	2006/20 Nov	46 20	17 10	1304/27 Nov	46 29	17 21	6d 17h	3.4
14	3700	4234	1239/22 Nov	46 02	17 14	1316/ 5 Dec	45 56	17 22	13d 1h	2.2
8	1000	1172	1616/22 Nov	46 10	17 13	1050/26 Nov	46 10	17 36	3d 18h	8.8
4			0324/24 Nov	46 08	17 11		L O S T			
15	4700	4675	0200/25 Nov	46 08	17 11	1022/ 8 Dec	45 58	17 27	13d 8h	2.7
8	1000	c.1000	2243/26 Nov	46 10	17 03	1332/ 4 Dec	46 30	17 36	7d 15h	7.7

*The mean residual current speeds indicated by the floats varied in magnitude by up to 50% during the tracking period.

TABLE 2

Summary of current meter data, north-east Atlantic: 17 November-13 December 1976

Station		Sounding at launch (m)	Meter number	Height of meter above bottom (m)	Length of record			Timing discrepancy (min)	Notes on performance
					days	hours	min		
23	46°34.8'N 17°07.2'W	4705	607	1005	25	03	31	- 1	Good record (T)
			414	50	25	03	30	0	Good record (T)
35	45°38.3'N 17°45.8'W	4520	703	820	24	04	51	- 1	Good record (T)
			629	50	7	01	50	-	Meter clock stopped prior to recovery; no timing check possible (T)
40	45°47.3'N 16°44.1'W	4567	095	870	22	01	01	+ 9	Good record (T)
			538	50	21	23	00	+10	Good record (T)

(T) indicates that thermistor fitted to meter.

deepest floats at 4234 and 4675 m some topographic control is of course inevitable since the valley sides rise locally to 3500 m in the west, >4000 m in the east and >4250 m to the south. However topographic control seems to have been equally strong in the case of the shallowest of this group of floats at 3356 m depth. The northern-most float at 3648 m did not participate in the general cyclonic valley circulation; apparently influenced by the spur at the western entrance to the valley the float became detached from the main group and was directed out of the valley towards the north-west.

(b) Current meters

The overall current vectors at the three moorings around the periphery of the valley are also shown at true geographical scale in Figure 3. At each mooring the vector labelled "B" corresponds to the bottom current meter, 50 m above the seabed, while the vector labelled "UB" (upper bottom) corresponds to the meter placed 3700 m below the surface. The records on which these vectors are based are generally between 21 and 25 days in length with the exception of the bottom meter at station 35 which provided only a 7-day record through a malfunction in the clock.

The characteristics of these records are as follows. First, in the short term, the 10-minute mean speeds did not exceed 14 cm sec^{-1} at any of the three stations; the actual distributions of 10-minute values are summarized in Table 3. In the longer term, this table also shows that mean daily residual speeds* ranged from 1.8-2.6 cm sec^{-1} in the near-bottom records and from 1.0-4.7 cm sec^{-1} in the "upper bottom" records, in broad agreement with speeds of floats in the 3300-4700 m layer. Second, these current meter records are characteristically dominated throughout their length by short-period motions close to the local inertial period (16.5 h) as illustrated in the time plots of hourly values from station 23 ("upper bottom" meter; Figure 4). The coherence of this inertial signal from record to record and its comparison with the theoretical local inertial frequency are currently under examination. As with the float trajectories, a third general feature of these current meter records concerns the fact that some topographic control appears to be implied in the residual drift in both the near-bottom and upper-bottom layers (see, for example, Figure 3). We can perhaps also see something of this influence not merely in the direction of residual drift per se, but also in its stability with time. For each complete current meter record a stability factor can be calculated which expresses the mean vector speed for the entire record as a percentage of the mean scalar speed (Ramster and Hughes, 1976). For the records under discussion this stability factor was high in 4 (possibly 5) of the 6 records (Table 4):

*24 h 50 m mean centred on mid-day.

Figure 4. TIME PLOTS OF HOURLY VALUES

METER 607 STATION 23/UB EXERCISE 46 34 N. 1707W

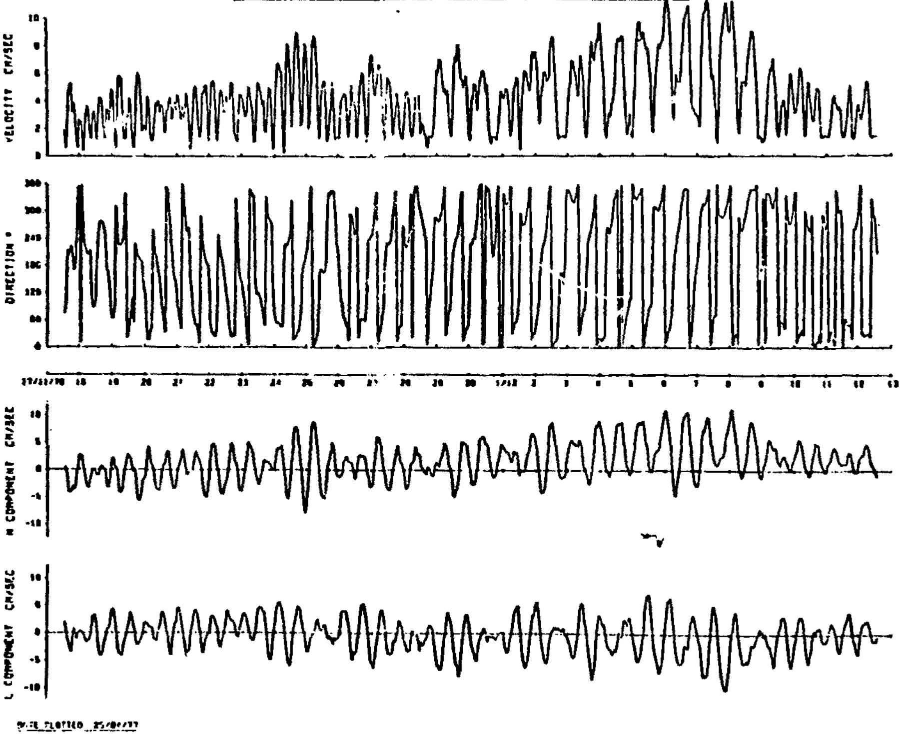


TABLE 3

Distribution of 10-minute mean speeds, all records, and mean daily residual speeds, cm sec^{-1} (* = short record)

Data interval (cm sec^{-1})	Station 23		Station 35		Station 40	
	B	UB	B*	UB	B	UB
0.0– 0.9	3	2	0	21	21	5
1.0– 1.9	775	828	290	1767	823	385
2.0– 2.9	171	252	90	345	246	66
3.0– 3.9	275	458	134	372	303	175
4.0– 4.9	564	757	190	513	603	514
5.0– 5.9	411	444	142	255	358	500
6.0– 6.9	605	341	124	192	401	681
7.0– 7.9	358	134	26	18	167	314
8.0– 8.9	263	215	21	3	116	314
9.0– 9.9	109	78	3		48	148
10.0–10.9	59	75			36	67
11.0–11.9	15	36			28	5
12.0–12.9	12	2			12	2
13.0–13.9	1				2	
Total no. of values	3621	3622	1020	3486	3164	3176
Mean speed (daily residual, cm sec^{-1})	1.9	2.2	1.8*	1.0	2.6	4.7

TABLE 4

Station	Stability factor % Bottom meter	Stability factor % Upper-bottom meter
23	66.7	80.0
35	94.5*	6.7
40	90.7	98.9

*Short record.

The extreme stability in the direction of residual drift at station 40 is further illustrated by the progressive vector diagrams of daily residuals shown in Figure 5.

DISCUSSION

As described above, this short-term but relatively intensive study of deep-water movements in a localized area of the eastern Atlantic does appear to show some evidence of "system" in the deep circulation. The Eulerian and Lagrangian estimates of drift appear consistent in both speed and direction and both imply some topographic control of the near-bottom circulation. Consistency is also shown when these direct estimates of drift are compared with the geostrophic flow calculated from two short hydrographic sections which were worked across the area from north to south and east to west. Figure 6 for example shows good general agreement between the paths of the two upper floats at 1000-1100 m and the distribution of dynamic height anomaly at 1000 m (relative to 4100 m), while Figure 7 also confirms this good agreement in comparing float velocities (east-west components) with the vertical velocity profile calculated for the north-south section.

Nevertheless, despite the fact that these observations appear to show a relatively simple deep circulation within the area during the four-week period of study it would be naive to suppose that this simplicity was characteristic of the area in anything but the very short term. Even if the apparent topographic control is real (lending some degree of stability to the circulation) it is entirely likely that in the longer term the deep circulation will be subject to radical change, for example, through the interaction of transient mesocale features with the mean flow. Indeed at the full-depth NEADS mooring maintained in the centre of the study area, preliminary results for the period December 1976-February 1977 provide ample evidence that the circulation at 4000 m depth is subject to major long period variations (Gould, pers. comm.). For this reason it is planned to extend the pilot study of November-December 1976 into a nine-month exercise using four long-term moorings during the period autumn 1977 to summer 1978.

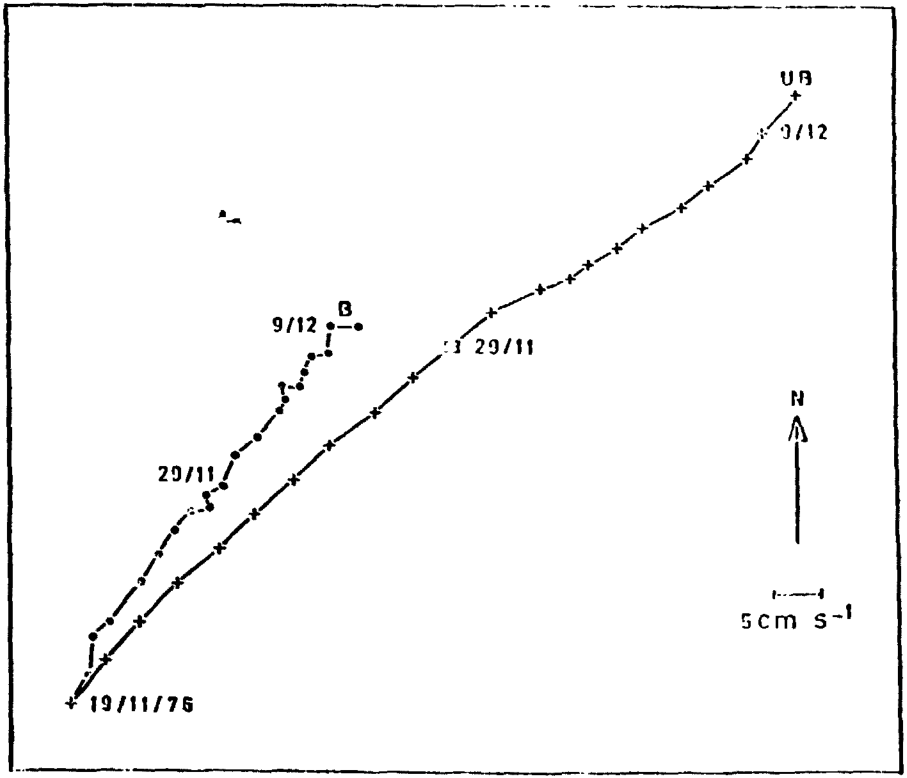


Figure 5 PVD daily residuals. Station 40/B,UB, Exercise 4547N, 1644W.

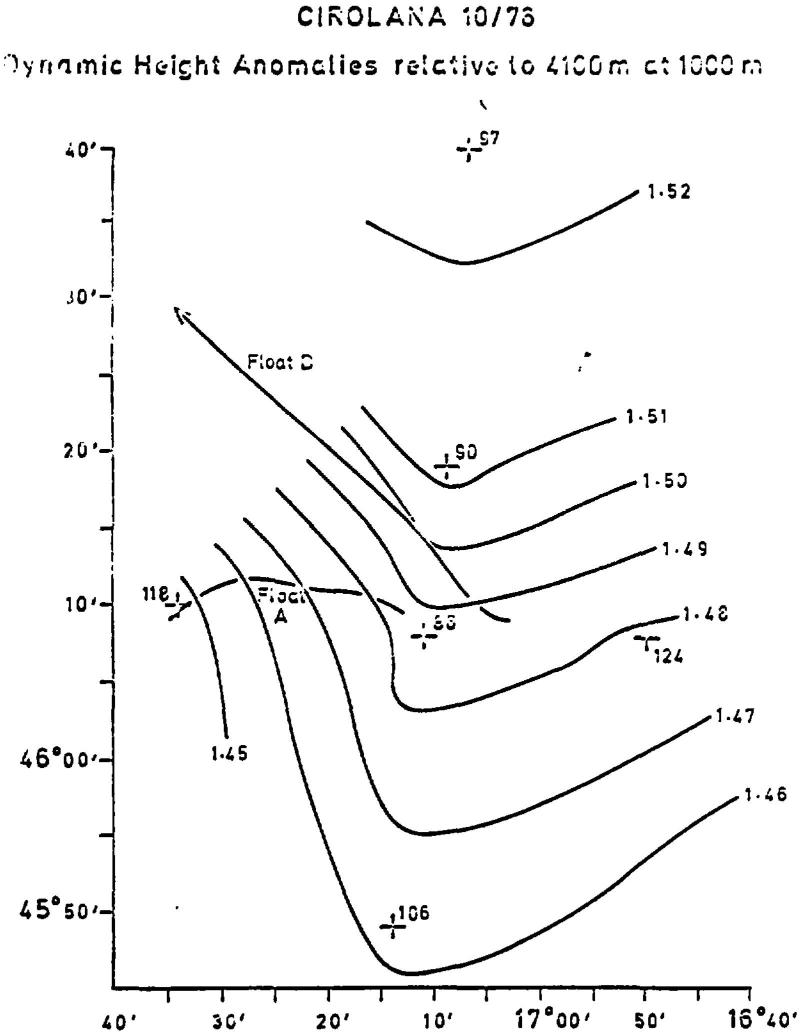
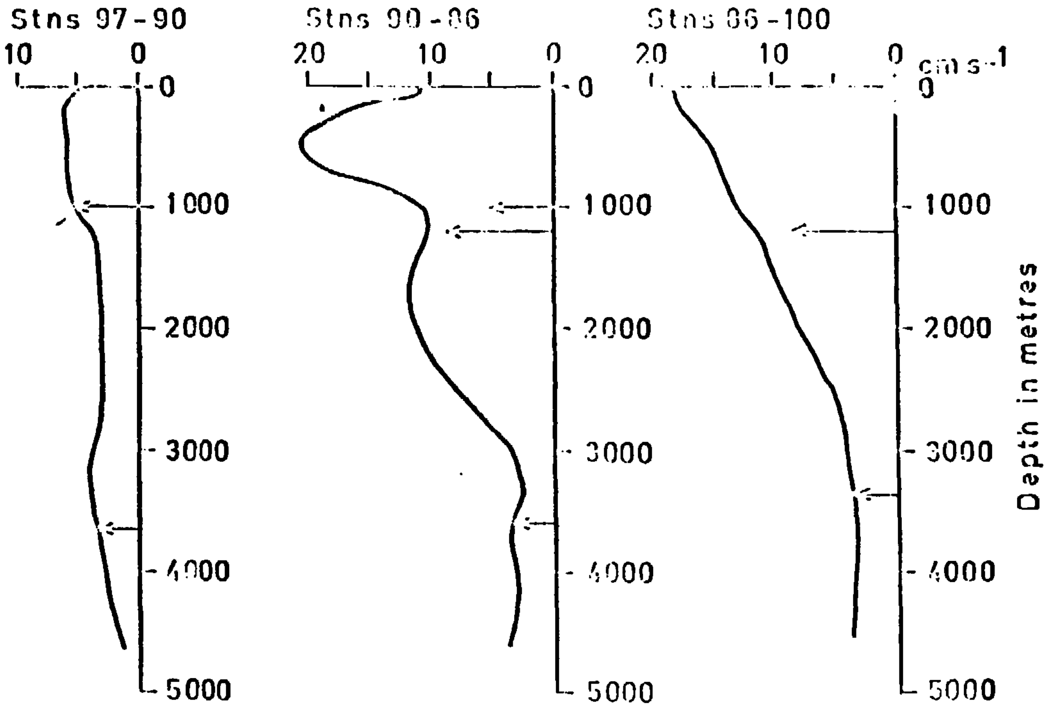


Figure 6 All hydrographic stations worked between 22 and 26 November 1976. Float A tracked from 22-26 November, Float B from 26 November-4 December 1976.

Figure 7

CIROLANA 10/76 Velocity Profiles, Stations 97-90-86-106

<- - = Float position



ACKNOWLEDGEMENTS

The authors are indebted to Messrs Gould, Millard, and Waddington of the Institute of Oceanographic Sciences, Wormley for contributing their float tracking equipment and expertise during the programme of fieldwork described above, and to John Gould for making available unpublished results from the NEADS mooring in the area.

REFERENCE

RAMSTER, J. W. and HUGHES, D. G., 1976. A stability factor for estimating variability of residual drift in current meter records of 20 days or more in length. ICES CM 1976/C"6, 3 pp. (mimeo).

MAFF PLANS FOR WATER COLUMN RESEARCH

Introduction

MAFF plans for water column research (physical oceanography, I would prefer) are essentially related to the "on-the-sea-bed" disposal option. However I realise that much of what we intend is also relevant to physical oceanography studies which might be required in respect of an "in-the-sea-bed" option. Having made that clear, I see the main aim as progressing towards a better understanding of the mixing and advective processes in the water column, both horizontally and vertically, to improve our predictions of the dispersion of radioactive wastes in the deep ocean. Clearly this research, as outlined below, is clearly allied to, and will necessarily need to be complemented by geochemical studies, and mathematical modelling of the physical processes. The geochemical work will have to include studies of the adsorption of the longer lived nuclides onto typical deep sea sediments (we hope to initiate work on this aspect in the near future at our Fisheries Radiobiology Laboratory in Lowestoft), sedimentation rates onto the bottom, the transport settling and re-entrainment of bottom sediments particularly in the benthic boundary and nepheloid layers, settling rates of particulates in the water column etc (these latter we would like to see encouraged, but would not currently expect to contribute to). Neither would we expect to contribute to the presently on-going work in the USA on the behaviour and distribution of naturally occurring radionuclides on the sea-bed (Radon 222, Radium 226 etc) which will lead hopefully to a better evaluation of the vertical diffusivity, but we would like to see it encouraged and expanded. Certainly these estimates of K_z would be valuable contributions to the type of Shepherd model which I presented in Washington. As far as the modelling is concerned we are planning to develop a three-dimensional diffusion-advection model with realistic topography and circulation (based on the models of Kirk Bryan, with whom we have already been in touch), incorporating various hypotheses for vertical motion, the parametrization of vertical mixing, and sorption onto sediments.

Physical Oceanography (Water Column)

We believe the following studies are necessary on a world wide basis. In MAFF we expect to contribute to the first seven areas of work within the North-east Atlantic.

1. Deep water releases of tracers (not necessarily, but probably radioactive) to estimate local horizontal and vertical diffusion rates. With releases of 10-100 Ci we estimate we might at least be able to

    a. say whether or not vertical mixing is indeed very slow in the interior of the deep ocean

    b. make direct measurements of horizontal dispersion.

We are tentatively planning the first release on a cruise in the summer of 1979.

2. Estimate the vertical circulation of the deep ocean. We are currently experimenting with Stommel and Scotts' method using intersecting vertical sections on data recently obtained in the N.E. Atlantic. (Further work planned during 1977 cruise in October-November; subsequently withdrawn after exploratory analysis.)

3. Attempt to estimate horizontal dispersion characteristics using batches of neutrally buoyant floats. (Planned for 1978)..

4. Co-operate with IOS to maintain the NEADS long term current meter sites. (Already on-going by IOS.)

5. Carry out spatial variability studies using small arrays of bottom current meter moorings complemented by neutrally buoyant float releases. To be expanded to include study of mesoscale processes. (Already started in co-operation with IOS - more work planned by MAFF in 1978.)

6. Moor long-term bottom current meter stations at present and planned low-level dump sites, and in mid-Atlantic ridge fracture zones to provide model validation date. (To begin in 1977 and continue through 1978.)

7. Carry out a bottom sediment sampling programme, CTD studies of the benthic boundary layer, and estimate transport across various latitudinal sections using CTD sections referenced by current meters and/or floats. (1977/1978).

8. Encourage expansion of existing studies of natural or man-made tracers (eg tritium, He-3, C-14 and Sr-90, which may tell us more about circulation and mixing processes at the larger scales.

It is very much hoped that the Institute of Oceanographic Sciences (IOS) will undertake a parallel and complementary set of physical oceanography studies to the above, specifically related to the sea-bed disposal problem, ie over and above the work which is currently on-going at IOS. The funding of this extra research is not yet agreed however. We would also like to see a near bottom tracer release (larger than envisaged at (1) and maintained for up to a year) specifically aimed at the study of sorption of radionuclides onto sediments and uptake of radionuclides by benthos, the intention of the former being to core around the release point and establish the in-situ distribution of activity in the sediment, both on the surface and beneath the surface. We cannot however see MAFF taking part in this experiment. Has anyone else similar plans?

Lastly, our next three scheduled cruises on this study are October-November 1977; June-July 1978 and November 1978. In accordance with Action Point 2, of the Washington meeting report, viz "to encourage and co-ordinate co-operative cruises and experiments among member nations, including the sharing of ship time between experiments of different nations", there would seem to be no reason why we should not take along one or two extra staff (and equipment if required). Therefore, if you have a specific proposal for a piece of work on one of these cruises, and wish to send soneone along, or if you can offer some co-ordination of programme with one of your ships, please let me know and we shall consider whether it can be fitted in.

CO-OPERATION IS THE NAME OF THE GAME.

H W Hill
19 July 1977

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APPENDIX V

VUGRAPHS USED DURING MEETING

PROGRAM OBJECTIVES

- ASSESS FEASIBILITY OF USING GEOLOGIC FORMATIONS BENEATH THE OCEANS AS REPOSITORIES FOR HIGH LEVEL WASTE OR SPENT FUEL

- DEVELOP AND MAINTAIN A CAPABILITY TO ASSESS THE FEASIBILITY OF OTHER OCEANIC NUCLEAR WASTE DISPOSAL CONCEPTS

OBJECTIVES OF THIRD INTERNATIONAL SEABED DISPOSAL WORKSHOP

- REVIEW STATUS OF NATIONAL PROGRAMS
- TASK GROUPS TO EXCHANGE DATA AND PLANS
- TASK GROUPS TO RECOMMEND AND COORDINATE MULTI-NATIONAL R&D IN THEIR AREA

BY THE END OF THE WORKSHOP

- OUTLINE A LETTER REPORT TO NEA-RWMC
- IDENTIFY AREAS OF TASK GROUP R&D COORDINATION
- RECOMMEND OTHER TASK GROUP MEMBERS
- DISCUSS HOW OTHER COUNTRIES MAY PARTICIPATE IN SEABED WORKING GROUP

ASSESSMENT OF SEABED DISPOSAL: INTERNATIONAL COOPERATION

ROLE OF SEABED WORKING GROUP/TASK GROUPS:

- PROVIDE FORUMS FOR DISCUSSION, ASSESSMENT OF PROGRESS, AND PLANNING OF FUTURE EFFORTS;
- ENCOURAGE AND COORDINATE COOPERATIVE CRUISES AND EXPERIMENTS, INCLUDING SHARING OF SHIP TIME;
- SHARE FACILITIES AND TEST EQUIPMENT;
- EXCHANGE INFORMATION;
- MAINTAIN COGNIZANCE OF INTERNATIONAL POLICY ISSUES

NEA-RADIOACTIVE WASTE MANAGEMENT COMMITTEE

SEABED WORKING GROUP

JAPAN	H. HOTTA
FRANCE	A. BARBREAU
UK	K.D.B. JOHNSON
US	D. GLENN BOYER

TASK GROUP	JAPAN	FRANCE	UK	US
WATER COLUMN	HOTTA*	MADELIN	HILL	ANDERSON *
CANISTER	EMURA	GRALL	CORBET	ANDERSON
WASTE FORM	-	-	MARPLES	JOHNSTONE
BIOLOGY	HOTTA *	BELOT	-	YAYANOS
SEDIMENT & ROCK	HOTTA *	SALLE	LEWIS	HEATH
SITE CRITERIA	HOTTA	BARBREAU	LAUGHTON	HOLLISTER
SYSTEM ANALYSIS	HOTTA *	DE MARCILY	WEBB	TALBERT

* ACTING CAPACITY

COMMERCIAL RADIOACTIVE WASTE DISPOSAL

		($ IN MILLIONS) FY 1977	FY 1978
TERMINAL STORAGE (DEEP GEOLOGIC FORMATIONS)	— WPR	$ 30.2	$ 68.0
TRANSMUTATION	— WPR	1.8	1.4
SPACE	— NASA	(0.4)*	(0.4)*
OCEAN BED	— ECT	1.0	2.75
	— BER	.3	.35
		$ 33.3	$ 72.5

*Funding by NASA not included in total.

DEPARTMENT OF ENERGY: RADIOACTIVE WASTE MANAGEMENT PROGRAMS

- MAIN THRUST IS TOWARD ISOLATION WITHIN STABLE GEOLOGICAL FORMATION, AT DEPTHS REACHABLE BY CONVENTIONAL MINING METHODS:
  - ROCK SALT
  - SHALES
  - BASALT
  - GRANITES
- RECENT IMPRESSIVE ADVANCES IN DEEP-SEA TECHNOLOGY MAKE US BELIEVE THE OCEAN BED MIGHT PROVIDE ALTERNATIVE DISPOSAL REPOSITORIES
- TRANSMUTATION AND SPACE DISPOSAL OF SELECTED WASTES MAY REDUCE THE TERRESTRIAL DISPOSAL REQUIREMENTS

ASSESSMENT OF OCEANBED DISPOSAL

NOTE OF CAUTION:

UNTIL ENVIRONMENTAL AND TECHNICAL FEASIBILITY IS ESTABLISHED, THOSE OF US WITH ENTHUSIASM FOR THE POTENTIAL FOR DEEP OCEANBED DISPOSAL SHOULD NOT:

- OVERSELL THE POTENTIAL
- DOWNGRADE OTHER DISPOSAL METHODS
- UNDERESTIMATE THE REMAINING CHALLENGES
  - — INTERNATIONAL LAWS
  - — EMPLACEMENT TECHNIQUES
  - — PORT AND SHIP REQUIREMENTS
  - — LICENSING AND PUBLIC ACCEPTANCE

ASSESSMENT OF OCEAN BED DISPOSAL

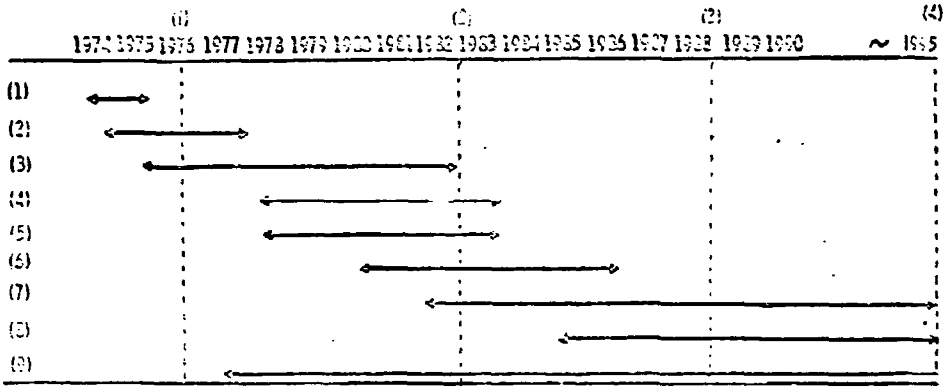
(THOUSANDS OF DOLLARS)

FY 1974	FY 1975	FY 1976	FY 1977	FY 1978
$1,500 A/	$ 260	$ 897	$1,300 B/	$3,100 B/

A/ OFFICE OF NAVAL RESEARCH/SANDIA LABS - DNA

B/ $300K IN FY 77; $350K IN FY 78 FROM BER

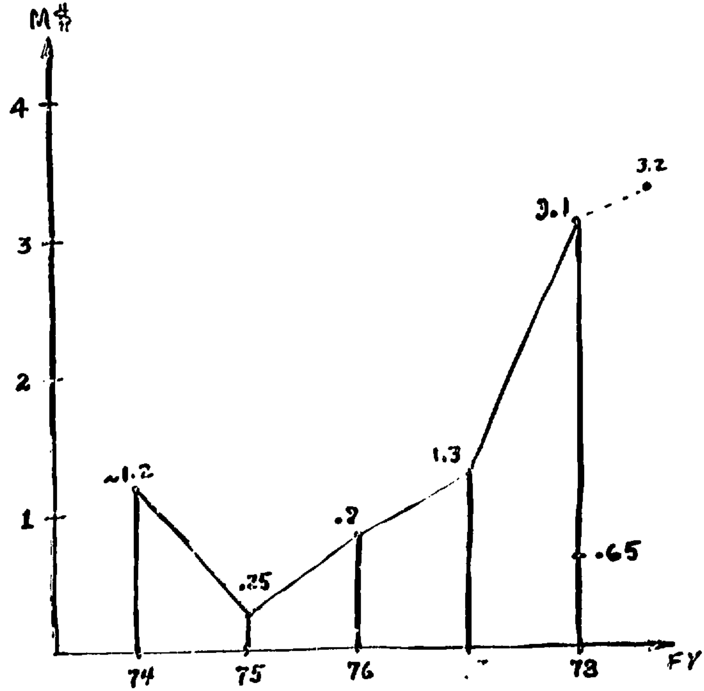
TIMETABLE FOR ACCOMPLISHMENTS



(1) DEVELOP SITE SELECTION CRITERIA
(2) SELECT GENERIC STUDY SITES
(3) IDENTIFY AND QUANTIFY ION MIGRATION BARRIERS
(4) DEVELOP PREDICTABILITY CRITERIA
(5) DEVELOP ENGINEERING EMPLACEMENT SYSTEM
(6) TEST SYSTEM
(7) ASSESS SAFETY AND ENVIRONMENTAL IMPACT
(8) DEVELOP PRODUCTION FACILITIES
(9) DEVELOP AN ASSESSMENT CAPABILITY FOR FOREIGN DISPOSAL OPTIONS

(1) FEASIBILITY ASSESSMENT FROM HISTORICAL FIELD DATA
(2) FEASIBILITY ASSESSMENT FROM NEW FIELD SCIENCE AND INITIAL LAB SCIENCE DATA
(3) FEASIBILITY ASSESSMENT FROM LAB SCIENCE AND INITIAL ENGINEERING DATA
(4) FINAL FEASIBILITY ASSESSMENT FROM A DEMONSTRATION FACILITY AND INITIAL SAFETY AND ENVIRONMENTAL EFFECTS

SEABED DISPOSAL PROGRAM FUNDING HISTORY



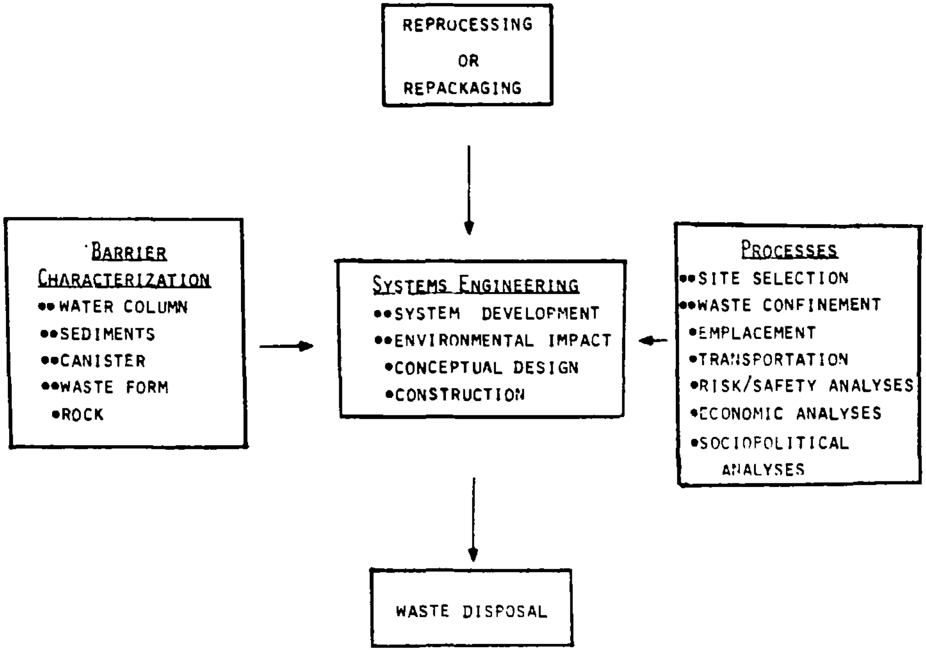
PROGRAM PARTICIPANTS

C. D. HOLLISTER - WHOI	GEOLOGY
V. T. BOWEN - WHOI	RADIOCHEMISTRY
P. RHINES - WHOI	PHYSICAL OCEANOGRAPHY
R. R. HESSLER - SIO	BENTHIC BIOLOGY
J. McGOWAN - SIO	WATER COLUMN BIOLOGY
A. YAYANOS - SIO	MICROBIOLOGY
K. SMITH - SIO	BIOLOGY
T. E. EWART - UW	OCEAN INSTRUMENTATION
D. E. HAYES - LDGO	GEOPHYSICS
A. J. SILVA - URI	GEOTECHNICAL PROPERTIES
G. R. HEATH - URI	GEOCHEMISTRY
K. KEIL - UNM	GEOLOGY
I. C. BUPP - H.U.	ECONOMICS
A. ROBINSON - H.U.	PHYSICAL OCEANOGRAPHY
D. A. DEESE - H.U.	LEGAL/POLITICAL ASPECTS
G. COYER - DOE/NCD	PROGRAM MANAGEMENT
H. HAMILTON - DOE/DOER	PROGRAM MANAGEMENT
K. BRYAN - P.U.	FLUID DYNAMICS
D. R. ANDERSON - SLA	PROGRAM MANAGEMENT
D. M. TALBERT - SLA	PROGRAM MANAGEMENT
W. P. SCHIMMEL - SLA	HEAT TRANSFER
C. E. HICKOX - SLA	HEAT TRANSFER
J. L. KRUMHANSL - SLA	HYDROTHERMAL GEOCHEMISTRY
P. R. DAWSON - SLA	CHEMISTRY
K. ERICKSON - SLA	CHEMISTRY
J. W. BRAITHWAITE - SLA	METALLURGY

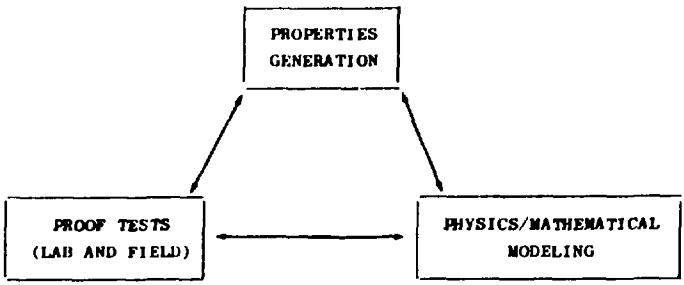
KEY QUESTIONS

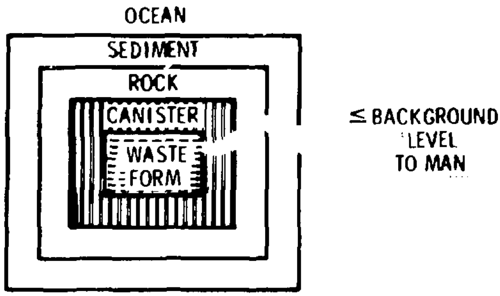
- o IS THERE A BARRIER OR SET OF BARRIERS WHICH IN THE NATURAL STATE OFFER SATISFACTORY CONTAINMENT OF RADIONUCLIDES ?
  - x WATER COLUMN
  - x BENTHIC BOUNDARY LAYER
  - x SEDIMENT
  - x ROCK
  - x CAN
  - x WASTE FORM

- o IS THE BARRIER(s) STILL ADEQUATE AFTER INTRUSION ?
  - x PHYSICAL DISRUPTION (HOLE)
  - x HEAT
  - x RADIATION
  - x FOREIGN IONS


REPROCESSING
OR
REPACKAGING
BARRIER CHARACTERIZATION
••WATER COLUMN
••SEDIMENTS
••CANISTER
••WASTE FORM
•ROCK
SYSTEMS ENGINEERING
••SYSTEM DEVELOPMENT
••ENVIRONMENTAL IMPACT
•CONCEPTUAL DESIGN
•CONSTRUCTION
PROCESSES
••SITE SELECTION
••WASTE CONFINEMENT
•EMPLACEMENT
•TRANSPORTATION
•RISK/SAFETY ANALYSES
•ECONOMIC ANALYSES
•SOCIOPOLITICAL ANALYSES
WASTE DISPOSAL

ITERATIVE-PREDICTIVE CAPABILITY DEVELOPMENT





$T_{CONTAINMENT} \geq X \times 10^{6}$ YEARS (GOAL)

$= T_{WASTE\ FORM} + T_{CANISTER} + T_{ROCK} + T_{SEDIMENT} + T_{OCEAN}$

$T_{WASTE\ FORM} = 10^{3}$ TO 10^{x} YR WHERE "x" = F (1/SOLUBILITY)

$T_{CANISTER} = 10^{2}$ TO 10^{3} YR

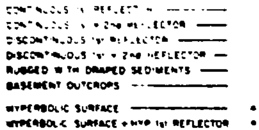
$T_{ROCK} = 10^{?}$ YR (BULK PERMEABILITY DUE TO THERMAL-CONTRACTION FRACTURES UNKNOWN)

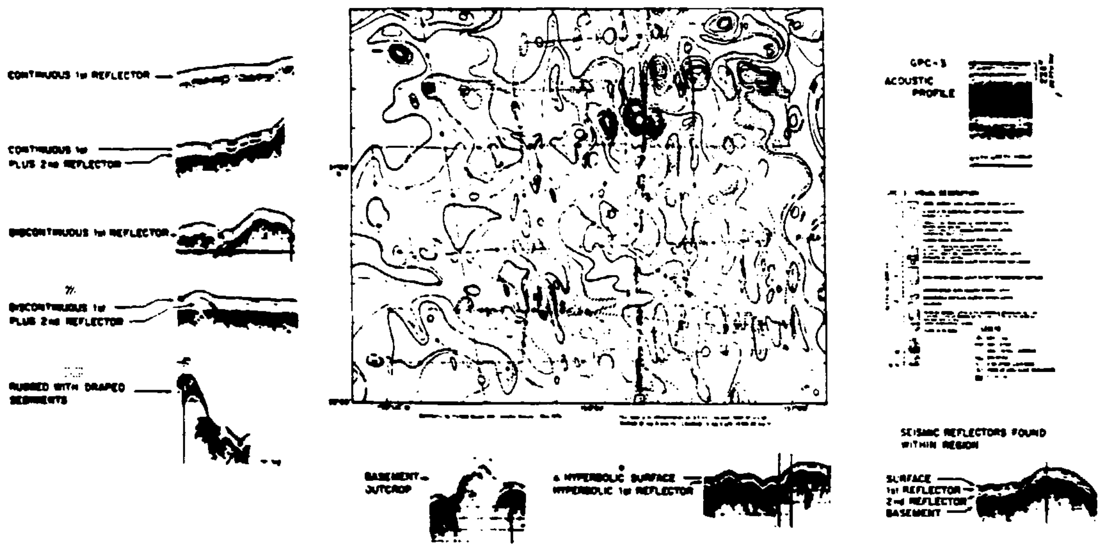
$T_{SEDIMENT} = 10^{6}$ YR/100 M (PORE DIFFUSION)

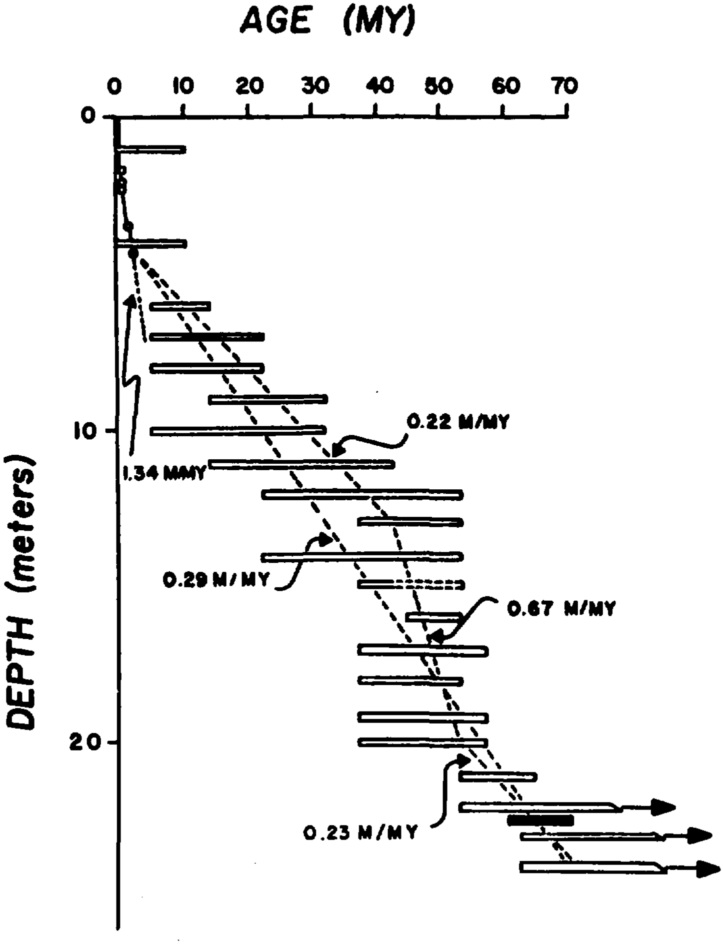
10^{13} YR/100 M (TH SORPTION + DIFFUSION)

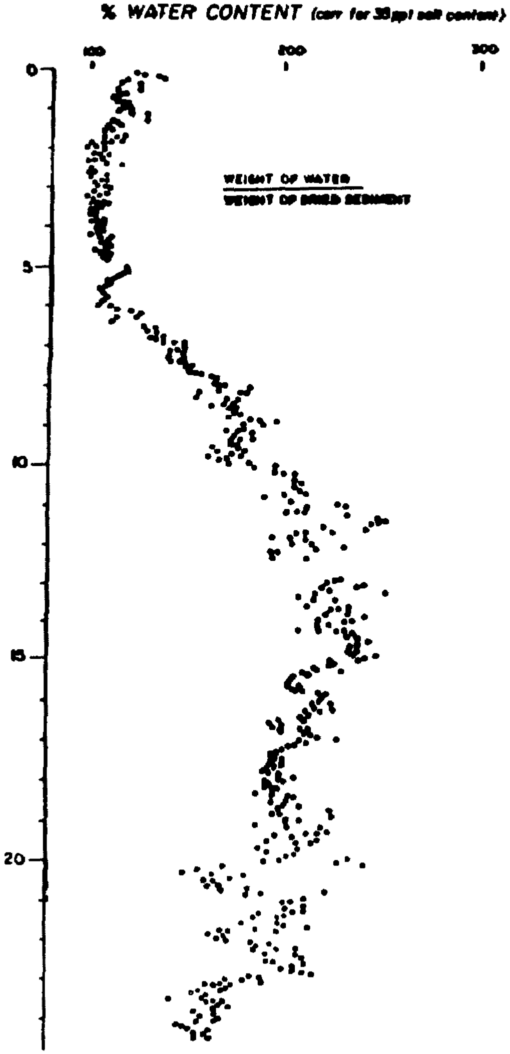
$T_{OCEAN} = 10^{2}$ TO 10^{3} YR (LESS IF BIOLOGICAL SHORT)

LATERAL CONTINUITY OF 3.5 KH$_z$ SEISMIC REFLECTORS MPGI

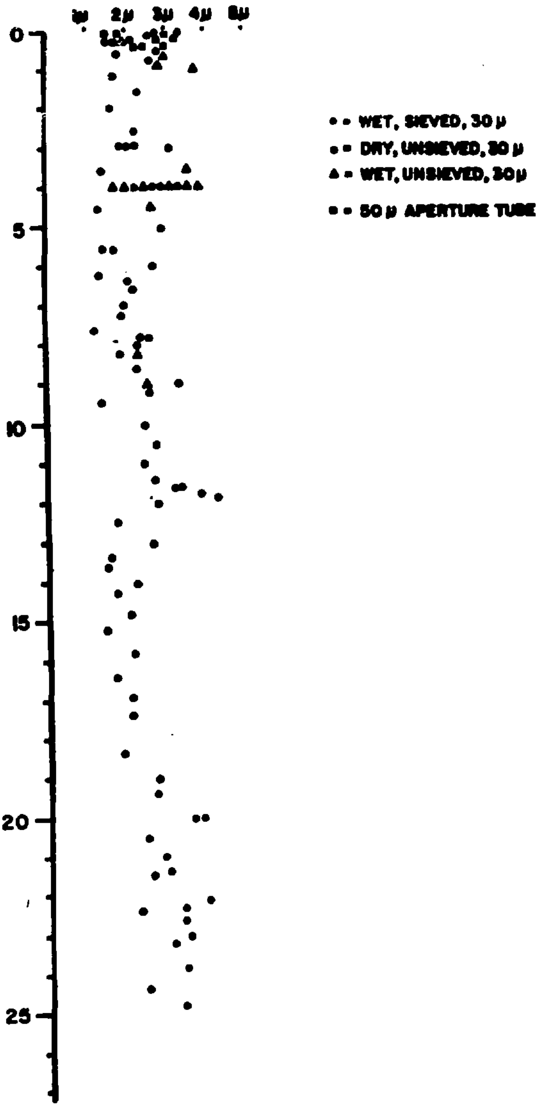


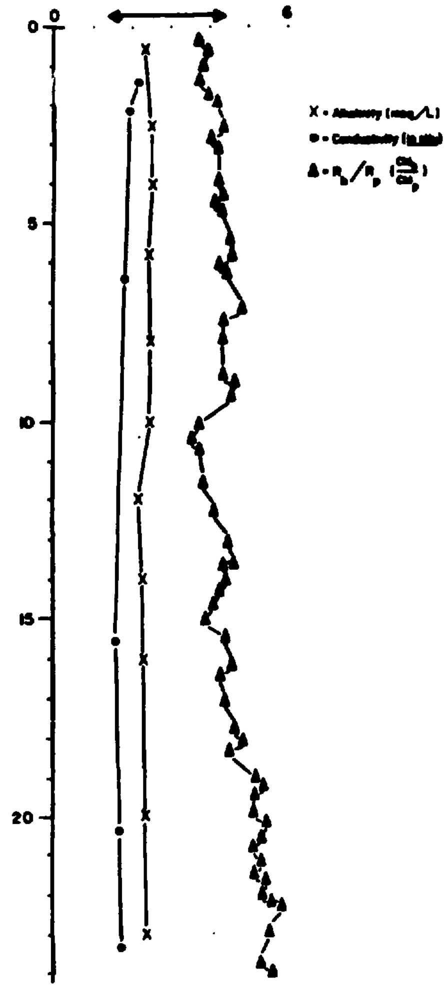


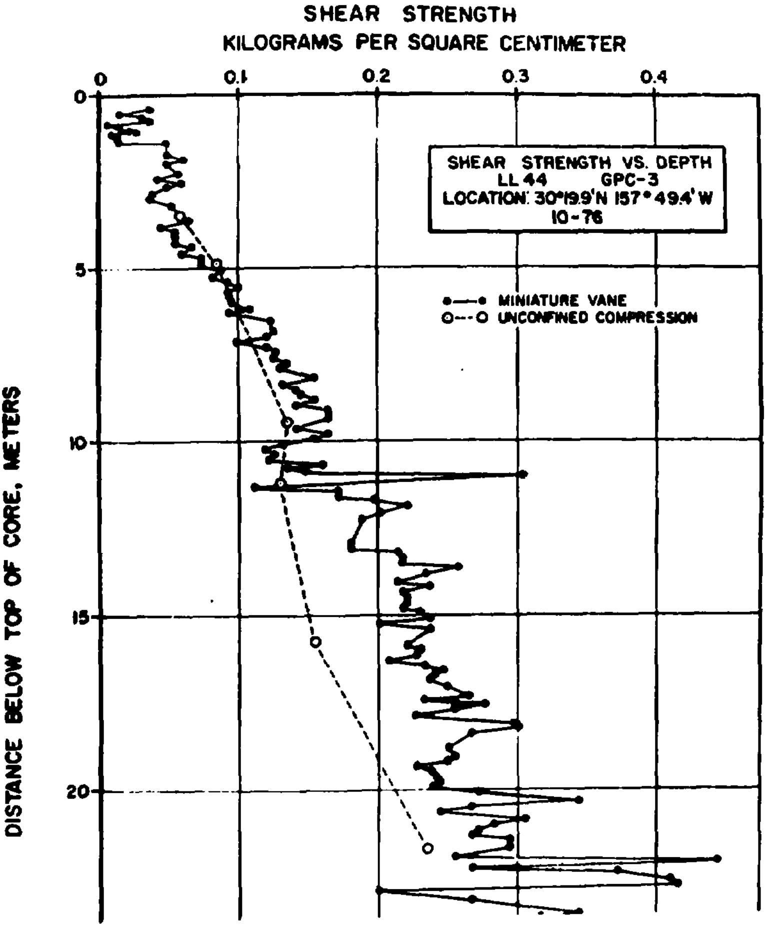

AGE (MY)
0
10
20
30
40
50
60
70
0
10
20
DEPTH (meters)
1.34 M/MY
0.22 M/MY
0.29 M/MY
0.67 M/MY
0.23 M/MY


% WATER CONTENT
100
200
300
WEIGHT OF WATER
0
5
10
15
20

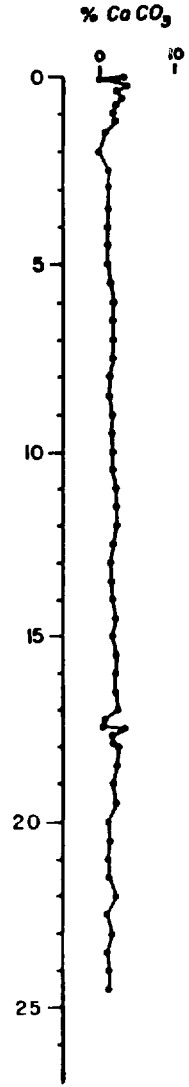
MEAN GRAIN SIZE (microns)

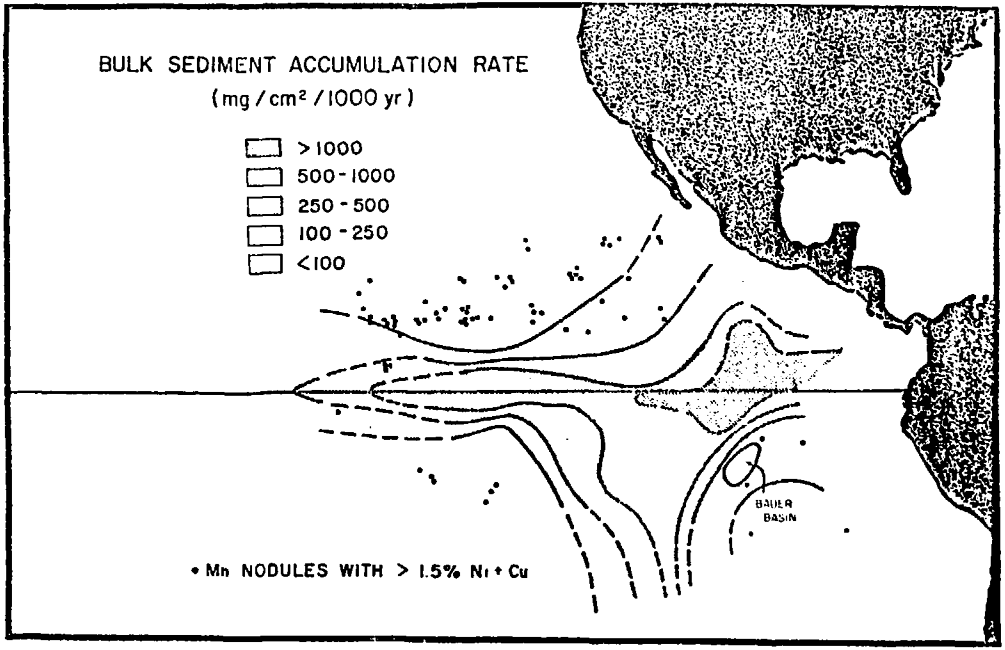



0
6
0
5
10
15
20



SHEAR STRENGTH
KILOGRAMS PER SQUARE CENTIMETER
0
0.1
0.2
0.3
0.4
0
5
10
15
20
DISTANCE BELOW TOP OF CORE, METERS
SHEAR STRENGTH VS. DEPTH
LL 44 GPC-3
LOCATION: 30°19.9'N 157°49.4'W
10-76
MINIATURE VANE
UNCONFINED COMPRESSION


% CaCO3
0
10
0
5
10
15
20
25


BULK SEDIMENT ACCUMULATION RATE
(mg / cm² / 1000 yr)
>1000
500 - 1000
250 - 500
100 - 250
<100
BAUER BASIN
• Mn NODULES WITH > 1.5% Ni + Cu

U S CORROSION PROGRAM

Objective: Find the most cost-effective material for constructing canisters. Main selection criterion will be corrosion resistance. The canister wall must remain intact for a yet to be determined time period in its seabed disposal site.

Note:

- No research is being conducted at present which addresses the canister design problem (i.e. pressure compensators, canister closure, fabrication and filling, handling, etc.)

- Waste form-canister compatibility is being studied at the Battelle Northwest and Savannah River Laboratories.

COMPLETED TO DATE

Laboratory

Autoclave laboratory in which various burial environments can be simulated has been constructed. This laboratory contains:

4 batch or static autoclaves
2 stirred autoclaves with electrochemical measurement capabilities

Experimental

- Nine month tests at 4, 25, and 90°C and 8000 psi using nickel, titanium, and zirconium based alloys

- Rotating disc electrochemical measurements on the above alloys at 25°C

PRELIMINARY RESULTS

A. Nine month autoclave tests

1. Materials chosen which should have long lifetimes
2. None are susceptible to stress corrosion cracking .
3. Typical corrosion rates at 8000 psi (55MN/m^2)

Material	Corrosion Rate (mm/yr x 10^5)		
	4^0C	25^0C	90^0C
C. P. Titanium	Nil	1.3	8
Ti-6-4	6	Nil	13
Zr-2	3.3	3.4	8
Zr-4	3.2	4.4	9
Hastelloy C 276	Nil	Nil	8
Udimet-700	Nil	4.3	8

B. Electrochemical tests

1. No susceptibility to pitting or differential aeration corrosion.

C. From these results, more inexpensive materials and coatings under more severe corrosive conditions can be considered.

IN PROGRESS (1978)

- At present, five materials are being studied: 1018 carbon steel, 304L stainless steel, Carpenter 20Cb3 stainless steel, Inconel 600, and the titanium alloy Ticode 12. This list will be expanded as more results are obtained.

- Static, batch experiments in deaerated seawater and sea-sediments

    1) Indefinite period (>1 year)

        25, 90, and 250°C

    2) Short term (~2-3 months)

        250°C

- Electrochemical autoclave experiments in seawater

    Used to determine the effects of the following on corrosion rate and susceptibility to pitting or differential aeration corrosion

    a) temperature

    b) oxygen activity

    c) hydrostatic pressure

    d) static or flow conditions

FUTURE PLANS

- Placement of selected coupons in seabed environment for long term in-situ experiments

- Based on the results obtained in 1978, materials will be selected to study the effects on corrosion of the following:

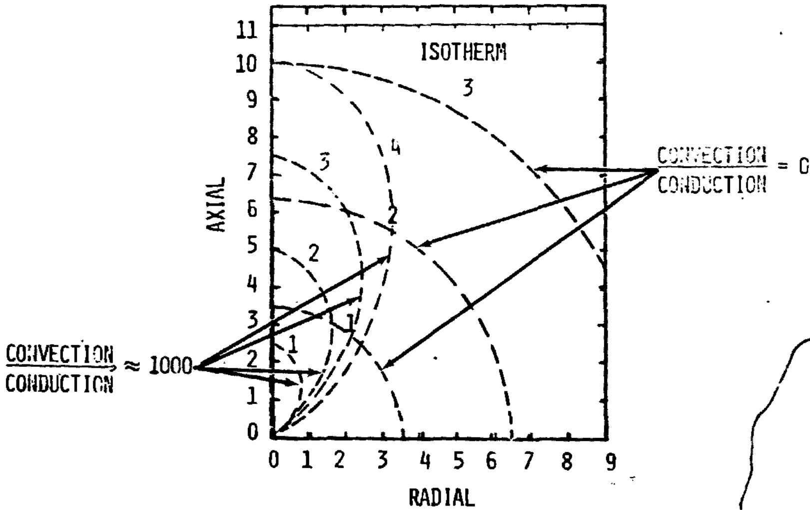
  1) Welding and sensitization
  2) Stress Corrosion Cracking
  3) Radiation (physical and radiolysis products)
  4) Surface treatments (surface oxidation, ion implantation, etc.)

SITE SELECTION

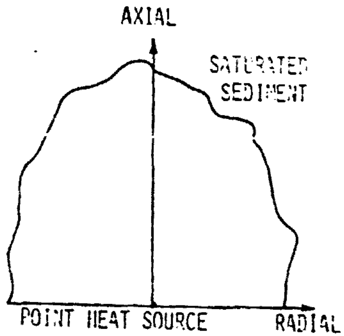
- EXCLUSION CRITERIA
  - x STABILITY
  - x PREDICTABILITY
  - x USE
- RANKING CRITERIA
  - x KIND OF SEDIMENT
  - x WATER MOVEMENT
  - x THICKNESS OF SEDIMENT
  - x BOTTOM TOPOGRAPHY
  - x ETC.
- RESULTS TO DATE

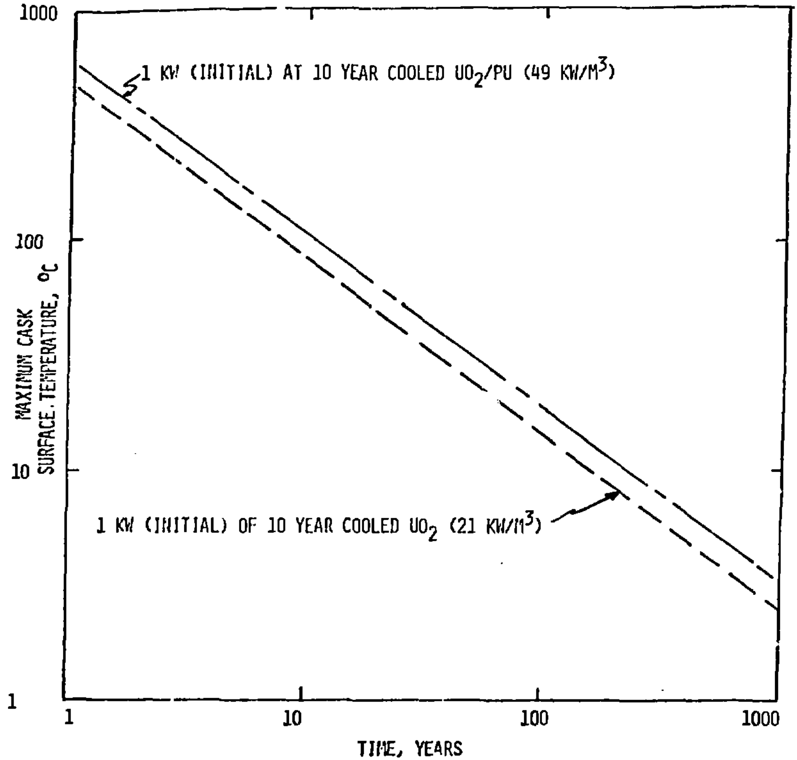
RESPONSE OF SEDIMENTS TO THERMAL SOURCE

- o DEVELOP AND VALIDATE PREDICTIVE THERMAL MODELS
- o ASSESS SEDIMENT MOVEMENT
  - x SURFACE EROSION
  - x BULK MOVEMENT
- o ASSESS CANNISTER MOVEMENT
- o ASSESS CANNISTER MOVEMENT
- o INDUCED PORE WATER MOVEMENT
- o HYDROTHERMAL AND RADIALYSIS (H&R) STUDIES
  - x CHARACTERIZATION OF THE (H&R) ENVIRONMENT
  - x EFFECTS ON THE SEDIMENTS
- o ISHTE
  - x VALIDATION OF THERMAL PREDICTIVE CAPABILITIES
  - x VALIDATION OF PREDICTED PORE WATER MOVEMENT
  - x VALIDATION OF PREDICTED ION MIGRATION
  - x VALIDATION OF THERMAL PROPERTIES

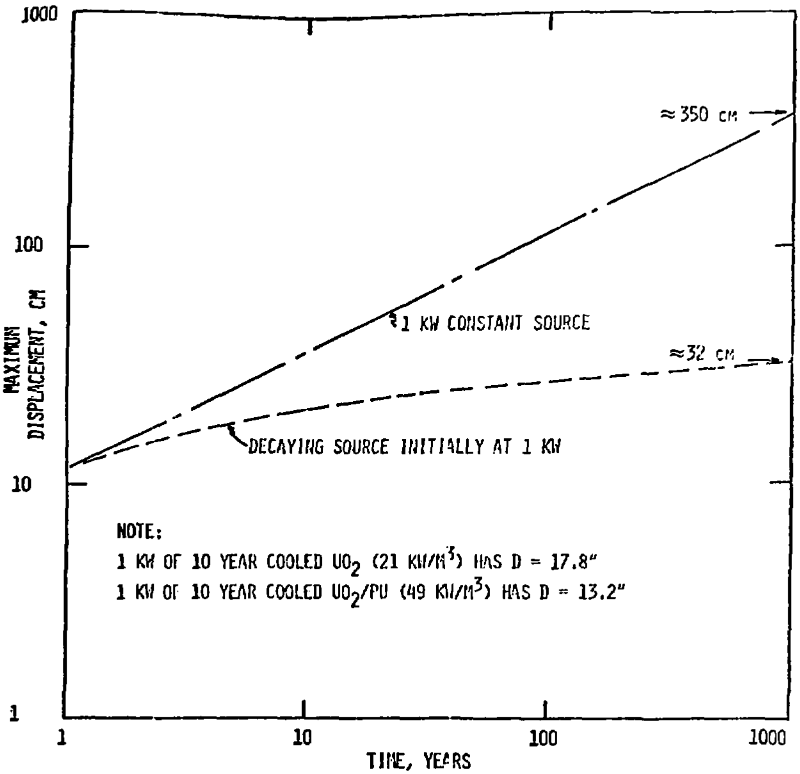


NOTE: FOR FINE GRAIN CLAY, $\frac{\text{CONVECTION}}{\text{CONDUCTION}} \approx .001$

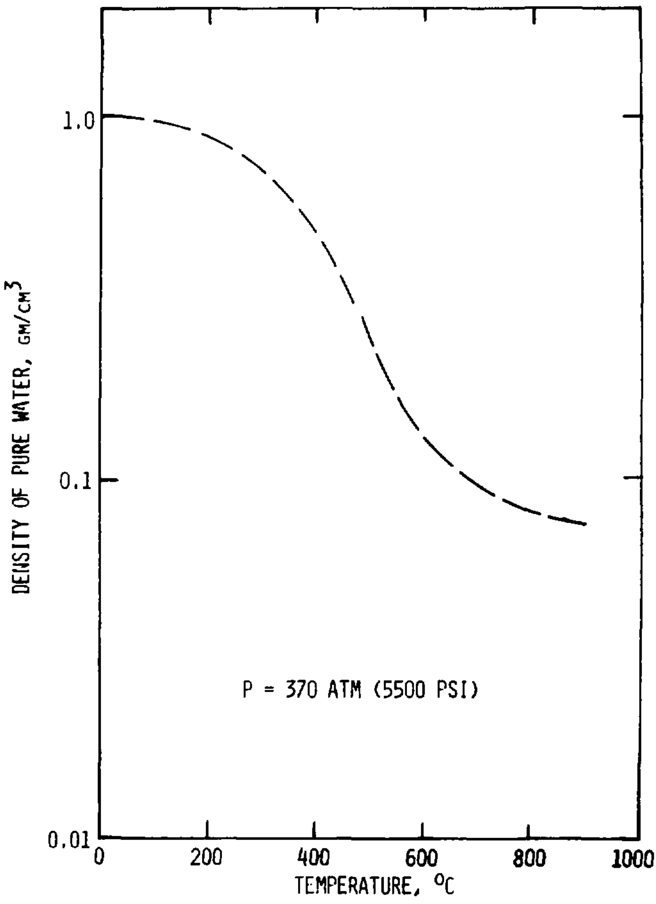




MAXIMUM SURFACE TEMPERATURE OF A SPHERICAL CASK CONTAINING 1.0 KW (INITIAL) OF HIGH LEVEL WASTES



MAXIMUM VERTICAL DISPLACEMENT OF A WATER MOLECULE WITH INITIAL POSITION DIRECTLY ABOVE THE CASK.



DENSITY OF PURE WATER AS A FUNCTION
OF TEMPERATURE AT HIGH PRESSURE

HIGHLIGHTS OF PLANNED THERMAL STUDIES

- A GENERAL PURPOSE COMPUTER CODE IS BEING DEVELOPED TO EVALUATE HEAT TRANSFER AND FLUID FLOW IN THE DEEPSEA SEDIMENTS. THIS CODE WILL BE CAPABLE OF INTERFACING WITH THE MECHANICAL AND CHEMICAL COMPUTER CODES.

- A COMPREHENSIVE EXPERIMENTAL EFFORT IS BEING CARRIED OUT WHICH WILL DETECT AND QUANTIFY POTENTIAL BREACH MECHANISMS FOR THE SEDIMENT BARRIER. THIS EFFORT INCLUDES ESTABLISHING A DATA BASE OF THERMO-PHYSICAL PROPERTIES FOR THE SEDIMENTS AT HIGH PRESSURE AND TEMPERATURE.

- AN IN SITU HEAT TRANSFER EXPERIMENT TO BE FIELDED IN AN ACTUAL GENERIC DISPOSAL SITE IS PRESENTLY IN THE PLANNING STAGE. THIS IS A LOGICAL FOLLOW-ON TO THE MODELING AND LAB SCALE EXPERIMENTS.

RADIONUCLIDE MOVEMENT THROUGH SEDIMENTS

- o DEVELOP TRANSPORT MODELS
- o ACQUIRE PROPERTIES
  - x NATURAL
    - PORE WATER FLOW
    - RANK SEDIMENT VIA SORPTION COEFFICIENT
    - SORPTION COEFFICIENT VS SEDIMENT DEPTH (RED CLAY)
    - COMPETETIVE ION STUDIES
    - COLUMN STUDIES
    - GLOBAL STUDIES
  - x INDUCED
    - CHANGES IN MATERIAL PROPERTIES WITH HEAT
    - CHANGES IN MATERIAL PROPERTIES WITH RADIATION
    - HYDROTHERMAL AND RADIATION STUDIES
    - PORE WATER MOVEMENT

NUCLIDE MIGRATION STUDIES

1. Objectives

   a. Determine the important sorption and nonconvective migration mechanisms in order to develop and evaluate mathematical models.

   b. Define and obtain appropriate matrices of data so that the critical parameters in those models (such as sorption distribution coefficients) for all relevant nuclides can be evaluated as functions of temperature, pressure, and composition.

2. Current Projects

   a. Acquisition of a matrix of equilibrium sorption distribution coefficients (using batch equilibration techniques) at ambient pressure and 4°C.

      (1) Results from preliminary experiments using 0.68 N NaCl solutions containing single species from the alkali, alkaline earth, or lanthanide elements are encouraging.

      (2) Refined experiments are being started which will use artificial seawater solutions and will also examine actinide elements and competitive ion effects.

   b. Analysis of experimentally determined, one dimensional migration rates in order to determine if any mechanisms (such as surface diffusion along the particle surfaces) tend to produce higher rates than those calculated assuming only molecular diffusion through the interstitial solution.

NUCLIDE MIGRATION STUDIES (cont.)

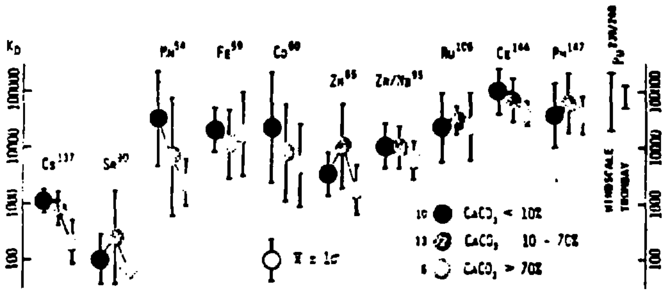
3. Future Projects

   a. Obtain sorption distribution coefficients at elevated temperatures and pressures.

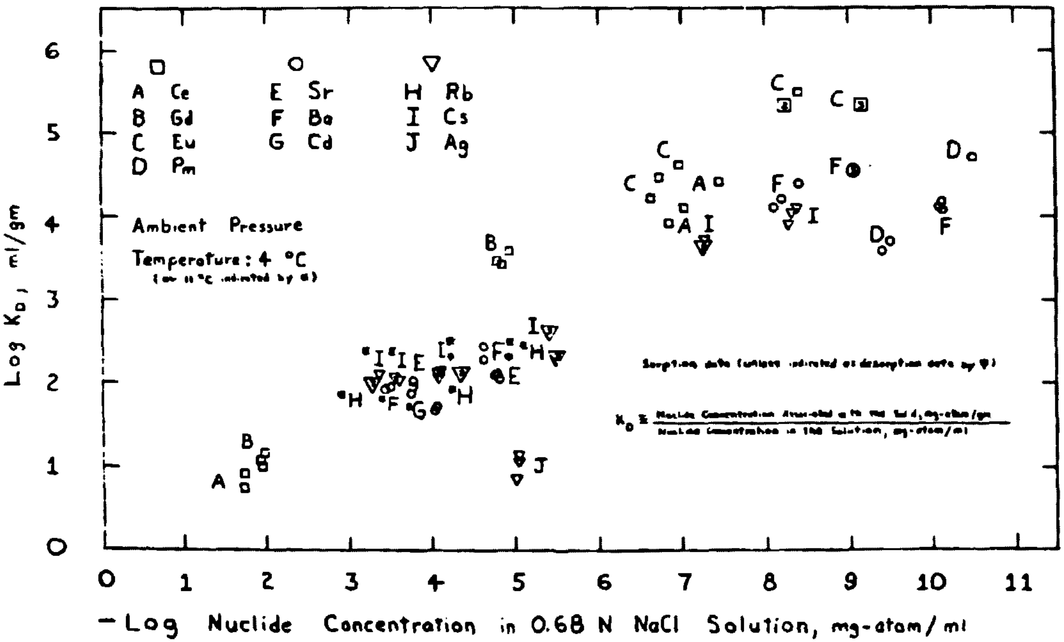
   b. Investigate sorption mechanism in detail.

   c. Evaluate other parameters such as ionic diffusion coefficients.

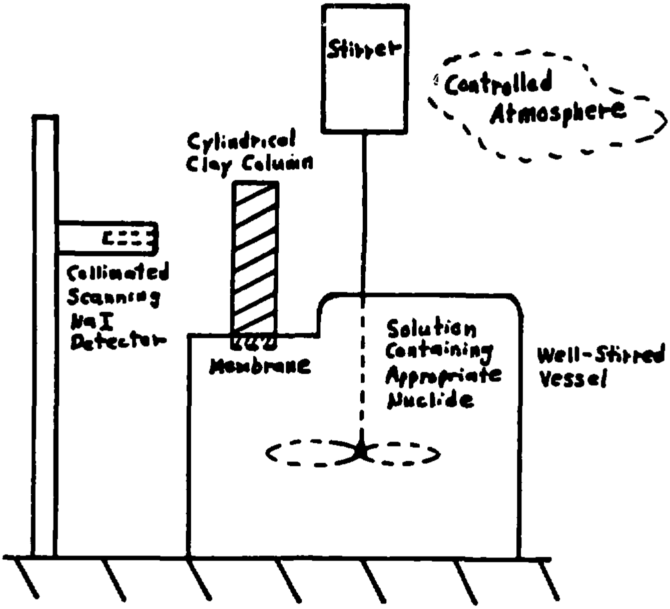
   d. Refine and extend data matrices and migration rate data.



Range of K_D values measured by Duursma and associates for fallout nuclides on 29 samples of deep-sea sediment in contact with seawater. Lithologic variations (illustrated by carbonate variations) have surprisingly little effect on K_D values.


A Ce
B Gd
C Eu
D Pm
E Sr
F Ba
G Cd
H Rb
I Cs
J Ag
Ambient Pressure
Temperature: 4 °C
Log K_D, ml/gm
0 1 2 3 4 5 6 7 8 9 10 11
0 1 2 3 4 5 6
− Log Nuclide Concentration in 0.68 N NaCl Solution, mg-atom/ml

"Column-Type" Diffusion Experiment



PHYSICAL RESPONSE OF SEDIMENTS - PHYSICAL INTRUSION

- o HOLE CLOSURE
  - x DEVELOP RESPONSE MODELS--STATIC, DYNAMIC
  - x ACQUIRE MATERIAL PROPERTIES
  - x LAB AND FIELD VALIDATION
  - x THERMAL INFLUENCE
- o CANNISTER MOVEMENT
- o BIO INTERACTIONS

SEABED WASTE DISPOSAL PROJECT

MECHANICAL ANALYSIS

Specific Problem Areas:

1. Penetration hole closure for any of the proposed emplacement schemes. Possible emplacement methods include free falling penetrometers, quasi-static canister penetration and drilling.

2. Thermally induced canister movement in which creep deformations of the sediment are a result of buoyant forces created as the sediment in the vicinity of the canister heats and expands.

SEABED WASTE DISPOSAL PROJECT

MECHANICAL ANALYSIS

Analytical and Numerical Modeling:

1. Dynamic elastoplastic analysis of the penetration process that includes cavity opening (in which the sediments are deformed past the yield point into the plastic regime) followed by unloading and rebound after the projectile has passed.

2. Coupled creep and heat transfer analysis capable of computing buoyant forces resulting from thermal expansion and incorporating rate dependent sediment creep behavior.

3. Two constituent models that incorporate the interaction of deformations of the sediment skeleton and porous flow of the pore water.

SEABED WASTE DISPOSAL PROJECT

MECHANICAL ANALYSIS

Material Behavior Modeling:

Characterize the sediment response to various loading conditions anticipated. This includes:

1. Quasi-static and dynamic triaxial loadings.

2. Long term creep behavior as a function of confining pressure, stress differences, temperature, and strain rate.

SEABED WASTE DISPOSAL PROJECT

MECHANICAL ANALYSIS

Process Modeling:

1. In-situ soil property measurements.

2. In-situ cavity expansion and rebound using a cylindrical bladder with controlled expansion rates.

3. In-situ thermally induced creep movement.

ONE-DIMENSIONAL HOLE CLOSURE STUDY

Geometry

Axisymmetric region with a cylindrical cavity along the centerline that is opened uniformly to the projectile diameter and then released to determine rebound rates.

Elastoplastic Model

Parameters varied in the study:

- Density
- Elastic Modulus
- Yield Stress
- Hardening Modulus
- Overburden Stress

Results:

Only the hardening modulus affected the final hole dimension by more than 10 percent.

Soil Model

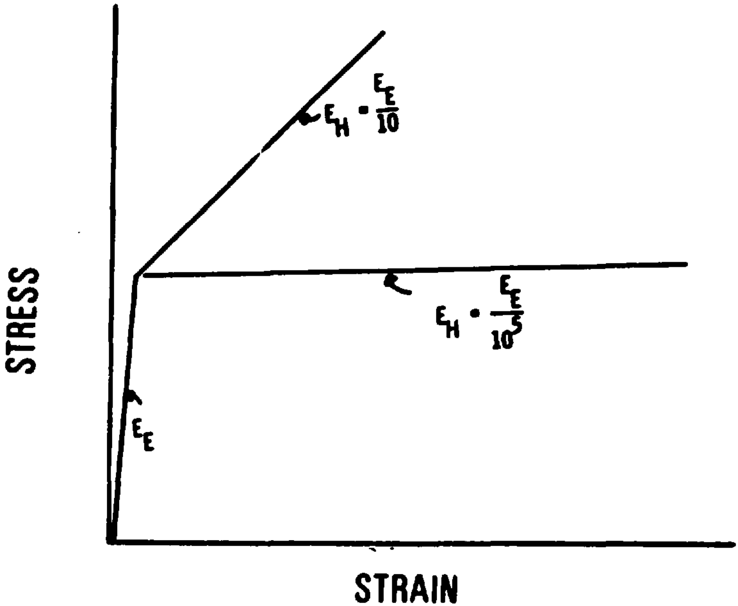
Parameters varied in the study:

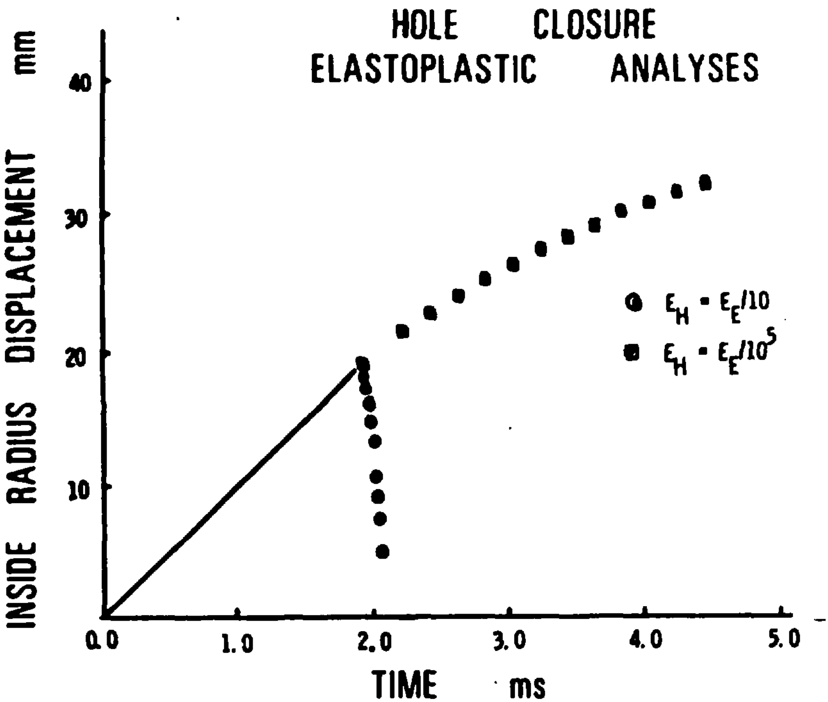
- Failure Surface (Von Mises or Mohr-Coulomb)
- Bulk Modulus

Results:

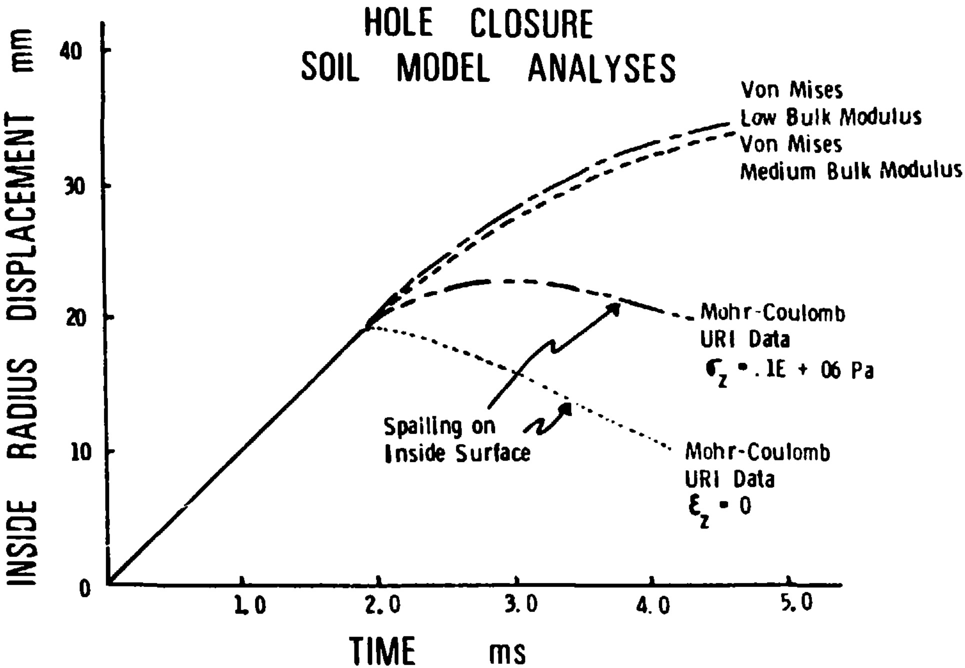
Inside radius spall occurs with Mohr-Coulomb model but not with the Von Mises model.

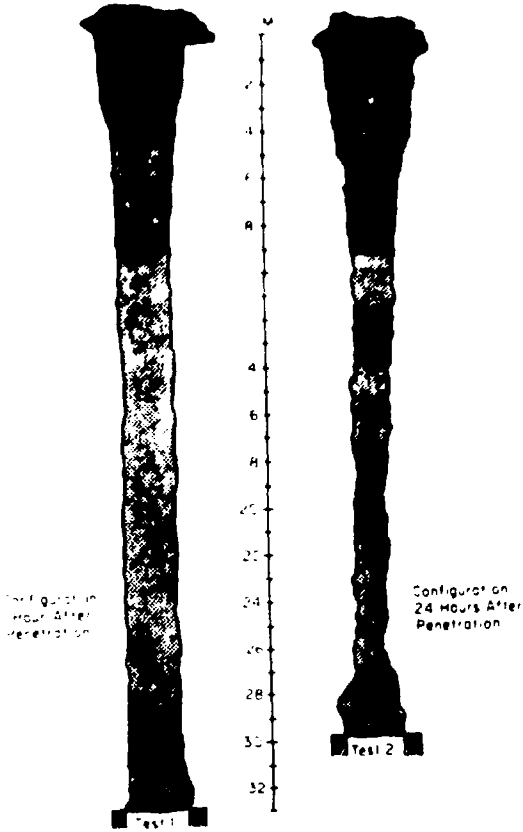
ELASTOPLASTIC MODELS



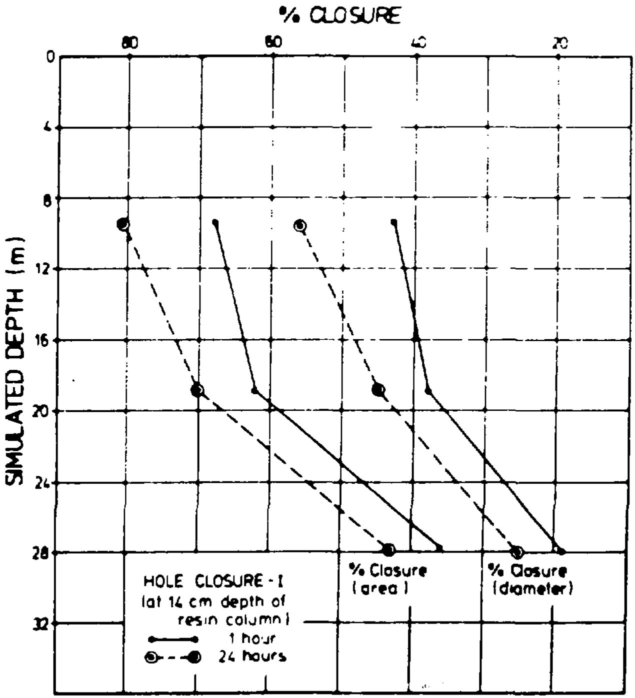


HOLE CLOSURE
ELASTOPLASTIC ANALYSES
INSIDE RADIUS DISPLACEMENT mm
40
30
20
10
0.0
1.0
2.0
3.0
4.0
5.0
TIME ms
E_H = E_E/10
E_H = E_E/10^5


HOLE CLOSURE
SOIL MODEL ANALYSES
INSIDE RADIUS DISPLACEMENT mm
TIME ms
0
10
20
30
40
1.0
2.0
3.0
4.0
5.0
Von Mises
Low Bulk Modulus
Von Mises
Medium Bulk Modulus
Mohr-Coulomb
URI Data
σ_z = .1E + 06 Pa
Spalling on
Inside Surface
Mohr-Coulomb
URI Data
ε_z = 0



Sketch of hole profiles in a homogeneous sediment after slow rate of penetration (10 centimeters per second) of a projectile. The profile on the left was taken 1 hour after test, and the one on the right 24 hours. Note the continuing closure with time that indicates gradual creep or flow of the walls due to overburden stress.



Results of static penetration test in hole closure experiment. The graph shows percent closure of the hole taken from three different tests at three different consolidation stresses (converted to simulated depth in this figure). The measurements used in this graph were taken at 14 cm. depth in the tank. Note that the rate and amount of closure decreases with stress (or depth).

BUOYANT MOTION OF SEDIMENT

Mechanism for Motion:

1. Heat from wastes raises temperature of nearby sediments.

2. Temperature rise results in expansion that reduces sediment density.

3. Lower density sediments are then buoyant relative to ambient surroundings.

4. Buoyant forces result in upward flow of sediment that could drag the canister upward.

Analysis:

1. Thermomechanical model for creep and heat transfer.

2. Coupling between the temperature distribution and velocity field in terms of temperature dependent body forces, temperature dependent material properties, and changing geometry.

3. Quasi-Lagrangian formulation tracing deformations and temperature rises as a function of time.

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