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Proceedings of the 1981 Subseabed Disposal Program Annual Workshop

D. M. Talbert, Workshop Chairman

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PROCEEDINGS OF THE 1981 SUBSEABED DISPOSAL PROGRAM ANNUAL WORKSHOP

D. M. Talbert, Workshop Chairman
Seabed Programs Division 4516

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I. INTRODUCTION TO THE PROCEEDINGS

D. M. Talbert, Workshop Chairman

The 1981 Annual Workshop was the twelfth meeting of the principal investigators and program management personnel participating in the Subseabed Disposal Program (SDP). The first workshop was held June 1973, to address the development of a program (initially known as "Ocean Basin Floors Program") to assess the deep sea disposal of nuclear wastes. Workshops were held semi-annually until late 1977. Since November 1977, the workshops have been conducted following the end of each fiscal year so that the program participants could review and critique the total scope of work. The workshops also keep the program participants as fully informed as possible of the total scope of program activities so that each individual can provide critical comment and advice from an informed, integrated picture of the SDP.

The following pages contain a snapshop view of the fiscal year 1981 (October 1980 - September 1981) program activities of the SDP as they were presented at the 1981 Annual Workshop. This volume contains a synopsis, as given by each Technical Program Coordinator, abstracts of each of the talks, and copies of the visual materials, as presented by each of the principal investigators, for each of the technical elements of the SDP.

This document is meant to make available, on a timely basis, a compilation of the data and results presented at the workshop. It is also intended to be a reference for the participants, and should not be taken as a full and complete report of the proceedings of the meeting. Detailed and complete reports of the past year's work from each of the team members will appear in the Subseabed Disposal Program Annual Report for fiscal year 1981, to be published at a later date.

II. GENERAL TOPICS

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UNITED STATES PROGRAMS ON GEOLOGIC DISPOSAL

D. Glenn Boyer
Office of Waste Isolation
Nuclear Waste Management and Fuel Cycle Programs
Office of Nuclear Energy

During 1981, the United States National Waste Terminal Storage (NWTS) Program has been more sharply focused on near term objectives. The Administration has expressed a strong commitment that nuclear energy will provide a significant share of the Nation's energy requirements. Associated with this commitment is a commitment to provide the capability to dispose of nuclear waste. Several policy positions have set the stage for our near-term focus. They include:

1. The Federal Government will no longer support development work on centralized Away-From-Reactor storage of spent fuel from reactors. Instead, private industry will be encouraged to develop the storage capacity it needs. The Federal Government will sponsor some research and development to assist utilities in the selection of alternative storage concepts.

2. Reprocessing is key to the formulation of the high-level waste program. Solidified wastes from reprocessing will be used as the reference for disposal. However, the disposal of spent fuel will be maintained as an option, should utilities choose to dispose of spent fuel rather than reprocessing.

3. Obtaining the capability to dispose of nuclear waste in a mined repository in stable geologic formations is a high priority effort in the Department of Energy (DOE), which should be completed as soon as possible.

In line with these positions, the NWTS Program has been restructured towards achieving a more aggressive and timely resolution of the issues of nuclear waste disposal. To this end, the major thrust of the restructured program (see Figure 1) includes the following:

	Action	Schedule
o	Reduce the number of bedded salt and dome salt sites into only one candidate site.	1982
o	Construct an exploratory shaft at a basalt, a tuff, and a salt site.	1982-1985
o	Conduct at-depth exploration at a basalt, a tuff, and a salt site (horizontal drilling, etc.).	1985-1988
o	Construct an at-depth Test and Evaluation Facility at the base on one of the exploratory shafts.	1985-1988
o	Recommend a repository site and apply to the Nuclear Regulatory Commission for a license.	1988
o	Emplace radioactive waste in the Test and Evaluation Facility.	1989

The principal decisions in the program are now identified as follows:

	Decision	Basis for Decision
1.	Select a site for the proposed Test and Evaluation Facility.	Site characteristics and experience from sinking the shafts in each rock type.
2.	Determine the suitability of basalt, tuff, and salt sites.	Site characterization data from in-situ testing and from horizontal drilling of each rock type.
3.	Select the first repository site from three candidate sites.	Site characterization reports and environmental reports on each site.
4.	Complete the design of the repository.	At depth in-situ testing and results from Test and Evaluation Facility.
5.	Apply for a license.	Preliminary Safety Analysis Report (PSAR).
6.	Start construction.	Nuclear Regulatory Commission review of PSAR and supplemental information.

The sinking of exploratory shafts at three sites in two different geologic media is now required by the Nuclear Regulatory Commission (NRC) as the minimum basis for making a selection of a site for the first repository.

At-depth testing will occur at the bottom of each of three exploratory shafts in order to characterize the host rocks and the hydrology prior to selecting any one site for a repository. Once a site is selected for a repository in 1987, the principal at-depth testing will continue at the selected site to obtain information for the final design of the repository.

Site exploration will continue during the period of 1981-1990 in order to develop the concept of regional repositories and to eliminate our dependence on a single repository in the next century. General study and exploration work in granite will continue.

The purpose of the proposed Test and Evaluation Facility (TEF) is to provide an early evaluation of the waste-handling equipment and operating procedures. It will be started without a decision that the TEF site is the site of the first repository. The TEF will be used to evaluate the handling of several hundred containers of radioactive waste. The specific equipment and procedures to be evaluated will be determined in 1982. The TEF will not be licensed. It will provide the opportunity for both NRC and DOE to study and evaluate proposed concepts during the time a license is pending before construction of the first repository.

Regulatory Activities

The Environmental Protection Agency (EPA) has the authority and responsibility for setting applicable standards for radiation in the environment. Although no EPA standards for disposal of high-level waste yet exist, EPA has suggested standards for regulating geologic disposal of high-level waste. The standards include specification of the allowable release of significant radionuclides.

It is the responsibility of the NRC to implement the EPA standards through NRC licensing actions and to assure that the public health and safety are protected.

On July 8, 1981, NRC published proposed rules (10 CFR Part 60) for the disposal of high-level radioactive waste in geologic repositories. Briefly, the intent of the rules can be stated as follows:

- A waste package should be designed to provide containment for at least 1000 years after decommissioning of the repository.

- Starting 1000 years after decommissioning, the annual release rate from the repository should be less than one part in one hundred thousand of the significant radionuclides present in the repository.

- The repository should be designed so that the option remains open to retrieve the wastes for up to 50 years after termination of waste emplacement. Retrieval, if conducted, should take no longer than the time required to load the repository.

The Department is submitting comments to NRC recommending that a more detailed technical basis for such performance objectives be established before the regulations are formally issued.

Organization

Waste management activities for defense operations have now been moved to the DOE Defense Waste & By-Products Management Office of Defense Programs rather than the Office of Nuclear Waste Management and Fuel Cycle Programs in order to centralize the defense waste management work. The work related to commercial operations remains with the Office of Nuclear Waste Management and Fuel Cycle Programs. The commercial fuel cycle work has been attached to the waste management office to permit closer integration of reprocessing, waste treatment and waste disposal. The NWTS program is directed by the Office of Waste Isolation and the director is Dr. Colin A. Heath.

Our organization within the NWTS program (see Figure 2) remains centered around the three projects to assess different host rocks and sites: basalt by Rockwell Hanford Company, Richland, Washington; tuff by the Nevada DOE Operations Office with the principal coordinating work assigned to Sandia National Laboratories; and salt by the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio. The Office of Nuclear Waste Isolation (ONWI) is the organization assigned to work with our States in finding a suitable site which is currently not owned by the Department of Energy. The feasibility of subseabed disposal in clay formations is also being assessed by Sandia National Laboratories as a supplement to mined repositories. We have assigned an Office of NWTS Integration (ONI), Battelle Memorial Institute, to coordinate and integrate the NWTS project activities (Figure 2). ONI technically reports to DOE Headquarters and assists in the direction and management of the NWTS projects.

Waste Isolation Pilot Plant

In addition to the NWTS Program which is oriented towards commercial wastes, construction of the Waste Isolation Pilot Plant (WIPP) has started as a research and development facility for demonstrating disposal of wastes from defense programs.

Construction of the first exploratory shaft, 3.65 meters (12 feet) in diameter, was started on July 4, 1981, and will be completed to a depth of 670 meters (2200 feet) in October 1981. A second shaft, 1.8 meters (6 feet) in diameter, will then be started. The WIPP will not be licensed since it is a defense R&D facility. An at-depth test area is included in the WIPP facility. Work is proceeding to define the type of tests which should be conducted. The shaft and rooms associated with the exploratory phase are scheduled to be completed by the end of 1983.

Status of the DOE Program

We believe the program is making good progress as evidenced by the following:

The technical thrust of the Department's program involves emphasis on the site, the repository, the waste package, and performance assessment. Recent technical accomplishments can be summarized briefly as follows:

Siting

1. We have drilled in all of the candidate rock formations and at potential sites for the first three exploratory shafts.

2. Drilling in tuff is now being concentrated on a single site at the Nevada Test Site.

3. Site exploration in basalt is now focused on a 180 km (70 mi) area on the Hanford Reservation in Washington.

4. Work on bedded salt is focusing on two specific areas in Utah.

5. Salt domes in Texas, Louisiana, and Mississippi have been explored sufficiently that four salt domes have been recommended for further study.

6. The eastern and northeastern states were notified of our desire to explore crystalline rocks, and work with those states is beginning.

Repository

1. Conceptual designs for a repository in bedded and dome salt have been completed. The conceptual design for a repository in basalt is about 50 percent complete and conceptual design work for a repository in tuff is beginning.

Waste Package

1. Several conceptual designs have been prepared as a basis for choosing the design. Two principal concepts of multibarrier design have been proposed.

2. Miniature canisters are being tested in autoclaves to evaluate materials performance.

3. Backfill materials are being tested to determine their suitability.

Testing

1. Field tests indicate measured temperatures in rock are satisfactory and are consistent with calculated predicted temperature distribution and heat conduction in salt, granite, and basalt.

2. At the Near Surface Test Facility, tests in basalt are continuing to measure the effects of heat and temperature using seven full-scale electric heaters.

3. Tests of granite in the Climax mine at Nevada are continuing, using eleven canisters of commercial light water reactor spent fuel and additional electric heaters.

4. Radionuclide-migration experiments are planned in the field and will begin this year at the Nevada Test Site.

5. Brine-migration tests in salt are planned at the Asse salt mine in cooperation with the Federal Republic of Germany.

6. Mass-buffer tests, ion-migration tests, and hydrogeologic measurements continue in granite under the International Stripa Project Agreement.

Performance Assessment

1. Models are developed for calculation of the hydrology of a site, the migration of radionuclides from a site, and the prediction of impacts to the population and the environment.

2. Near-field models to describe the release of radionuclides from waste packages within the repository are about 50 percent developed.

3. Rock-mechanics models are developed to describe the stability of the host rock in a repository.

4. Laboratory data have shown the importance of Eh and pH on the solubility of radionuclides and the corresponding possible migration of radionuclides from the site.

Specific Emphasis

Several parts of the NWTS Program will be receiving attention over the next year, as follows:

1. Siting work will concentrate on deciding which salt domes and which bedded salt sites are suitable for location of the exploratory shaft.

2. Repository work will focus on the development plans to complete the conceptual design and overall criteria and specifications for a repository.

3. Waste-package work will focus on conceptual designs, costs, materials of construction, and the development of specifications and testing of waste-package components. Requirements for hot-cell testing will be developed.

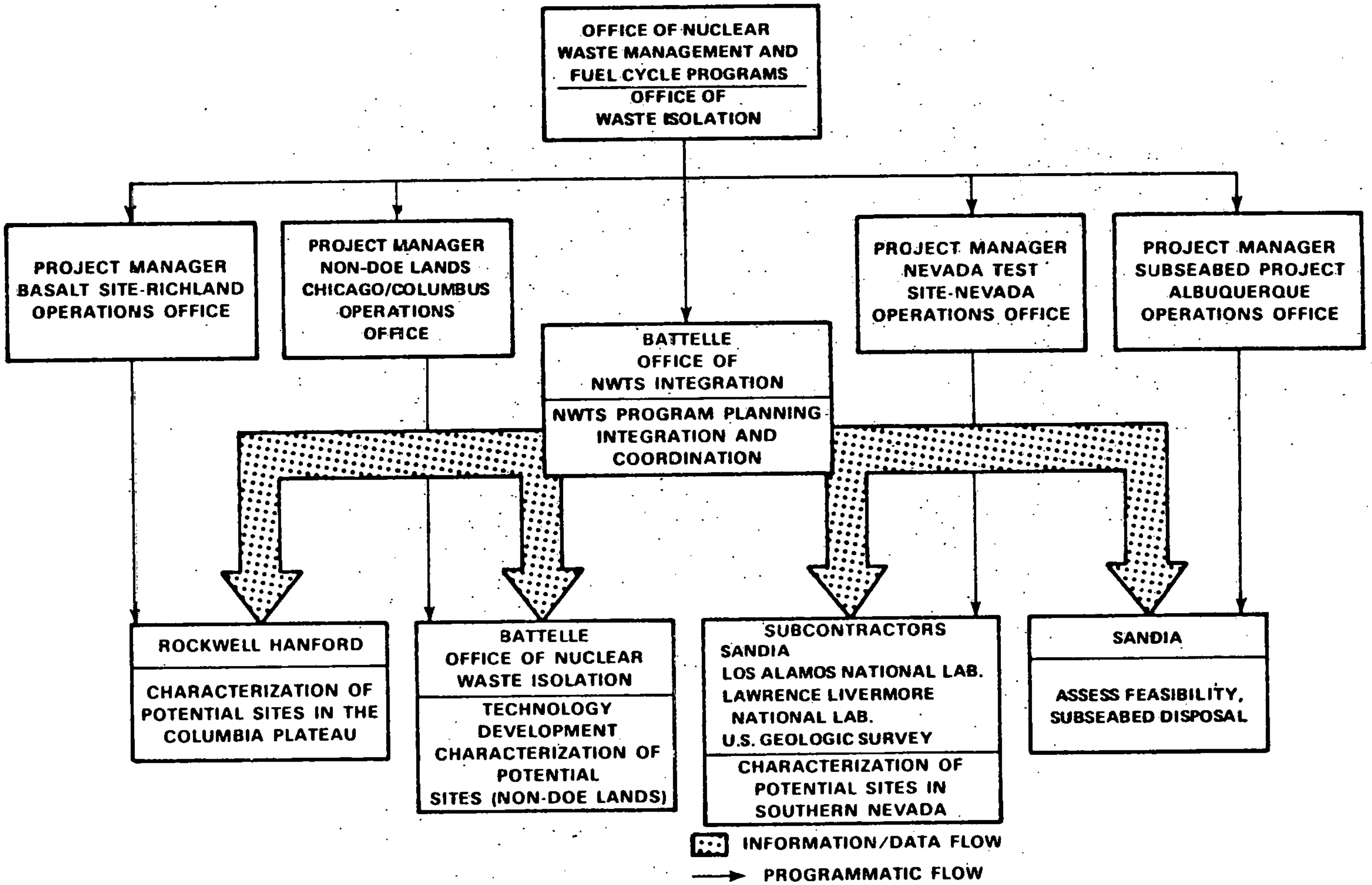
4. Performance-assessment work will focus on the evaluation of sites and the modeling of near-field phenomena in the repository.

5. Testing work will emphasize materials evaluation and the continuation of tests in Climax granite, Near Surface Test Facility in basalt, and cooperative work on granite with the NEA Stripa Project and on salt in the Asse mine tests.

6. Plans will be developed for the sinking of exploratory shafts at three sites to determine if the sites are suitable for use as a repository. Tests on repository horizon characteristics will be performed.

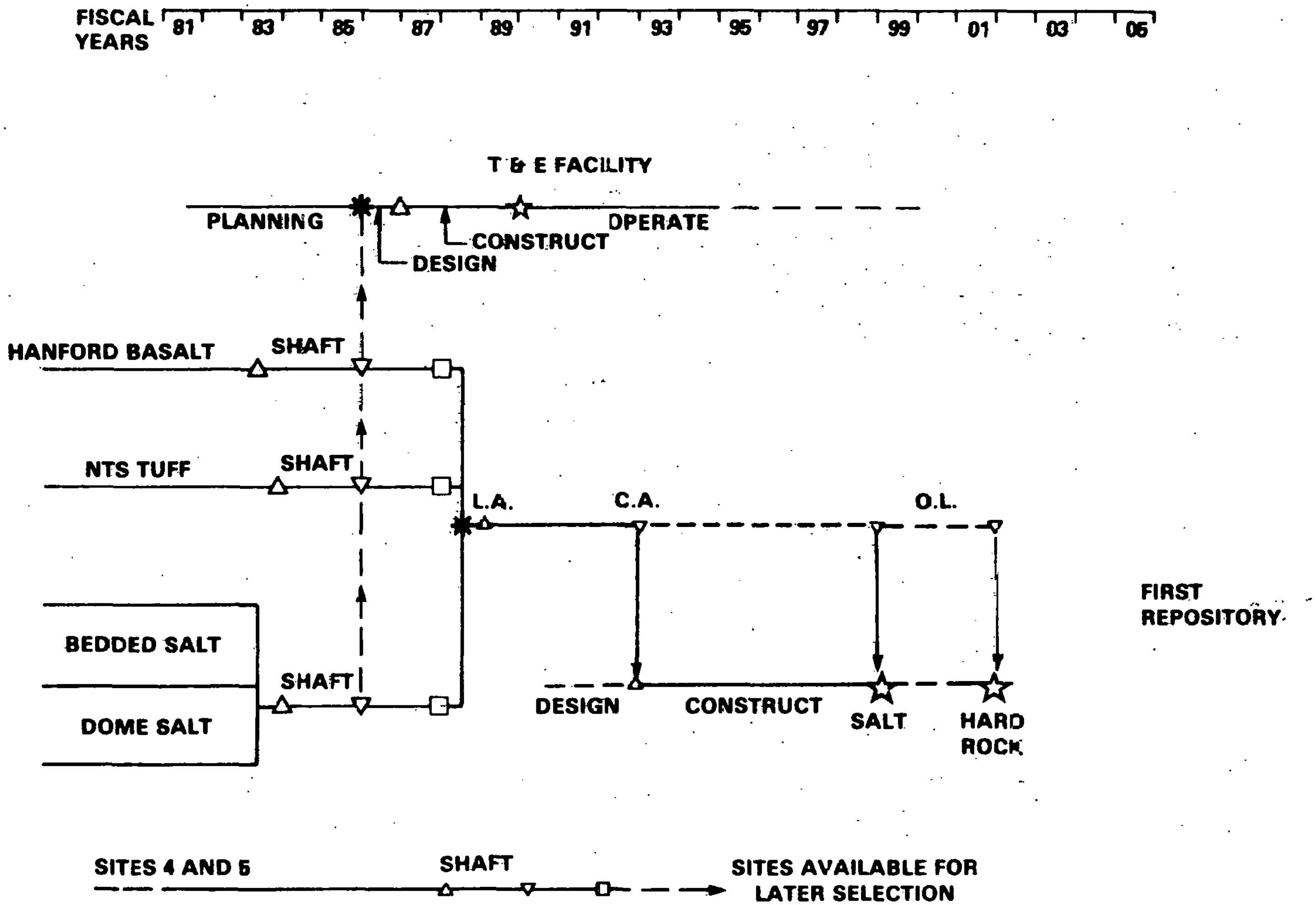
7. Plans will be developed for a proposed Test and Evaluation Facility to be constructed at one of the three sites. The decision on where to locate the proposed Test and Evaluation Facility will be made in 1985.

In summary, the near-term objective of the NWTS Program has been focused to develop the capability to complete the assessment of at least three rock types as a basis for recommending one site for the first repository in 1988.



NWTS PROGRAM MANAGEMENT STRUCTURE

WASTE ISOLATION PROGRAM



△ START
▽ COMPLETE
☆ STARTUP
□ REPOSITORY SITE SUITABILITY DETERMINED
✲ SITE SELECTION

L.A. LICENSE APPLICATION
C.A. CONSTRUCTION AUTHORIZATION
O.L. OPERATING LICENSE

COMMERCIAL NUCLEAR WASTE TERMINAL ISOLATION R&D

	FY 1980	FY 1981	FY 1982 (CURRENT)
SALT AND NON-DOE OWNED LANDS (ONWI)	84.8	105.5	109.4[a]
BASALT AT HANFORD (BWIP)	42.2	37.6	32.3
NEVADA SITE, GRANITE, AND TUFFS (NNWSI)	20.6	22.6	43.0
SUBSEABED	7.7[b]	6.9	3.9[c]
	155.3	172.6	188.6

(a) INCLUDES $7.2 MILLION AS HEADQUARTERS RESERVE FOR EXPLORATORY SHAFT LONG LEAD PROCUREMENT ITEMS.

(b) PRESIDENTIAL BUDGET REQUEST INCLUDED $5.9 MILLION, WITH $1.8 MILLION ADDED DURING THE FISCAL YEAR

(c) SUBSEABED OPERATING AND EQUIPMENT COST (BO) IS $5.9 MILLION IN FY 1982.

SDP and ALO

R. Y. Lowrey, DOE/Albuquerque Operations Office

The Waste Management and Transportation Development Division, U.S. Department of Energy, Albuquerque Operations Office, became involved in the Subseabed Disposal Program (SDP) responsibilities on March 24, 1981 the date the U.S. Department of Energy headquarters transmitted the Program Management Agreement between the Office of the Deputy Secretary for Nuclear Waste Management and the Albuquerque Operations Office (ALO). The assignment of the SDP to ALO as the lead field office is consistent with the headquarters policy of decentralizing nuclear waste program management responsibilities to DOE field offices. Other lead assignments at ALO include the Waste Isolation Pilot Plant, Inactive Uranium Mill Tailings, Transuranic Waste Technology Development, and Nuclear Materials Transportation Program. The latter two programs are assigned to my division. At present, I do not have approval to hire a full-time SDP Manager, nor do I anticipate receiving such approval in the near future. I have appointed myself as the Acting SDP Manager for an indefinite period of time. I do feel fortunate in that the Program is well established and there exists at Sandia Laboratories an effective lead contractor organization with Rip Anderson as the Program Manager. Also, involvement at DOE headquarters has been effective due to Glenn Boyer's participation and I expect he will continue to be involved, particularly in the International areas.

I consider a key milestone in regard to DOE support of the SDP to be the DOE Record of Decision dated April 16, 1981, prepared pursuant to the Regulations of the Council on Environmental Quality, 40 CFR 1505, on the selection of a strategy for the disposal of commercially generated wastes and the supporting program of research and development. The strategy adopted is to develop mined geologic repositories of commercially generated high-level and transuranic radioactive wastes (while continuing to examine subseabed and very deep hole disposal as potential backup technologies). R&D will be accomplished to support repositories and long-term containment of wastes.

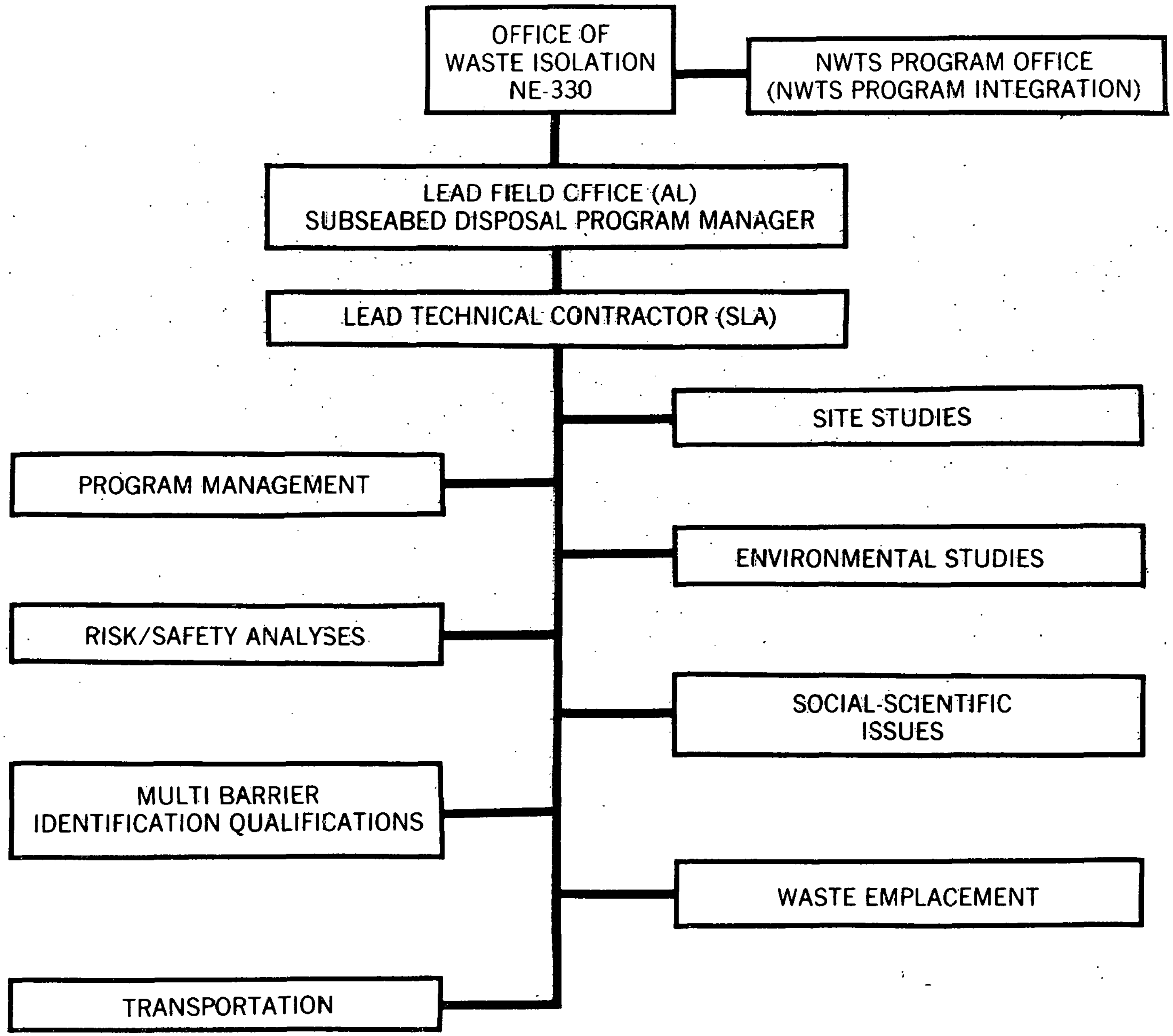
Regarding the SDP, the Record of Decision statement is: "For subseabed, the Department has decided to continue studies of the environmental, technical, legal, and institutional feasibility of isolating wastes within the sedimentary geological formations of the deep seabed. This concept is considered a longer-term supplementary disposal method to mined repositories."

Figure 1, already described by Glenn Boyer, and Figure 2 reflect the organizational relationships among ALO; the NWTS Program -- HQ, ONWI, ONI, BWIP, AND NNWSI; and the SDP with Sandia National Laboratories as the lead contractor.

The latest NWTS program guidance (FY-82 milestones) received from DOE headquarters' Office of Waste Isolation is depicted in Figure 3. The program budget has already been summarized by Glenn Boyer. The guidance and budget for FY-82 appears to be final, and I do not anticipate any changes. In addition to SDP specific guidance, there is Terminal Isolation R&D guidance applicable for the most part to BWIP, NNWSI, ONWI, AND ONI; however, a statement directed to SDP is "Subseabed activities should establish the capability to complement the geologic disposal by specialized waste disposal and by support to regional disposal concepts."

I bring your attention to the milestone requiring an outline for a Subseabed Disposal Program Status Report. This report, which DOE headquarters has requested be submitted in FY-83, is highly important. I predict the decision-makers and others will look to this particular report for the purpose of understanding (1) the definition of technical, environmental, and institutional feasibility, (2) specific work remaining in each of the program areas to allow a decision on feasibility, and (3) the remaining budget requirements to complete the feasibility phase of the SDP.

Finally, I will comment on the forthcoming dismantling of the DOE. As most of you are aware, the SDP began in 1973 under the Atomic Energy Commission (AEC). The AEC and ERDA are now predecessors of the DOE and the DOE is about to become predecessor to yet another federal agency which, I believe, will have similar responsibilities as did the AEC. Budget Director Stockman would have the new agency titled the Federal Nuclear Administration. I read recently that dismantling of the DOE can expect to take about one and one-half years including the required legislation and reorganization.


OFFICE OF
WASTE ISOLATION
NE-330
NWTS PROGRAM OFFICE
(NWTS PROGRAM INTEGRATION)
LEAD FIELD OFFICE (AL)
SUBSEABED DISPOSAL PROGRAM MANAGER
LEAD TECHNICAL CONTRACTOR (SLA)
SITE STUDIES
PROGRAM MANAGEMENT
ENVIRONMENTAL STUDIES
RISK/SAFETY ANALYSES
SOCIAL-SCIENTIFIC
ISSUES
MULTI BARRIER
IDENTIFICATION QUALIFICATIONS
WASTE EMPLACEMENT
TRANSPORTATION

Subseabed Disposal Project

Systems

o Update Subseabed Activities Input to AIDS	12/81
o Update Subseabed Activities Input to AIDS	6/82
o Complete Preliminary Emplacement Safety Assessment	9/82
o Publish Biological and Physical Oceanography Sensitivity Report	9/82

Waste Package

o Submit a List of R&D Needs for Subseabed Waste Package Development to ONWI	7/82

Site

o Complete ISHTE Simulation Test	3/82
o Participate with Europeans in North Atlantic Cruise	8/82
o *Complete ISHTE Platform for Shallow-water Test	9/82
o Complete Vema Cruise Data Work-up (N. Pacific)	9/82

Program Management

o *Draft Plan for Implementing Modified Program to Supplement/Complement Mined Geologic Disposal	3/82
o *Prepare Annotated Outline for Subseabed Disposal Program Status Report	9/82

Subseabed Disposal Program Status Report
and
Potential Supplemental Programs

D. R. Anderson, Sandia National Laboratories
SDP Program Manager

I would like to again welcome all of the to the Subseabed Disposal Program Annual Meeting. I am happy to see most all of the old faces here--hungry though we all are. I will only take a few minutes this morning to stress two points.

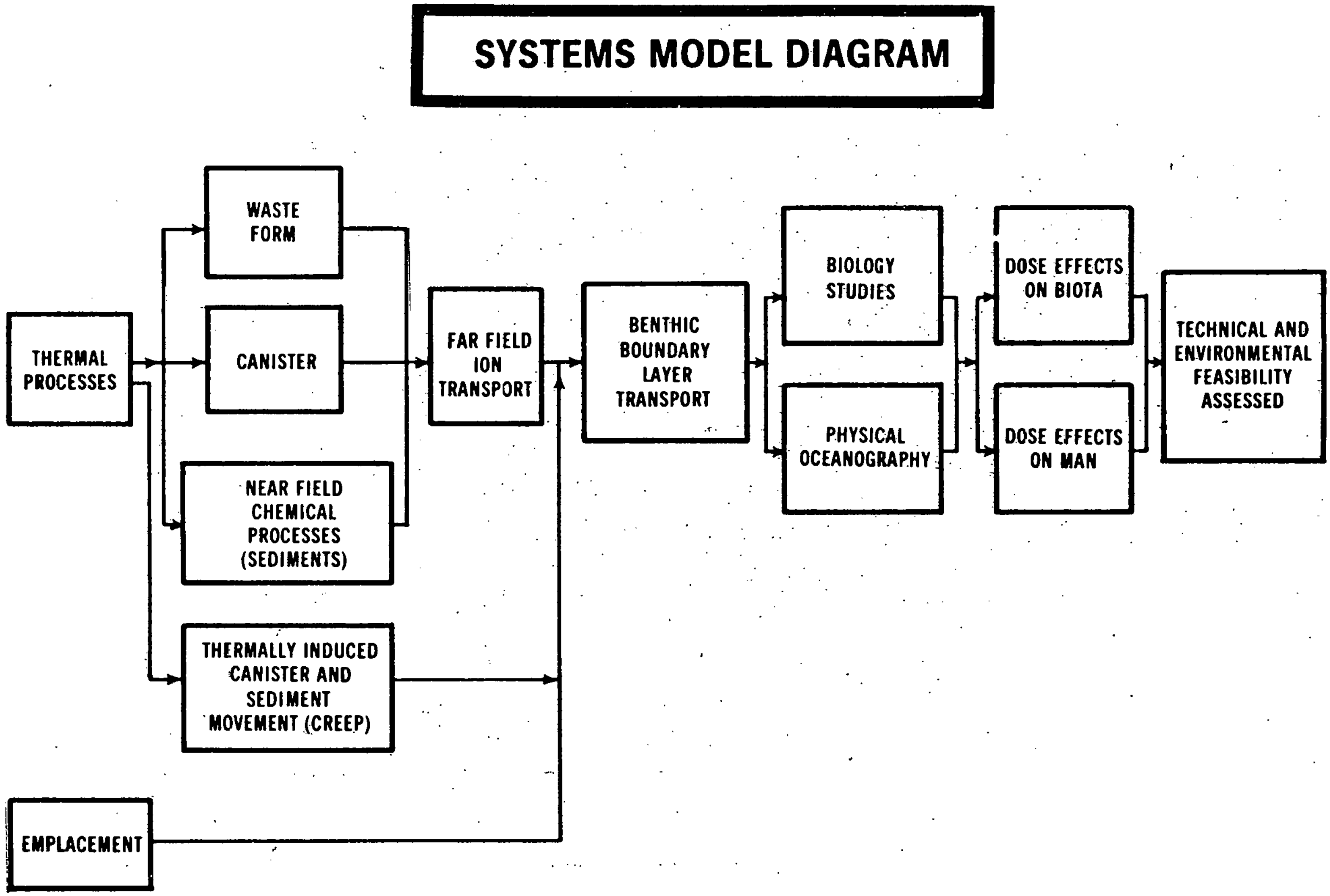
The first point is that the Subseabed Disposal Program is still alive and moving forward. I think it will continue at a modest level for the next several years. Beyond that, it is anyone's guess. The budget for 1982 is 5.0 million expense dollars and 0.9 million equipment dollars (Figure 1). We have been asked by DOE to prepare a status report by the end of 1983; thus, during this next year and a half we will do those things which will best develop the program for not only that report but also best perform our new task: to see how the SDP can best supplement the NWTS program in the disposal of all types of nuclear wastes. The second point, then, is that I would appreciate any inputs, thoughts, ideas for developing supplemental programs.

As background for future planning, we have almost completed the development of our modeling tasks (Figures 2, 3, and 4). By the end of 1983 we should have the first two lines completed and will be able to use them for other wastes programs. The list of generic wastes from the nuclear fuel cycle are shown in Figure 5. Anyone who has any additional ideas on how we may use the ocean as a repository for these wastes, please see me.

Now let me turn the meeting back to Dan and then Les to begin the technical sessions.

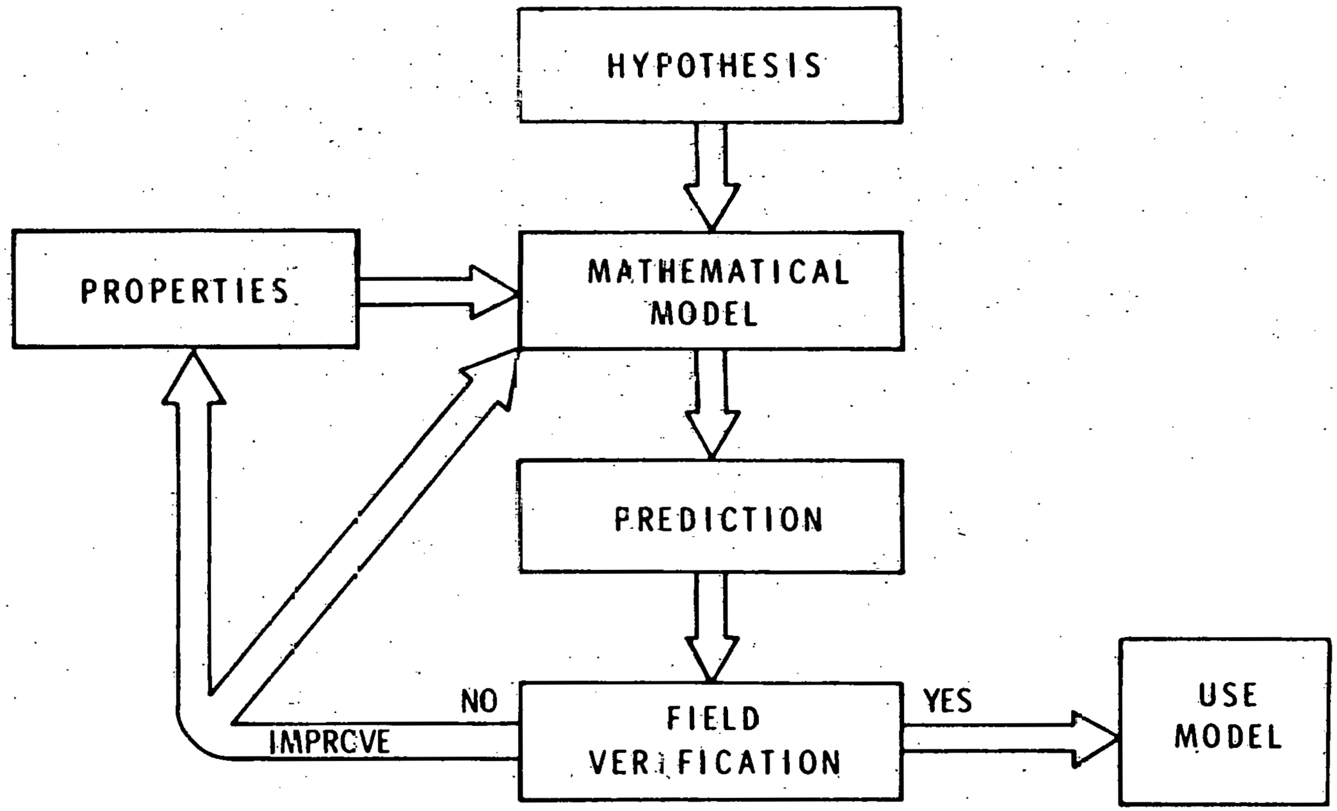
BUDGET

	FY 1981	FY 1982
Expense:	6.25M	5.50M
Equipment:	0.80M	0.94M


SYSTEMS MODEL DIAGRAM
WASTE FORM
THERMAL PROCESSES
CANISTER
NEAR FIELD CHEMICAL PROCESSES (SEDIMENTS)
THERMALLY INDUCED CANISTER AND SEDIMENT MOVEMENT (CREEP)
EMPLACEMENT
FAR FIELD ION TRANSPORT
BENTHIC BOUNDARY LAYER TRANSPORT
BIOLOGY STUDIES
PHYSICAL OCEANOGRAPHY
DOSE EFFECTS ON BIOTA
DOSE EFFECTS ON MAN
TECHNICAL AND ENVIRONMENTAL FEASIBILITY ASSESSED

WMTDD (0781)

RESEARCH APPROACH



SUBSEABED DISPOSAL PROGRAM SCIENTIFIC/ENVIRONMENTAL FEASIBILITY MATRIX

	Earth Science	Biological Oceanography	Physical Oceanography	Thermal	Near Field Chemical	Far Field Chemical	Mechanical	Waste Package	Emplacement	Transportation	Regulatory & Institutional	Systems Analysis
Models	X	A	A	X	A	X	X	A	A	A	A	A
Properties Estimated	X	A	A	X	A	X	X	A	A	0	A	A
--- End of Phase 2												
Properties Acquired	A	A	A	X	A	A	A	A	0	0	A	A
Field/Lab. Verification	0	0	0	A	A	A	A	0	0	0	0	0

A = Active
X = Complete
0 = Not Yet Initiated

PROGRAMS

Ongoing

FUSRAP

Large Pieces of Structures

Future

Regional Repository (within 200 miles)

Iodine

Technetium

Krypton

Carbon – 14, Tritium

Cesium, Strontium

Hulls

Low Level Waste

III. SITE STUDIES

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INTRODUCTION

L. E. Shephard, SNLA

1981 Site Assessment Program activities continued to focus on identifying and characterizing submarine formations suitable for nuclear waste disposal. The "Site Qualification Plan," predicated on stability and barrier criteria, documents the procedure employed in the Ocean Basin Screening Study to systematically downgrade large regions of the ocean basin while continuing to focus on smaller areas in increasing detail. The screening study involves five steps which should provide sufficient information to address the central site issue: the adequacy of submarine geologic formations for the safe containment and disposal of nuclear waste. Secondary issues requiring a more timely resolution include the benefits of a layer-cake stratigraphy, maximum and minimum burial depths (hence sediment thickness) for both the shallow and deep disposal concept, respectively, and the necessary criteria for deep-disposal.

This year's site activities focused on three areas. Preliminary geophysical and sedimentalogical characterization studies on candidate locations B_1, C_1, and E_2 indicate these locations are stable, uniform and predictable and that the screening studies should continue on these locations. The North Atlantic Studies focused on ranking of the various regions being considered by all of the NEA/SWG members and a detailed compilation of available Nares Abyssal Plain data.

SITE ASSESSMENT PROGRAM

OBJECTIVE

- Identify and Characterize Submarine Formations Suitable for Nuclear Waste Disposal

PROCEDURE

- Site Qualification Plan
  - Stability Criteria
  - Barrier Criteria
- Ocean Basin Screening Studies
  - Review Data Archives
  - Marine Geology and Geophysics Cruise
  - Swathmapping Cruise
  - Deep-Tow Cruise
  - Field Verification

SITE STUDIES

CENTRAL SITE ISSUE

- Are Submarine Formations Adequate for Safe Nuclear Waste Disposal?

RELATED ISSUES

- Are Alternating Oxidized and Reduced Sediments Necessary?
- How Deep is Deep?
  - What is the Maximum Depth for Shallow Disposal?
  - What is the Minimum Depth for Deep Disposal?
  - Are Deep Disposal Site Criteria Necessary?

SITE STUDIES

1981 ACTIVITIES

NORTHWEST PACIFIC: VEMA 36 - 12

- Geophysical Characterization
  - Detailed Bathymetry
  - Sediment Thickness
  - Echo Character
  - Synthetic Seismograms
- Sediment Characterization
  - Physical Properties
  - Magnetic Stratigraphy
  - Clay Minerology
- Hydrogeology

NORTH ATLANTIC

- International Program Activities
  - North Atlantic Site Evaluation Exercise
- U. S. Program Activities
  - Nares Abyssal Plain

SITE STUDIES

1982 SITE PROGRAM EMPHASIS

- VEMA 36-12 ANALYSES
- INTERNATIONAL PROGRAM
- NARES ABYSSAL PLAIN

PENDING SITE DEVELOPMENTS

- DSDP DRILLING:
  - NORTHWEST PACIFIC
  - NARES ABYSSAL PLAIN

ANALYSIS OF GEOLOGICAL AND GEOPHYSICAL DATA FROM STUDY LOCATIONS C_1, B_1, AND E_2 IN THE NORTHWEST PACIFIC PAC 1 STUDY REGION

DENNIS E. HAYES
JOHN E. DAMUTH
ROBERT D. JACOBI
ROGER D. FLOOD

Lamont-Doherty Geological Observatory of Columbia University

During May-June 1980 we conducted detailed marine geological and geophysical surveys of three Study Locations (C_1, B_1, and E_2, Fig. 1, top) each of which are about 1° × 1° (latitude × latitude) and which are being evaluated as candidate disposal sites. The ship track and station locations for the survey of Study Location E_2 are shown in Figure 1 (bottom). During 1981 we have continued to analyze and evaluate the data collected from these surveys.

One major task of this study is to construct detailed bathymetric maps of the three Study Locations as well as detailed isopach maps showing sediment thickness variability between the sea floor and prominent acoustic reflectors observed on 3.5 kHz echograms. We have recently developed, at Lamont-Doherty, a computer digitizing program to rapidly and accurately map bathymetry as well as the thickness of reflecting intervals digitized from seismic records. The depth to sea floor as well as the travel times to prominent sub-bottom reflectors are digitized at one-minute intervals along the entire ship-track for each Study Location. A computer program converts these digitized reflection times to sub-bottom depths using sediment velocities measured directly from piston cores or calculated from sonobuoy or pinger-hydrophone measurements, and plots corrected bathymetric depths plus seismic interval thicknesses along ship track. Bathymetric and sediment isopach maps can then be contoured by hand or by computer.

In addition we can plot bathymetric and seismic profiles along various ship tracks through a Study Location or we can project and plot these along lines at any specified angle to the ship tracks. These profiles can be plotted at any desirable scale and vertical exaggeration. Examples are shown for Profile K-L in Figure 2 from Study Location E_2 (profile location shown in Fig, 1, bottom). The 3.5 kHz echogram recorded along K-L is shown at the top of Figure 2. Along this profile we mapped depth of sea floor (reflector 1, Fig. 2); two continuous reflectors (2 and 3, Fig. 2) in the well-stratified upper 20 m; an intermittently-present reflector (4, Fig. 2) at about 40 m sub-bottom; and a very strong continuous reflector (5, marked "chert" in Fig. 2) at about 60 m sub-bottom. The three profiles below the echogram are line tracings of computer-generated profiles along K-L at the same horizontal scale as the echogram but with vertical exaggerations of 50:1 (about the same VE as the echogram), 20:1, and 10:1. These computer plots show the remarkably low variability of the sea floor and the four acoustic sub-bottom reflectors (2 to 5) mapped from the original echogram above.

A second major task is to study the mass physical and acoustic properties of the uppermost sediments of the Study Locations in order to relate these properties (measured from piston cores) to reflection patterns observed on the

3.5 kHz echograms and to thereby "calibrate" the deeper reflection patterns in terms of the likely physical and geological properties of the deeper unsampled sedients. Sediment mass physical properties (eg. bulk density) and sound velocity were measured at 10 cm intervals down one piston core at the center of each Study Location. At each of these core sites, as well as at all other core sites in each Study Location, we recorded on analog tape the 3.5 kHz vertical incidence reflections received on the ship using both the ships hull-mounted transducer and a near-bottom pinger suspended about 200 m above the sea floor. Prominent reflecting horizons were traced between core sites within each Study Location by means of the surface-ship 3.5 kHz echograms. Although these studies are underway for all Study Locations, only the results of E_2 are briefly discussed here.

Figure 3 shows the correlation of acoustic signals at core sites in E_2. Reflectors 2, 3 and 5 (shown in Fig. 2) are correlated by dashed lines and are numbered on the right. These surface-ship recordings show that the acoustic profile changes only slightly from core site to core site. This may suggest that little lateral variability in sediment physical properties occurs throughout E_2. One exception is at core site 51 where reflecting horizon 2 becomes less distinct.

Additional detailed investigations are being undertaken at the core site at the center of each Study Location where physical properties and velocities were measured in the piston cores. The measured velocities (corrected to in-situ conditions) were used along with bulk density measurements to calculate the acoustic impedences (the product of seismic velocity and density) and reflection coefficients (reflectivity of each sediment layer) down core. Figure 4 shows the down-core plots of velocity, density, impedence, and reflection coefficient for core 52 from the center of Study Location E_2.

The calculated reflection coefficient profile for core 52 (Fig. 4) was convolved (in the time domain) with the measured out-going pulse of the surface-ship 3.5 kHz echosounder (measured with the near-bottom hydrophone) to generate a synthetic seismogram for core 52 (right side of Figure 5). The results for the convolution of two physical-property models are shown; one model is based on the measured density whereas the other incorporates corrections assuming a constant density for sedimentary particles (constant grain density). Several recorded 3.5 kHz echo returns are shown on the left side of Figure 5 for comparison. The prominent reflection at 15 milliseconds below the sea floor can be correlated with a 2 cm ash layer at 935 cm depth in core 52 (The inferred depth of this ash layer is 1162 cm below the sea floor; see Fig. 5.). The relatively high acoustic velocity of this layer is responsible for the strong reflection. At other depths in the core, there do not appear to be distinct geological horizons which can be linked directly to reflection horizons. Instead, the other shallow horizons may result from constructive interference between numerous weak reflecting horizons which arise from rapid variations of bulk density down the sediment column. At present the geological reasons for this down-core density variation are unknown; however, additional core studies should resolve this problem.

FIGURE CAPTIONS

Figure 1. Top: Locations of Study Locations C_1, B_1 and E_2 which were surveyed during VEMA 36-12 cruise. Bottom: Cruise trackline of V36-12 survey of Study Location E_2. Station locations (SN) and sonobuoy locations (SB) are shown (C = core, DHF = digital heat-flow measurement). Dotted lines show previous ship tracks (V32-12 and GECS D). A 3.5 kHz echogram along KL is shown in Figure 2.

Figure 2. At top is a 3.5 kHz echogram along profile K-L (Location in Fig. 1). The line drawings below are computer-generated plots of this profile at various vertical exaggerations showing the seafloor and reflectors 2 to 5. Note that in the two lower profiles the apparent convergences of reflectors at various points are an artifact of photo reduction of the original plots, and are not true convergences (eg. top profile).

Figure 3. Surface-ship 3.5 kHz echo returns at each piston core site in Study Location E_2. Prominent reflectors 2, 3 and 5 can be correlated between core sites (see Fig. 2). Reflector 4 only occurs intermittently in the survey area. Echo traces end abruptly at about 70 milliseconds because of the window of the digitizer used to plot out the traces. Reflector 5 positions for cores 48, 52 and 49 are from the on-site 3.5 kHz records. Depth scale assumes a one-way sound speed of 1550 m/sec.

Figure 4. Sediment physical properties, core 52. Depth scale includes an estimated 1.8 m of sediment not sampled by the piston core. Reflection coefficients are calculated for interpolated sediment layers 10 microseconds thick.

Figure 5. Measured on-site 3.5 kHz echoes compared with synthetic seismograms generated for physical properties measured on core 52. Model B uses the measured velocities and bulk densities (shown in Fig. 4) whereas Model A uses measured velocities and bulk densities calculated from measured water contents (grain density assumed constant). Ash layer at 935 cm in the core generates a strong echo in both models which appears to correlate with a strong reflection (horizon #2) at a depth of 15 milliseconds. This suggests that the ash layer is actually at a depth of 1162 cm below the seafloor.

FIG. 1

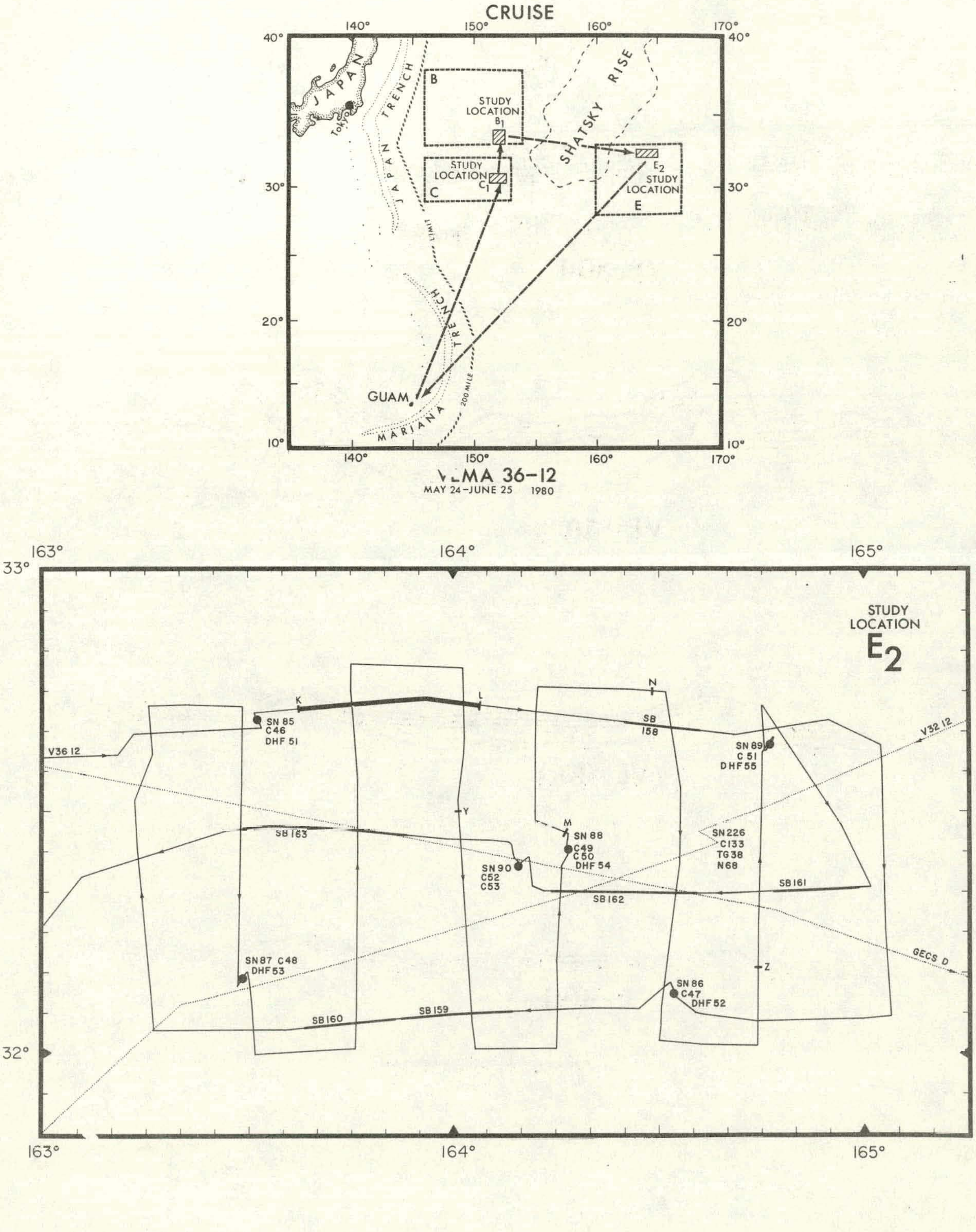
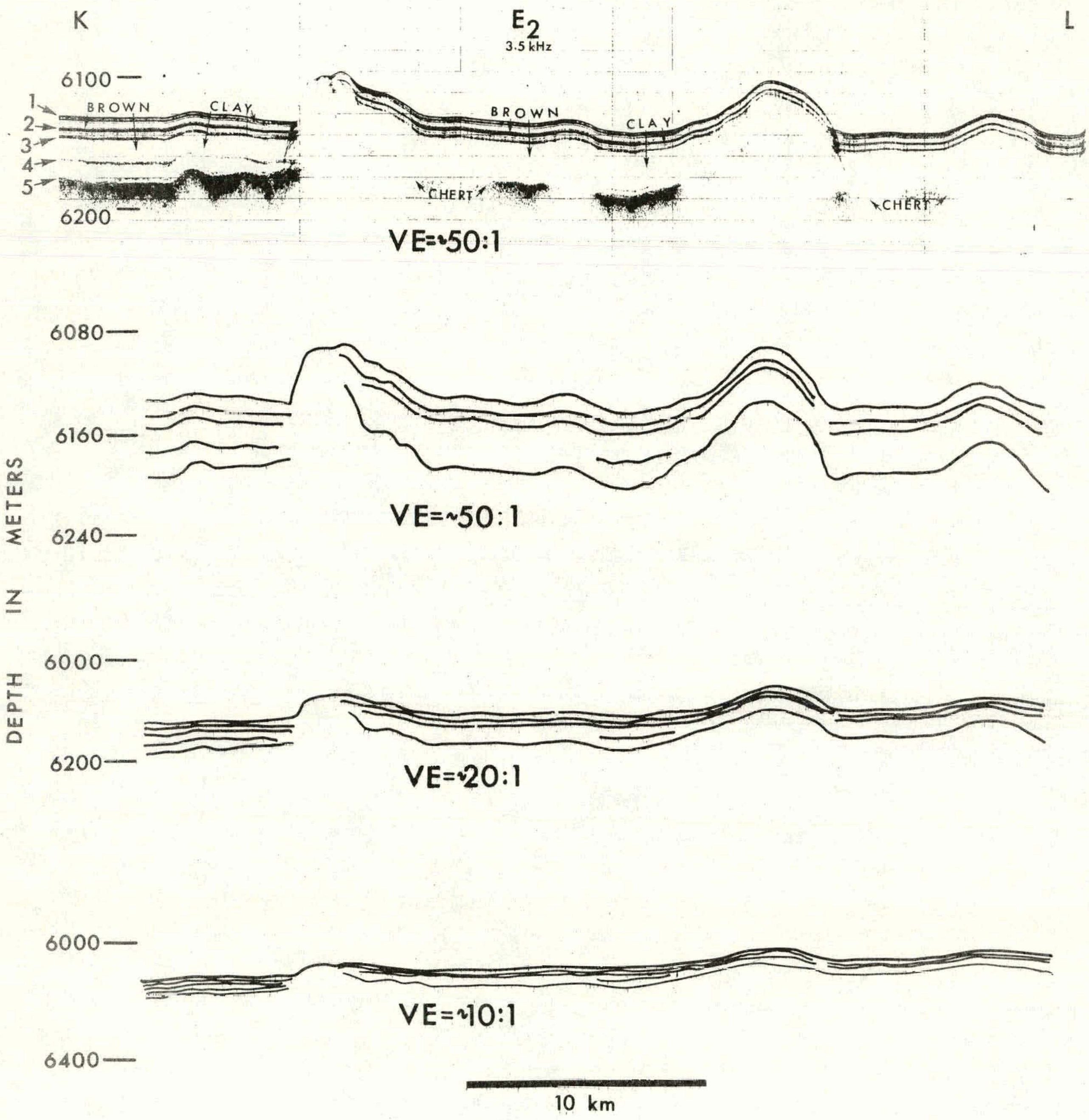

CRUISE
VEMA 36-12
MAY 24-JUNE 25 1980
JAPAN
Tokyo
JAPAN TRENCH
B
STUDY LOCATION
B1
C
STUDY LOCATION
C1
SHATSKY RISE
E2
STUDY LOCATION
E
LIMIT
200 MILE
TRENCH
MARIANA
GUAM
140°
150°
160°
170°
40°
30°
20°
10°
STUDY LOCATION
E2
163°
164°
165°
33°
32°
V36 12
V32 12
GECS D
K
L
N
M
Y
Z
SB 158
SB 163
SB 162
SB 161
SB 160
SB 159
SN 85
C46
DHF 51
SN 89
C 51
DHF 55
SN 88
C49
C50
DHF 54
SN 90
C52
C53
SN 226
C133
TG 38
N68
SN 87 C48
DHF 53
SN 86
C47
DHF 52

FIG. 2


K
E2
3.5 kHz
L
6100
1
2
3
4
5
BROWN
CLAY
BROWN
CLAY
CHERT
CHERT
6200
VE=~50:1
6080
6160
6240
VE=~50:1
DEPTH IN METERS
6000
6200
VE=~20:1
6000
VE=~10:1
6400
10 km

STUDY LOCATION E2 (V36-12)

CORE-SITE SURFACE-SHIP 3.5 KHZ ECHO

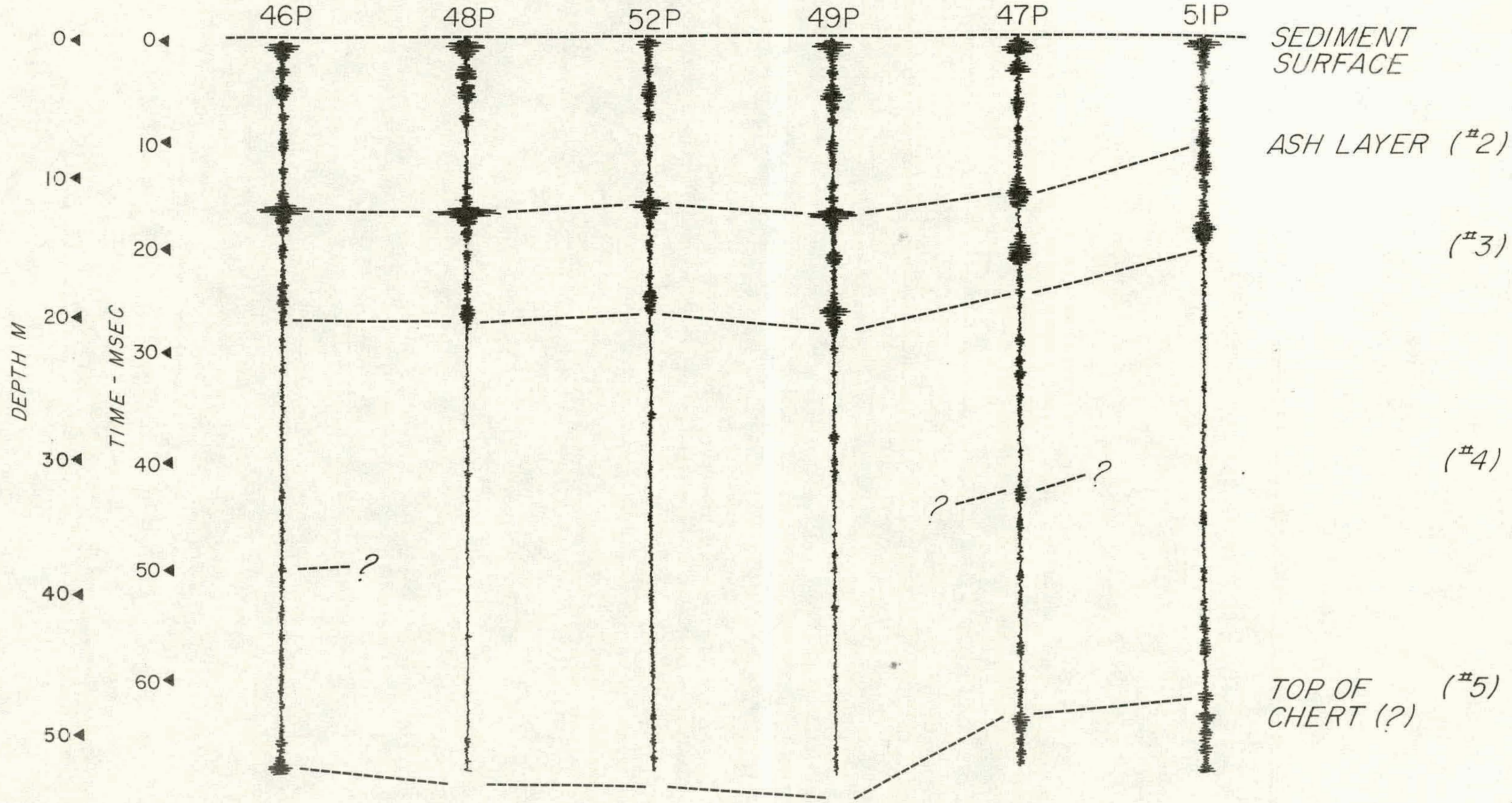
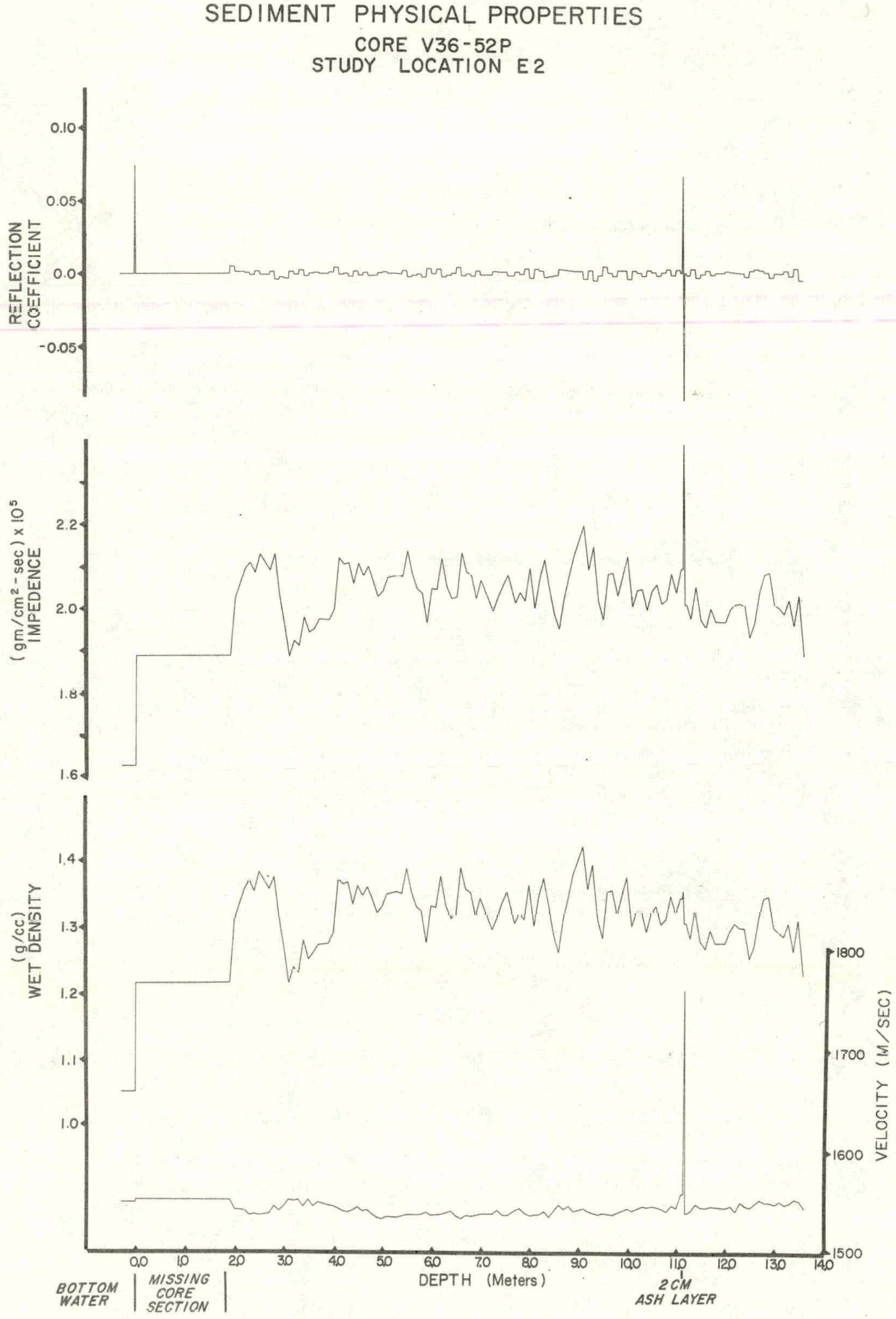


FIG. 3

FIG. 4



SEDIMENT PHYSICAL PROPERTIES
CORE V36-52P
STUDY LOCATION E2
REFLECTION COEFFICIENT
0.10
0.05
0.0
-0.05
(gm/cm²-sec) x 10⁵ IMPEDENCE
2.2
2.0
1.8
1.6
(g/cc) WET DENSITY
1.4
1.3
1.2
1.1
1.0
VELOCITY (M/SEC)
1800
1700
1600
1500
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
DEPTH (Meters)
BOTTOM WATER
MISSING CORE SECTION
2 CM ASH LAYER

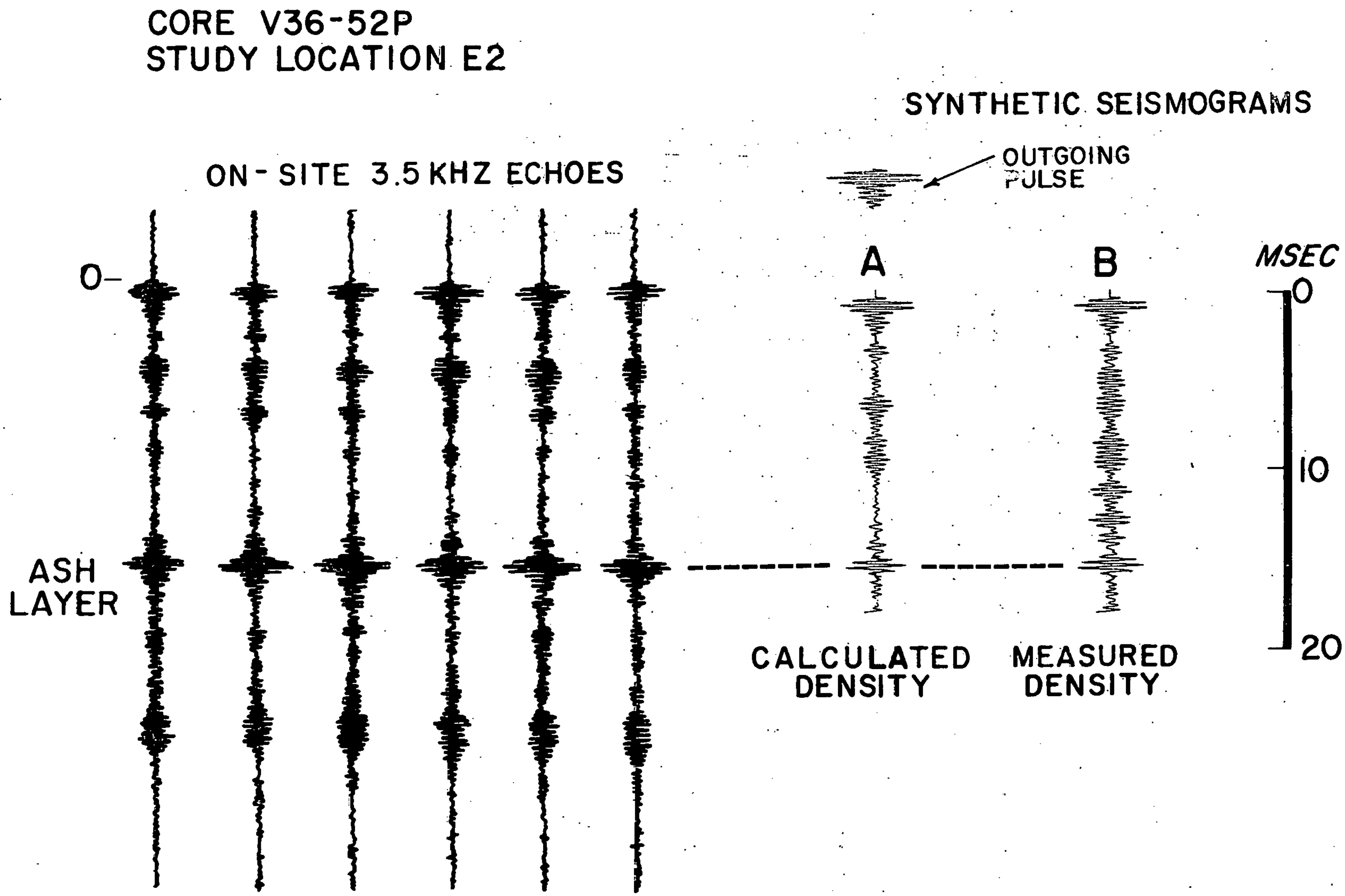

CORE V36-52P
STUDY LOCATION E2
ON-SITE 3.5 KHZ ECHOES
SYNTHETIC SEISMOGRAMS
OUTGOING PULSE
A
B
MSEC
0
10
20
0-
ASH LAYER
CALCULATED DENSITY
MEASURED DENSITY

FIG. 5

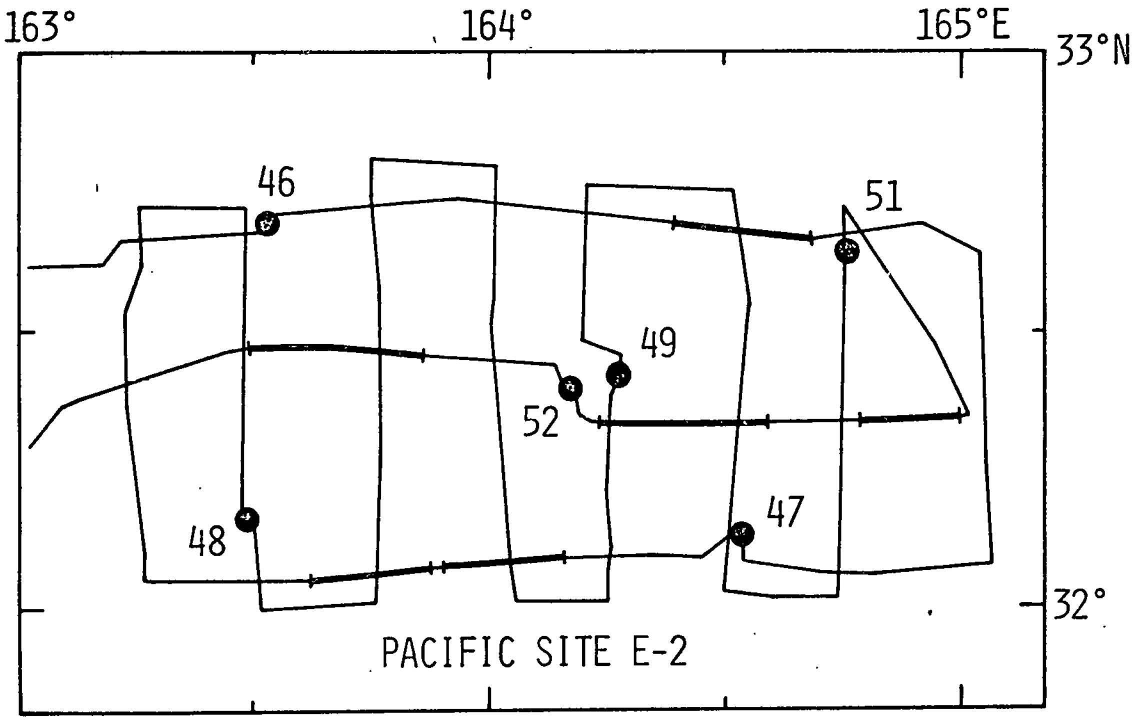
PACIFIC SITES : SEDIMENT CHARACTERIZATION

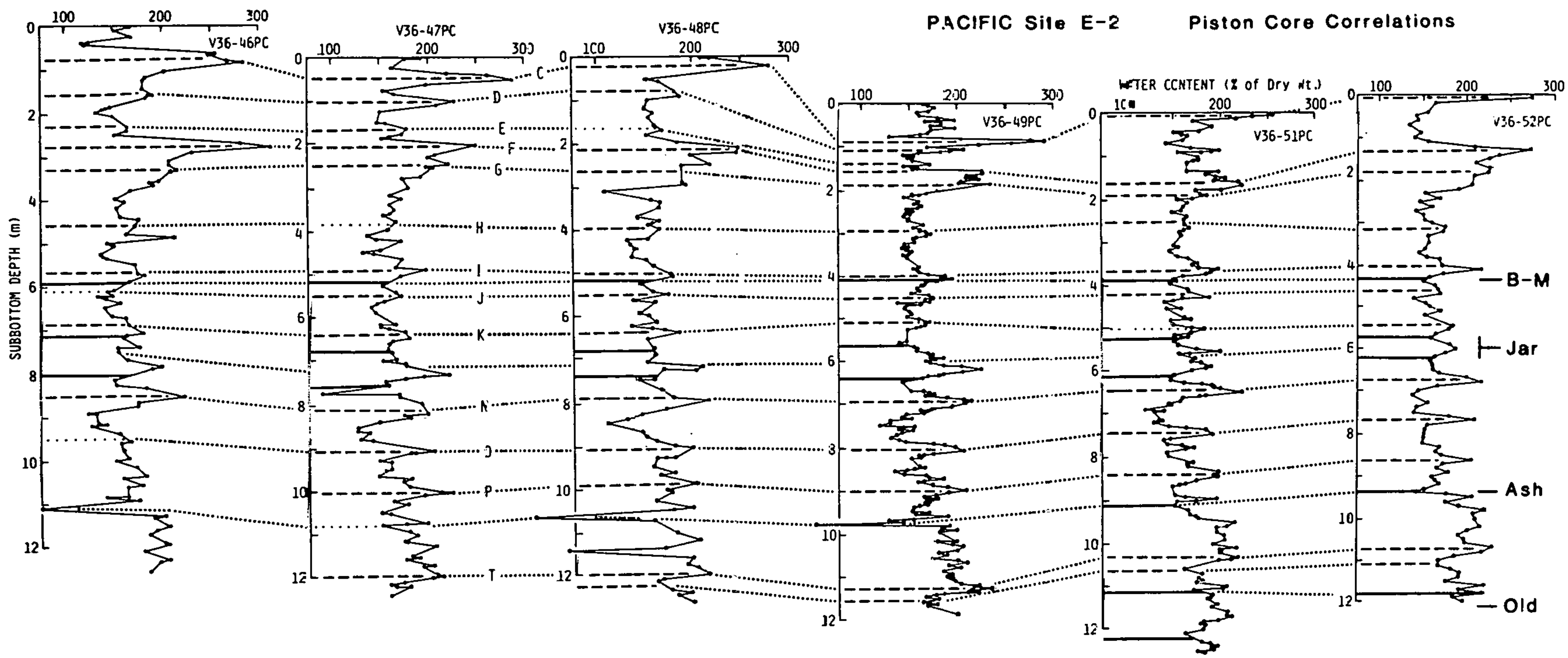
G. Ross Heath, Nicklas G. Pisias, Carlos Lopez

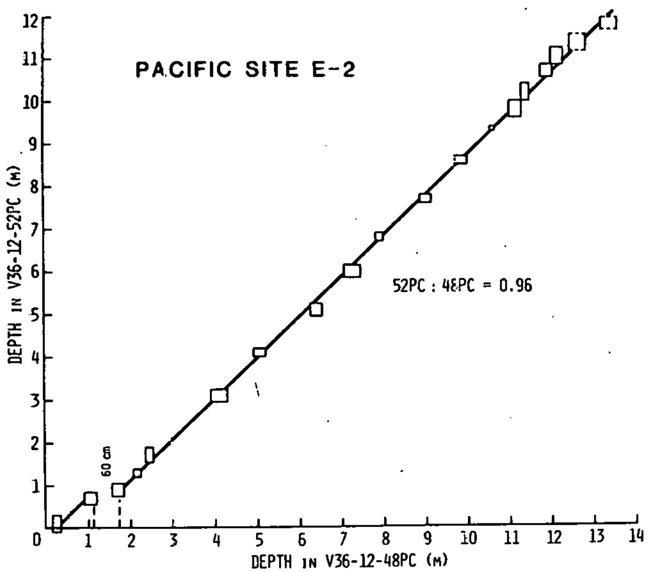
This year's efforts have focussed on workup of the Vema-36 cores from sites B-1, C-1 and E-2. Emphasis has been placed on the correlation of thin ash layers (primarily based on refractive indices) and detailed water-content profiles within areas and between B-1 and C-1. Barton's magnetic data provide some absolute time control. Within E-2, all cores except the top 1-2 meters of 49PC have relative sedimentation rates that are constant to within 10%. Short hiatuses (less than 1m of missing sediment) are present near the tops of cores 51PC and 52PC, but otherwise the area shows remarkably uniform and consistent deposition for the past couple of million years.

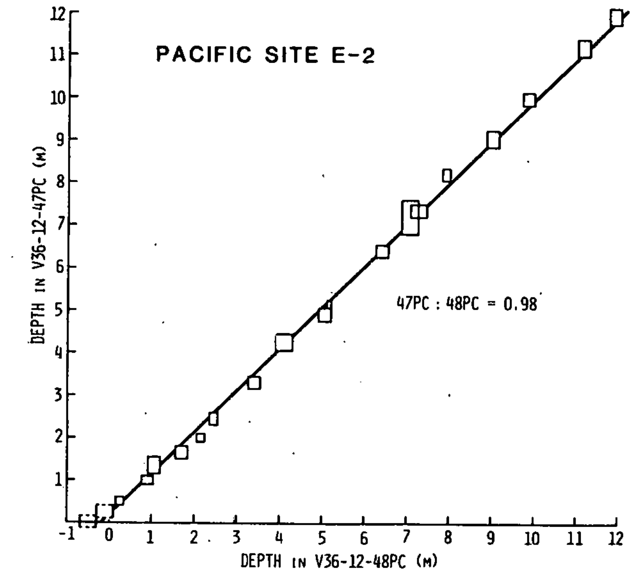
Deposition at B-1 and C-2 is less uniform, with relative accumulation rate changes in all cores. At B-1 the relative accumulation rate varies by a factor of 10 across the area. In both areas, however, there is no evidence for hiatuses in the sampled sedimentary section.

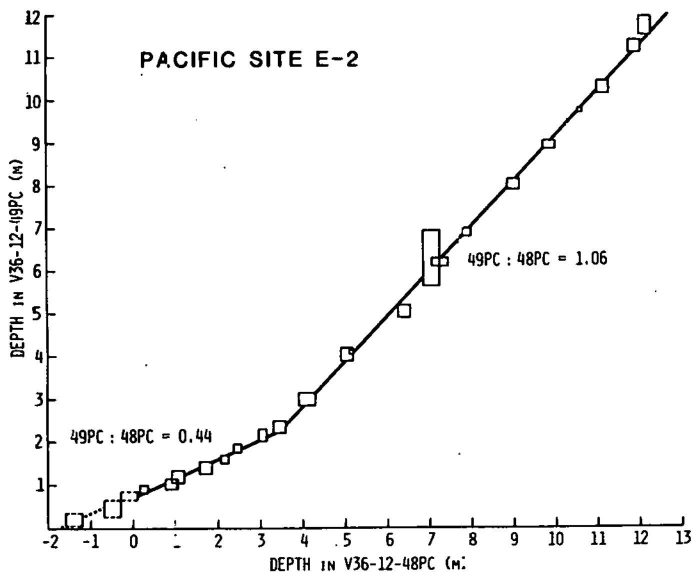
During the coming year, efforts will focus on assigning time scales to the cores, defining geochemical components of the sediments, and on collecting complete sediment sections during Leg 86 of the Deep Sea Drilling Project.

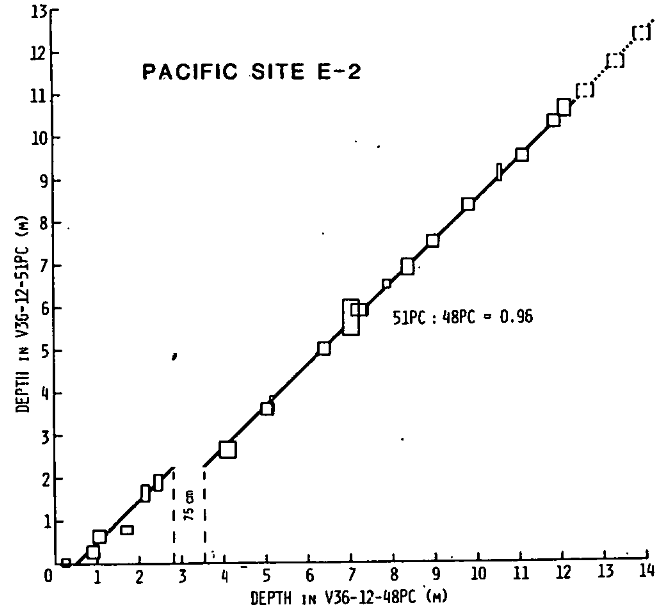

163°
164°
165°E
33°N
32°
46
51
49
52
48
47
PACIFIC SITE E-2

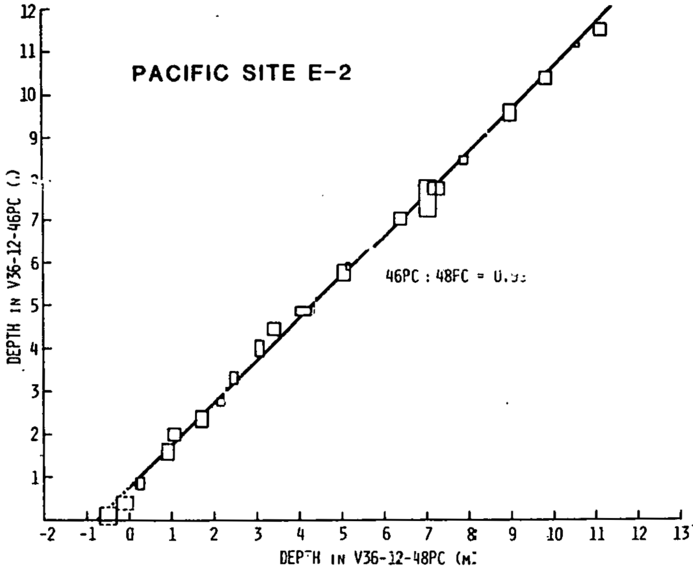

PACIFIC Site E-2
Piston Core Correlations
SUBBOTTOM DEPTH (m)
WATER CONTENT (% of Dry Wt.)
V36-46PC
V36-47PC
V36-48PC
V36-49PC
V36-51PC
V36-52PC
100
200
300
C
D
E
F
G
H
I
J
K
N
O
P
T
B-M
Jar
Ash
Old

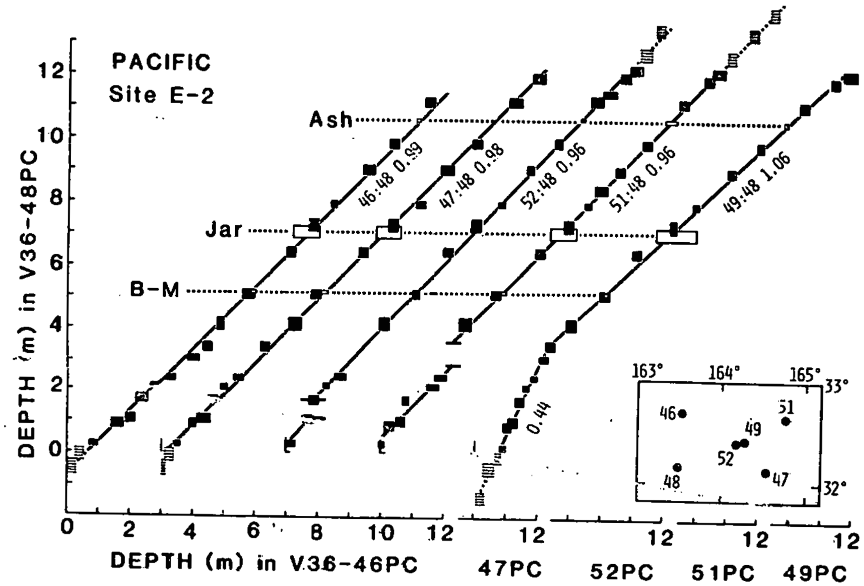

PACIFIC SITE E-2
52PC : 48PC = 0.96
60 cm
DEPTH IN V36-12-52PC (M)
DEPTH IN V36-12-48PC (M)

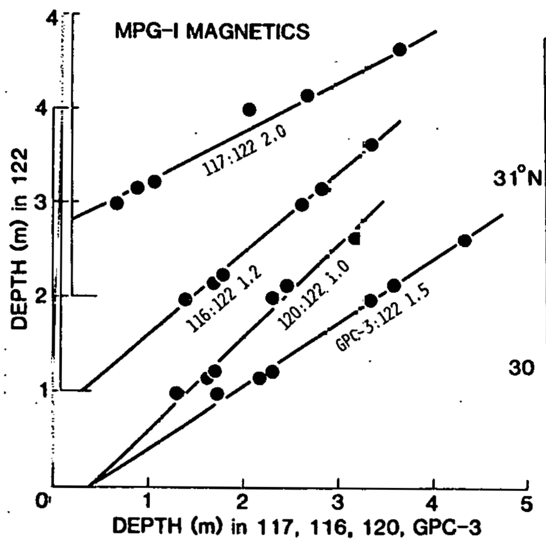

PACIFIC SITE E-2
47PC : 48PC = 0.98
DEPTH IN V36-12-47PC (M)
DEPTH IN V36-12-48PC (M)

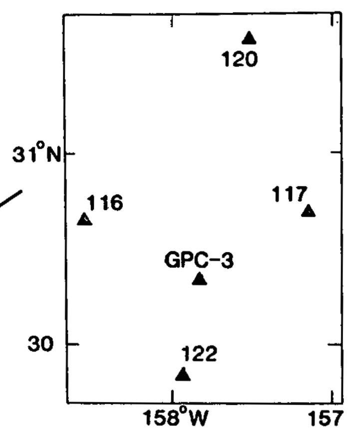

PACIFIC SITE E-2
49PC : 48PC = 1.06
49PC : 48PC = 0.44
DEPTH IN V36-12-49PC (M)
DEPTH IN V36-12-48PC (M)

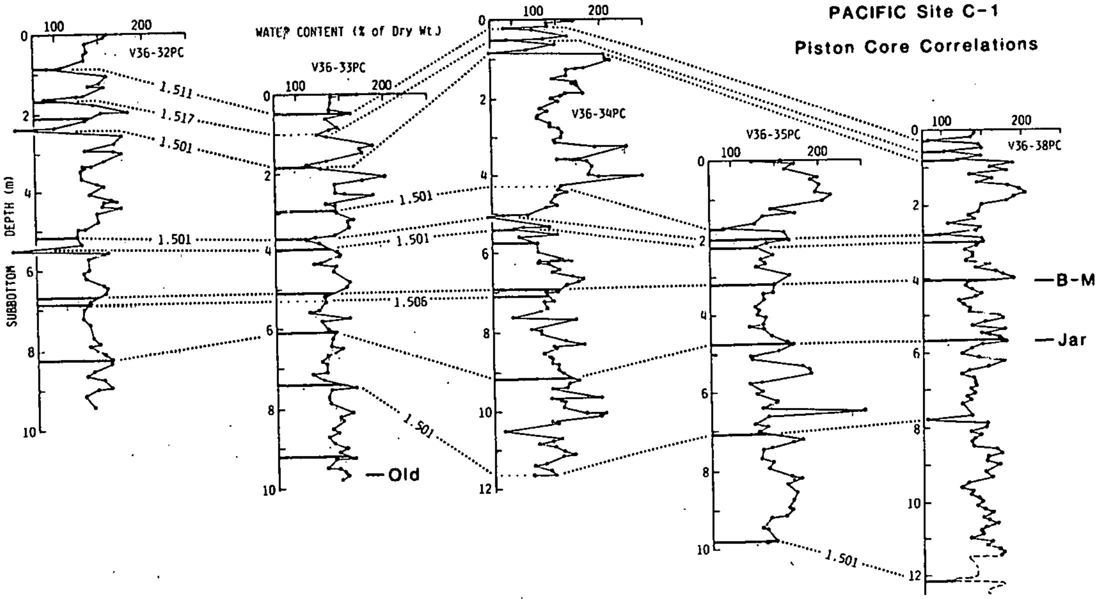

PACIFIC SITE E-2
51PC : 48PC = 0.96
75 cm
DEPTH IN V36-12-51PC (M)
DEPTH IN V36-12-48PC (M)

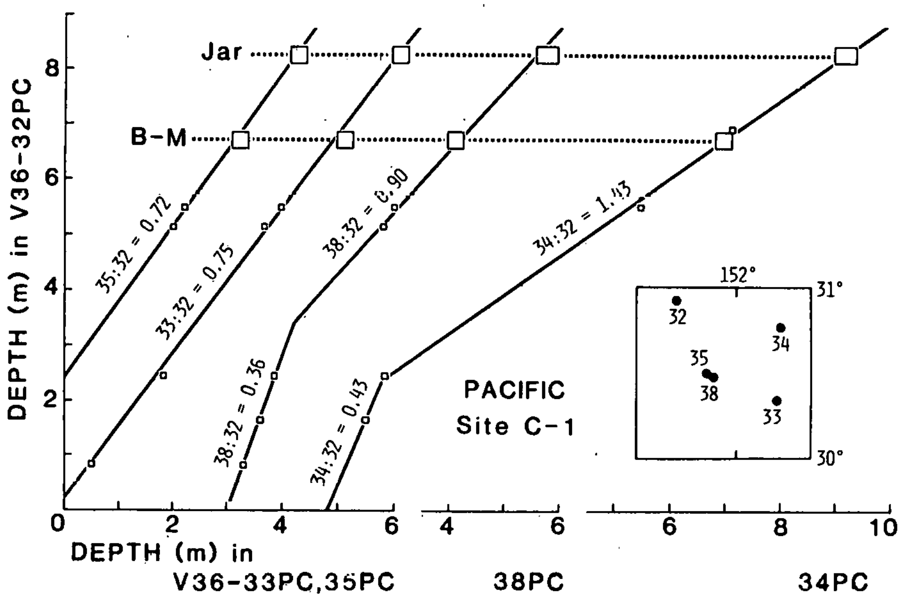

PACIFIC SITE E-2
46PC : 48PC = 0.9
DEPTH IN V36-12-46PC
DEPTH IN V36-12-48PC
-2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
1 2 3 4 5 6 7 8 9 10 11 12

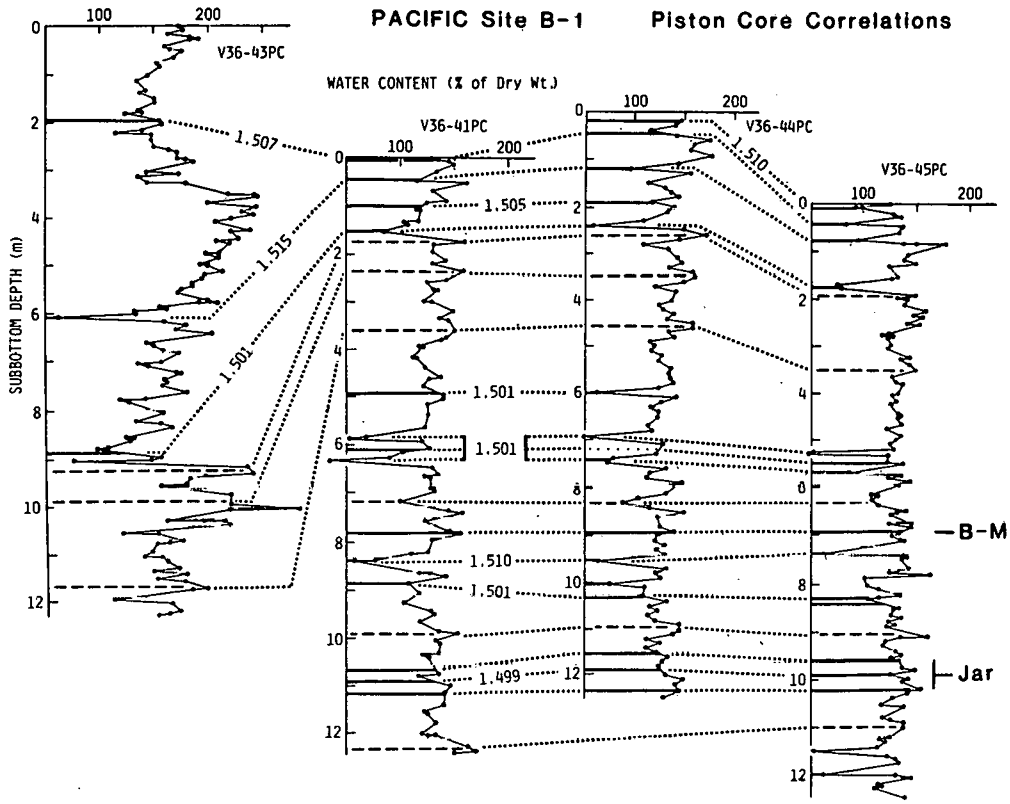

PACIFIC
Site E-2
Ash
Jar
B-M
46:48 0.99
47:48 0.98
52:48 0.96
51:48 0.96
49:48 1.06
0.44
DEPTH (m) in V36-48PC
DEPTH (m) in V36-46PC
47PC
52PC
51PC
49PC
163°
164°
165°
33°
32°
46
47
48
49
51
52

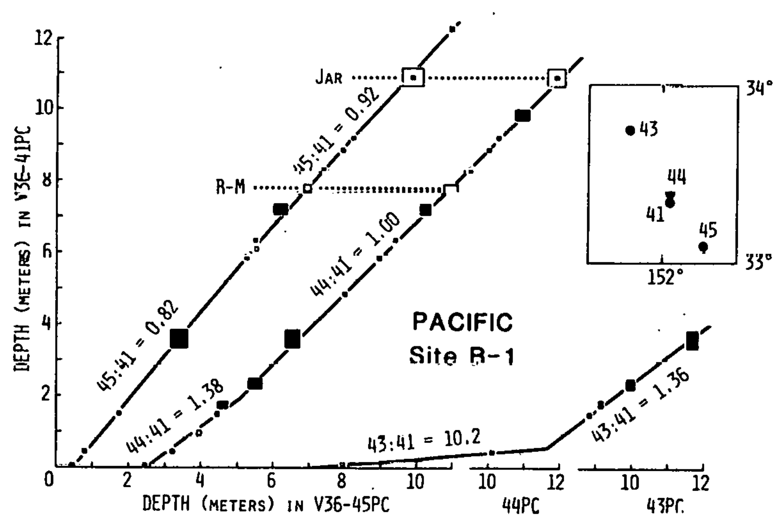

MPG-I MAGNETICS
117:122 2.0
116:122 1.2
120:122 1.0
GPC-3:122 1.5
DEPTH (m) in 122
DEPTH (m) in 117, 116, 120, GPC-3
0 1 2 3 4 5

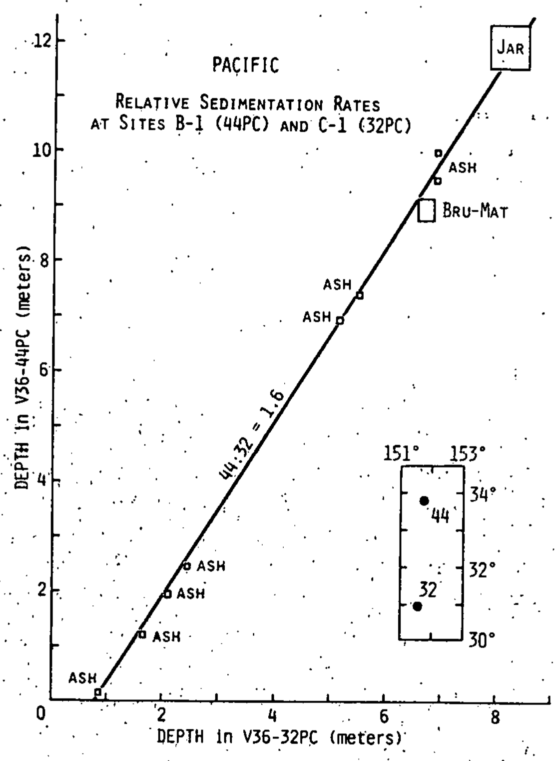

120
31°N
116
117
GPC-3
30
122
158°W
157

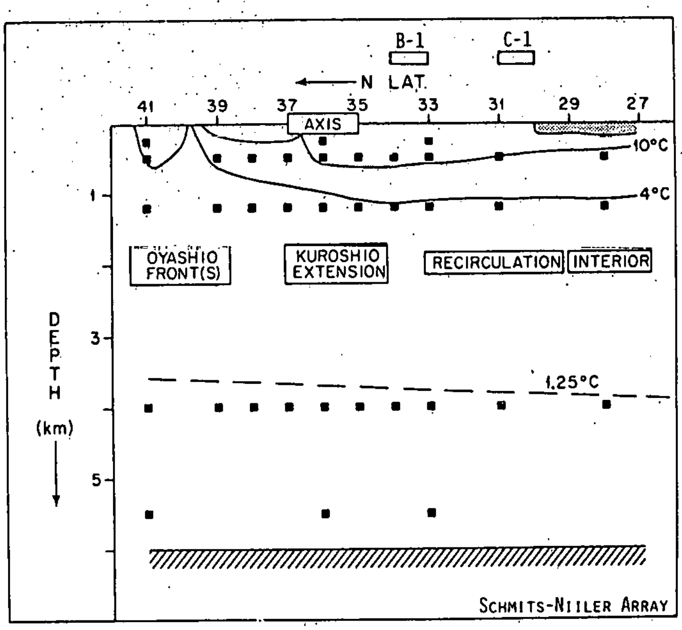

PACIFIC Site C-1
Piston Core Correlations
WATER CONTENT (% of Dry Wt.)
SUBBOTTOM DEPTH (m)
V36-32PC
V36-33PC
V36-34PC
V36-35PC
V36-38PC
1.511
1.517
1.501
1.506
—B-M
—Jar
—Old


Jar
B-M
DEPTH (m) in V36-32PC
35:32 = 0.72
33:32 = 0.75
38:32 = 0.90
38:32 = 0.36
34:32 = 0.43
34:32 = 1.43
PACIFIC
Site C-1
152°
31°
30°
DEPTH (m) in
V36-33PC,35PC
38PC
34PC


PACIFIC Site B-1 Piston Core Correlations
WATER CONTENT (% of Dry Wt.)
SUBBOTTOM DEPTH (m)
V36-43PC
V36-41PC
V36-44PC
V36-45PC
1.507
1.515
1.501
1.505
1.510
1.499
B-M
Jar


JAR
B-M
45:41 = 0.92
45:41 = 0.82
44:41 = 1.00
44:41 = 1.38
43:41 = 10.2
43:41 = 1.36
PACIFIC
Site B-1
DEPTH (METERS) IN V36-41PC
DEPTH (METERS) IN V36-45PC
44PC
43PC
43
44
41
45
34°
33°
152°


PACIFIC
RELATIVE SEDIMENTATION RATES AT SITES B-1 (44PC) AND C-1 (32PC)
JAR
ASH
BRU-MAT
44:32 = 1.6
151° 153°
34°
32°
30°
44
32
DEPTH in V36-44PC (meters)
DEPTH in V36-32PC (meters)


B-1
C-1
N LAT.
41 39 37 35 33 31 29 27
AXIS
10°C
4°C
OYASHIO FRONT(S)
KUROSHIO EXTENSION
RECIRCULATION
INTERIOR
1.25°C
DEPTH (km)
SCHMITS-NIILER ARRAY

Mineralogical Characterization of Northwest Pacific Candidate Sites for Subseabed Disposal of Nuclear Waste

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Graduate School of Oceanography
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882 - 1197

The surface sediments of piston cores from cruise V36-12 have been analyzed for qualitative and quantitative mineralogy. This study was done to provide a set of reference data on surface sedimentation in the western North Pacific. This reference is necessary for downcore studies of mineralogic variability at candidate sites. The mineralogic variability is an indication of the geologic stability of the area and is also necessary to constrain models of ion migration.

Surface samples from the core had quartz contents within about 1 weight percent of quartz contents of previously studied cores from nearby northwest Pacific sites. Northwest Pacific fine grained sediment is dominated by the clay mineral, illite. The illite contents of the surface sediments were markedly different from those determined for other northwest Pacific cores. Subsequent studies of the cores have shown that variable amounts up to 1.5 m of sediment are missing from the top of the cores due to coring problems. Thus, the lack of correspondence between illite contents of the V36-12 cores and other analyses in the area can be explained as a result of not having analyzed geologically equivalent samples.

OBJECTIVES OF MINERALOGICAL ANALYSIS OF SEDIMENTS

1) SITE EVALUATION

MINERAL COMPOSITION OF SEDIMENTS IS SENSITIVE TO CHANGES IN PALEO-ENVIRONMENT

MONITOR OF GEOLOGIC STABILITY OF SITE

2) MODELING RADIONUCLIDE MIGRATION

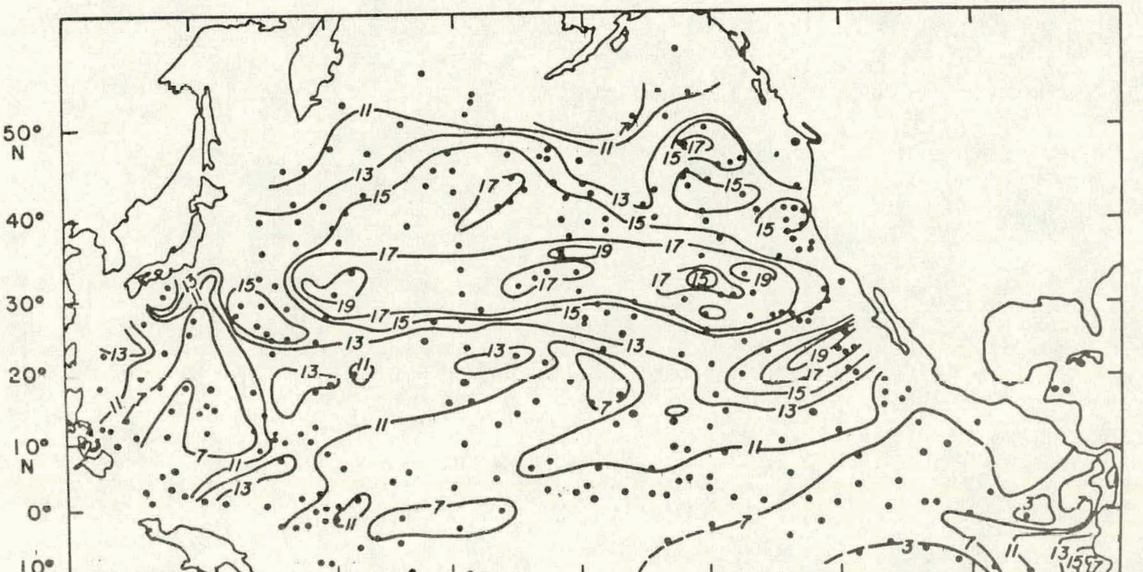
CLAY MINERAL GROUPS HAVE DIFFERENT ABSORPTION CHARACTERISTICS

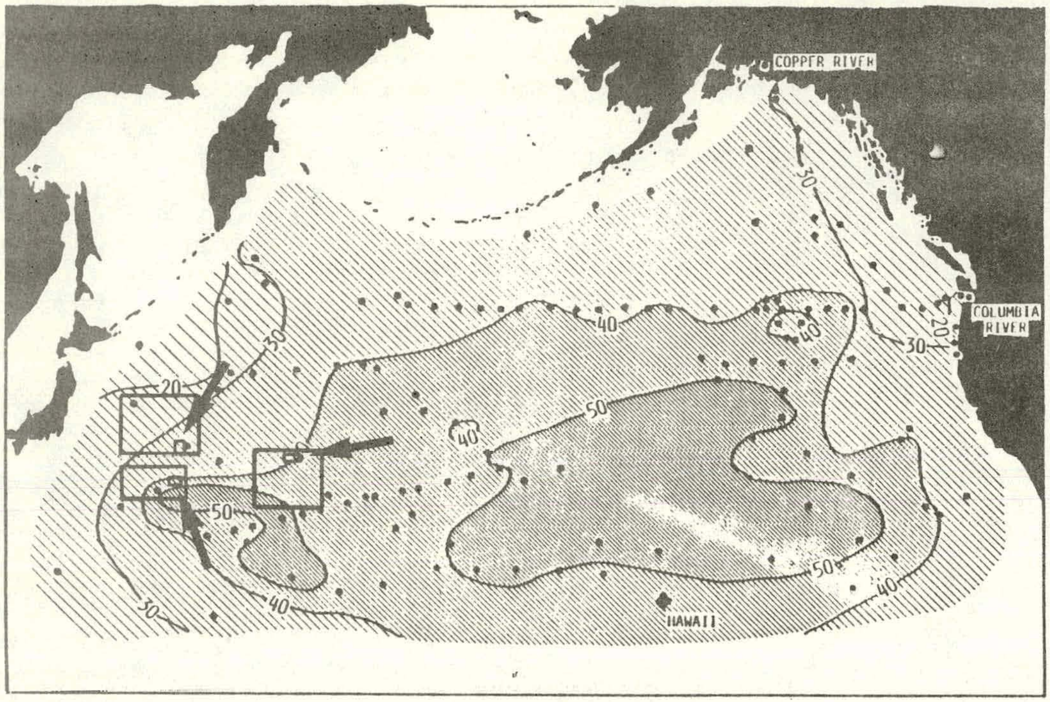
QUANTITATIVE MINERALOGY IS NECESSARY TO MODEL ABSORPTION AND CONSTRAIN THE DEGREE OF VARIABILITY IN THE PATH OF RADIONUCLIDE MIGRATION

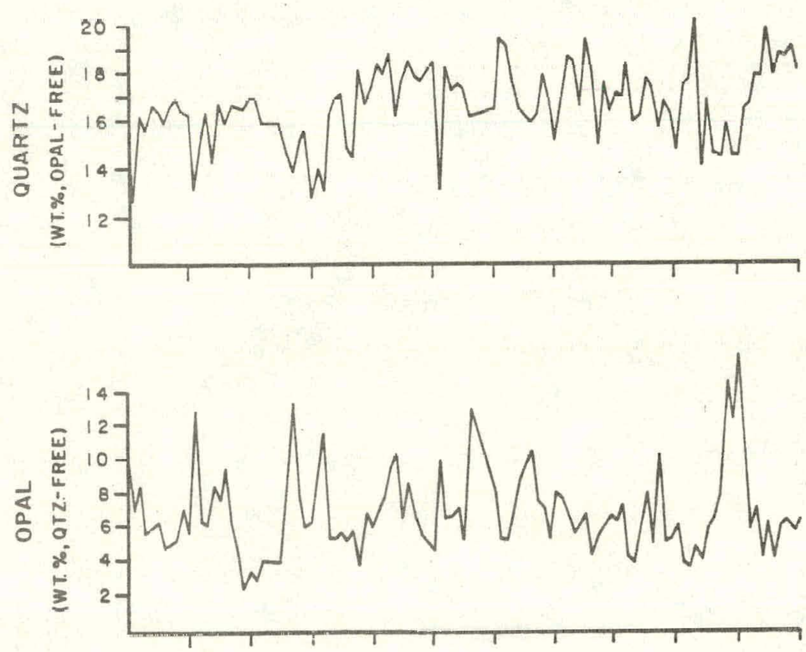
STRATEGY FOR MINERALOGICAL STUDIES OF PROPOSED SITES

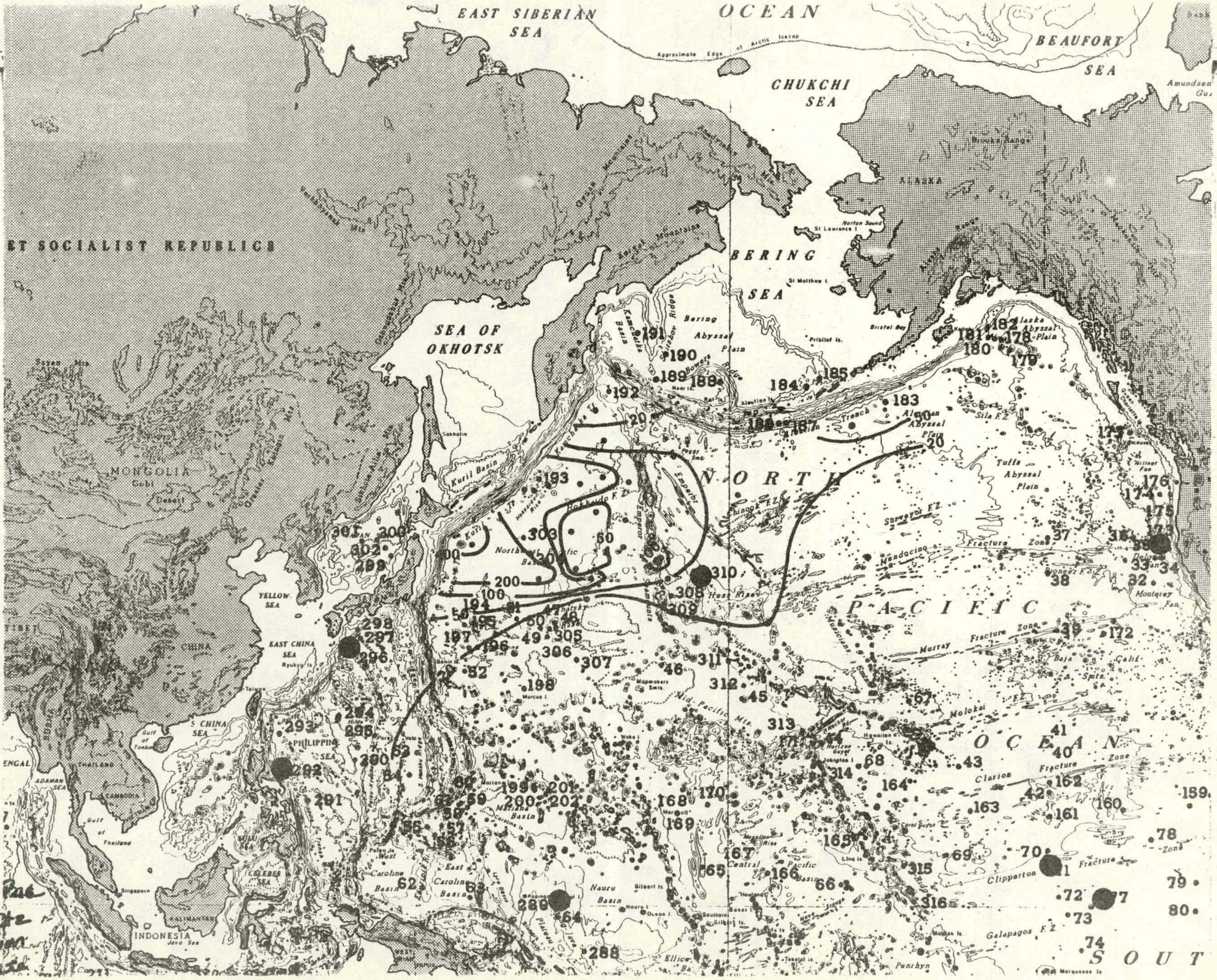
1) DETERMINE THE RELATIONSHIP OF THE PRESENT SEDIMENTATION AT PROPOSED SITES TO THAT IN THE NORTHWEST PACIFIC

2) EXAMINE THE NATURE OF MINERALOGICAL CHANGE DOWNCORE IN CORES FROM THE PROPOSED SITES




COPPER RIVER
COLUMBIA RIVER
HAWAII
20
30
40
50


QUARTZ
(WT.%, OPAL-FREE)
20
18
16
14
12
OPAL
(WT.%, QTZ.-FREE)
14
12
10
8
6
4
2


EAST SIBERIAN SEA
OCEAN
BEAUFORT SEA
CHUKCHI SEA
ALASKA
BERING SEA
SEA OF OKHOTSK
SOCIALIST REPUBLICS
MONGOLIA
CHINA
YELLOW SEA
EAST CHINA SEA
S. CHINA SEA
PHILIPPINE SEA
THAILAND
CAMBODIA
INDONESIA
NORTH
PACIFIC
OCEAN
SOUT
Alaska Abyssal Plain
Aleutian Abyssal Plain
Tufts Abyssal Plain
Mendocino
Murray Fracture Zone
Molokai
Clarion Fracture Zone
Clipperton Fracture
Galapagos F.Z.
Hess Rise
Central Pacific Basin
Nauru Basin
East Caroline Basin
West Caroline Basin

GOALS FOR DOWNCORE MINERALOGICAL ANALYSIS

1) IS THERE A CONSISTENT RELATIONSHIP BETWEEN WATER CONTENT VARIATION AND TOTAL CLAY CONTENT?

2) DOES ANY SUCH RELATIONSHIP HOLD FOR THE ENTIRE SURVEY AREA OR DOES IT APPLY ONLY TO A SINGLE SITE?

3) IS THERE A CONSISTENT RELATIONSHIP BETWEEN WATER CONTENT VARIATION AND MINERALOGICAL COMPOSITION?

4) CAN MINERALOGICAL VARIATIONS BE RELATED TO SEDIMENT CHEMISTRY?

5) CAN MINERALOGICAL VARIATIONS BE RELATED TO KNOWN CHANGES IN PALEOENVIRONMENT SO THAT WE CAN PREDICT THE STABILITY OF THE SITES IN THE FUTURE?

RESULTS AND PLANS

European Field Program — Ed Laine

Annual Meeting (Denver) — October 27-29, 1981

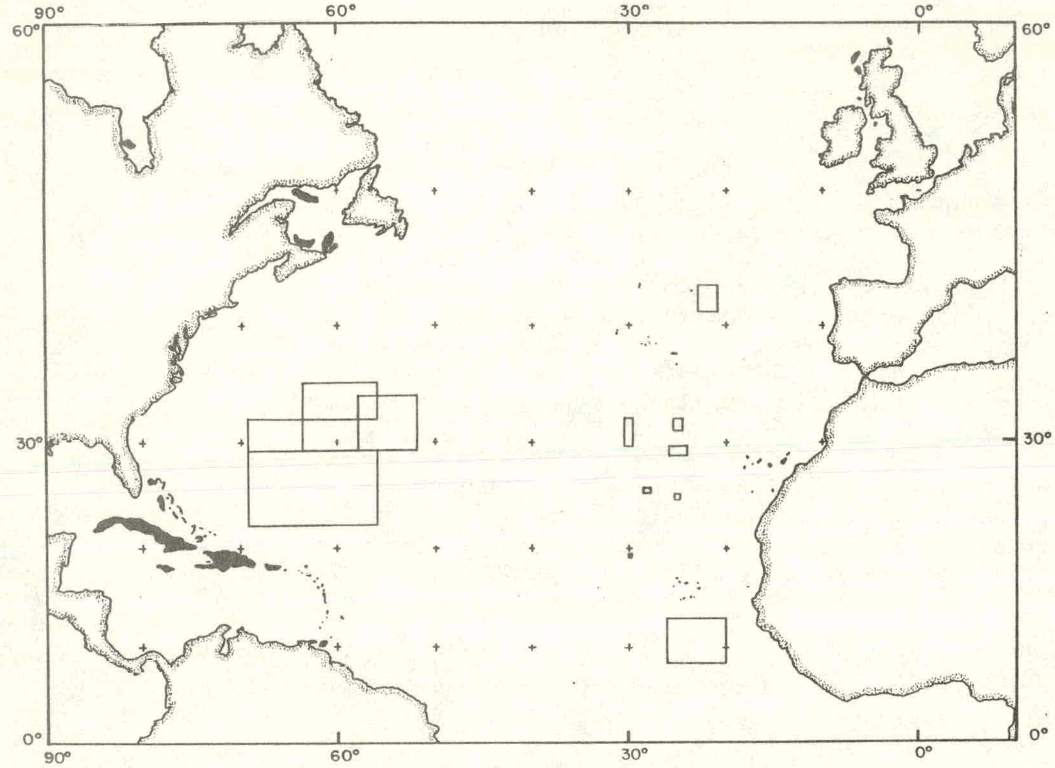
1. North Atlantic Site Qualification - Using the results of European field investigations and continuing review of the US data archives all proposed study areas in the North Atlantic have been evaluated. The Nares Abyssal Plain and the abyssal plain region east of Great Meteor Seamount (Great Meteor East) appear to be the first two areas in which the more detailed investigations of Phase 3 of the Site Qualification Program Plan can be performed. When the results of on-going studies are available several other areas may also be considered suitable for detailed analysis. This continuing evaluation of results will be a major part of my work in 1982.

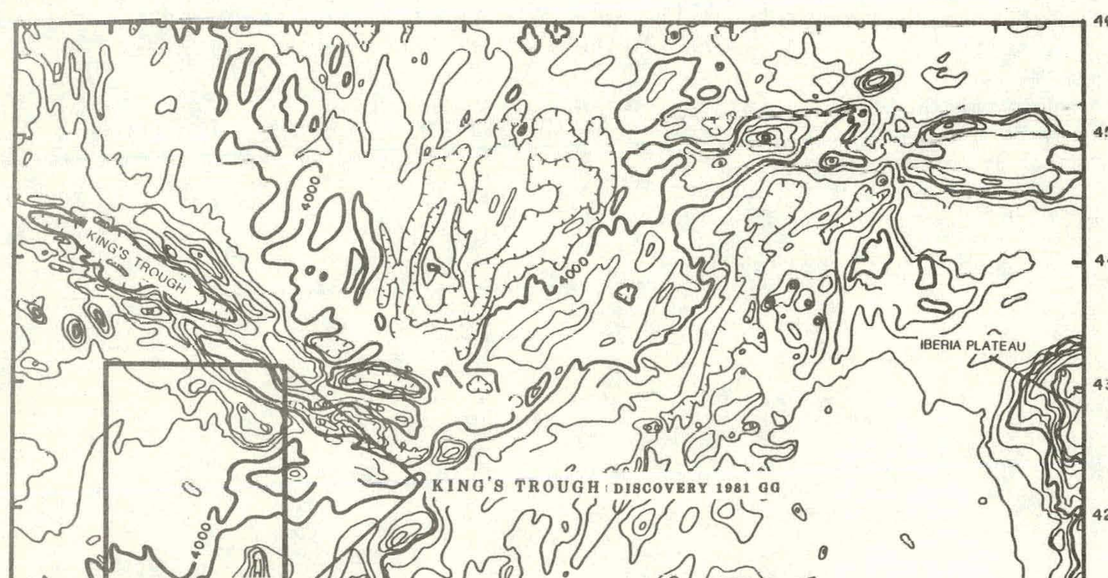
2. Glomar Challenger Drilling - These are plans within the Seabed Working Group to fund Glomar Challenger drilling at one or more study locations in the North Atlantic. Strong pressure for this drilling program stems from the possibility that the Glomar Challenger might be laid-up in late 1983.

3. Site Qualification Cookbook - The site qualification program plan is completed and will appear as a Sandia technical publication. The version to appear in "Radioactive Wastes in the Oceans" still awaits reviewers' comments!

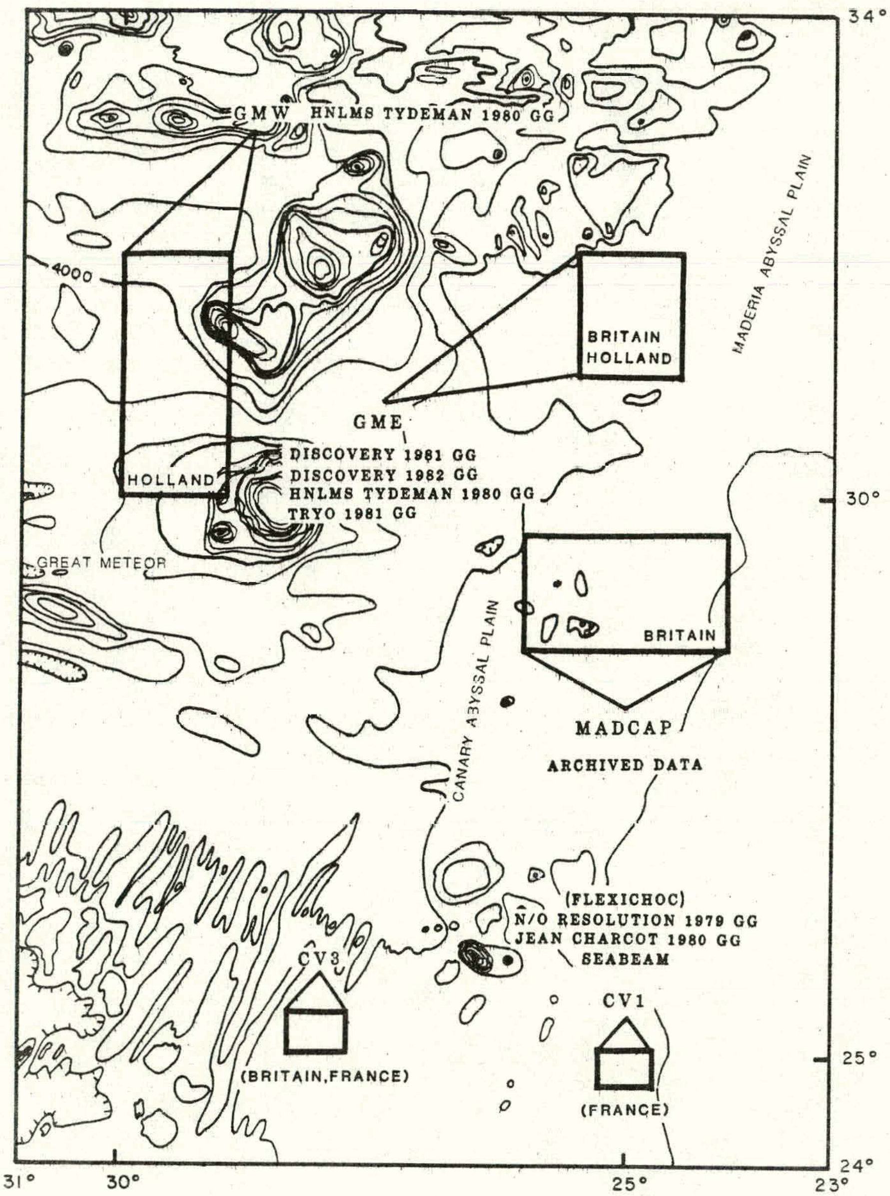
4. Paleomagnetic Analysis of PAC 1 Sediments - The paleomagnetic analysis of PAC 1 sediments has been completed by Dr. C. Barton. Alternating field cleaning at a peak field of 200 Oersteds does not significantly alter the pattern of reversal boundaries and sedimentation rates previously reported based on NRM data alone. With the exception of the loss of core tops through coring the pattern of sedimentation appears continuous and stable.

5. Sohm Abyssal Plain - A detailed contour map is presently being made of the southern portions of the southeastern Sohm Abyssal Plain, one of the several study areas which may prove suitable for further study (item #1). This map will be used as background for a Canadian funded GLORIA survey (1 day) of a selected portion of the southern Sohm in Spring of 1982.

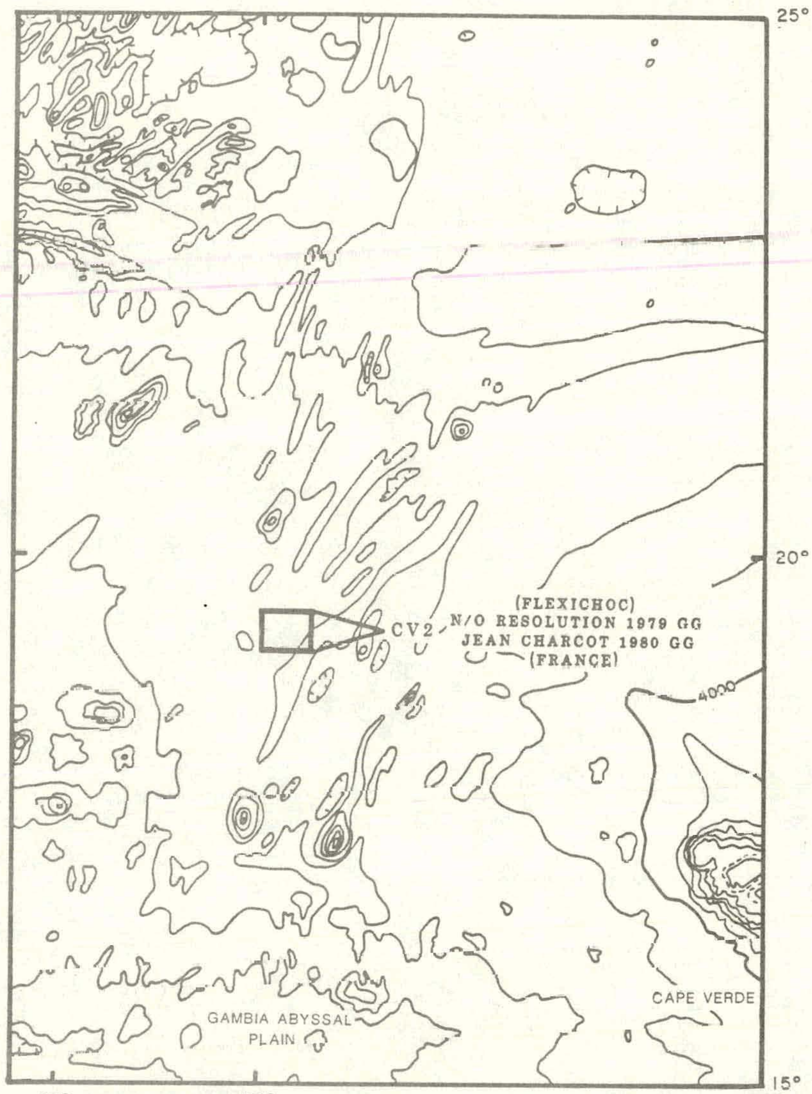

90°
60°
30°
0°
60°
30°
0°
90°
60°
30°
0°


KING'S TROUGH
4000
IBERIA PLATEAU
KING'S TROUGH: DISCOVERY 1981 GG
BRITAIN
46°
45°
44°
43°
42°
41°
40°
24°
20°
15°
12°

DISPOSAL OPTIONS		REGION	SEDIMENT THICKNESS (m)	CURRENTS	MASS MOVEMENT	SEAMOUNTS	ACOUSTIC UNIFORMITY	LATERAL UNIFORMITY	HIATUSES	SANDS	OTHER
Deep	Shallow										
-	D	*King's Trough*	~300-500	+	?	+	?	?	?	?	Rocks Shallow

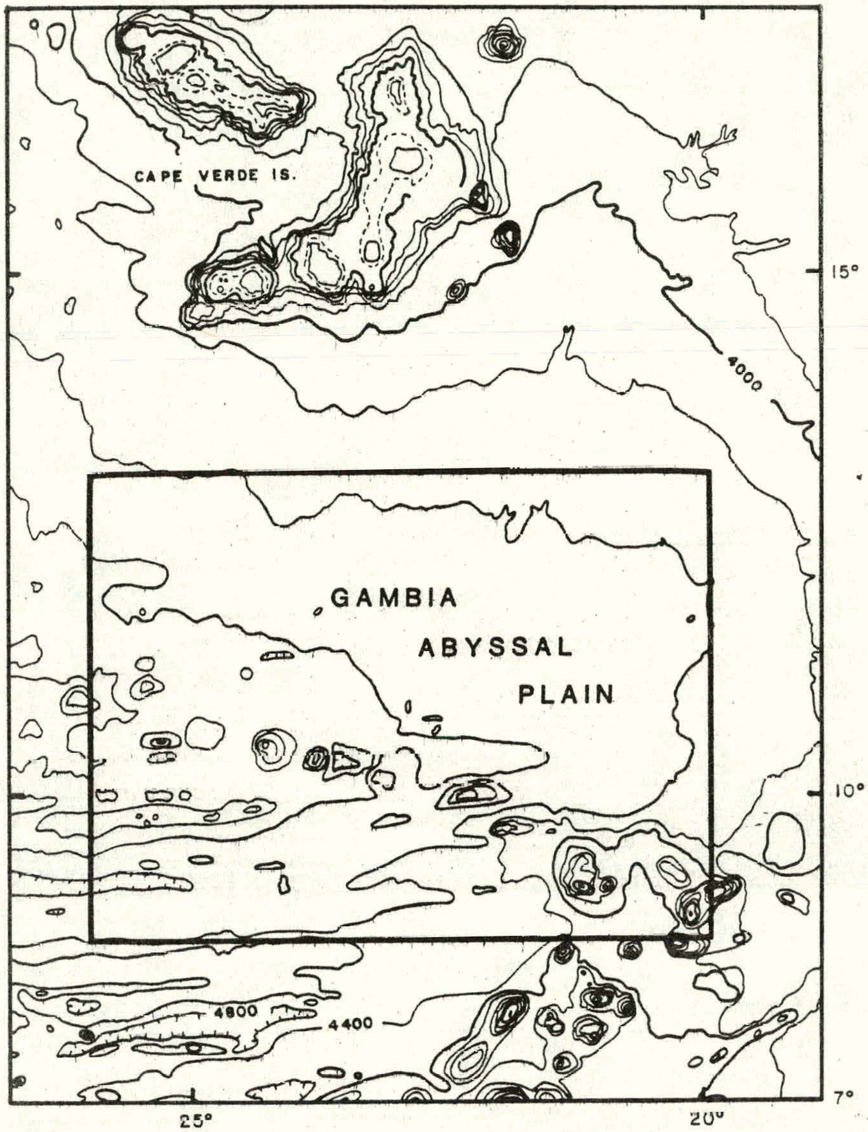

34°
GMW
HNLMS TYDEMAN 1980 GG
4000
BRITAIN
HOLLAND
MADERIA ABYSSAL PLAIN
GME
DISCOVERY 1981 GG
DISCOVERY 1982 GG
HNLMS TYDEMAN 1980 GG
TRYO 1981 GG
HOLLAND
30°
GREAT METEOR
BRITAIN
CANARY ABYSSAL PLAIN
MADCAP
ARCHIVED DATA
(FLEXICHOC)
N/O RESOLUTION 1979 GG
JEAN CHARCOT 1980 GG
SEABEAM
CV3
CV1
(BRITAIN,FRANCE)
(FRANCE)
25°
24°
31°
30°
25°
23°

DISPOSAL OPTIONS Deep	Shallow	REGION	SEDIMENT THICKNESS (m)	CURRENTS	MASS MOVEMENT	SEAMOUNTS	ACOUSTIC UNIFORMITY	LATERAL UNIFORMITY	HIATUSES	SANDS	OTHER
-	2	Great Meteor East	~200	+	+	+	+	-	?	-	
+0	D	Cape Verde CV1	~200-800	+	-	+	-	-	?	-	
-	D	Great Meteor West	~200	+	-	-	-	?	-	+	Shallow
0	?	Cape Verde CV3	~300-500	+	+	+	+	?	?	?	
-	D	Mad Cap	?	?	?	-	-	-	?	-	

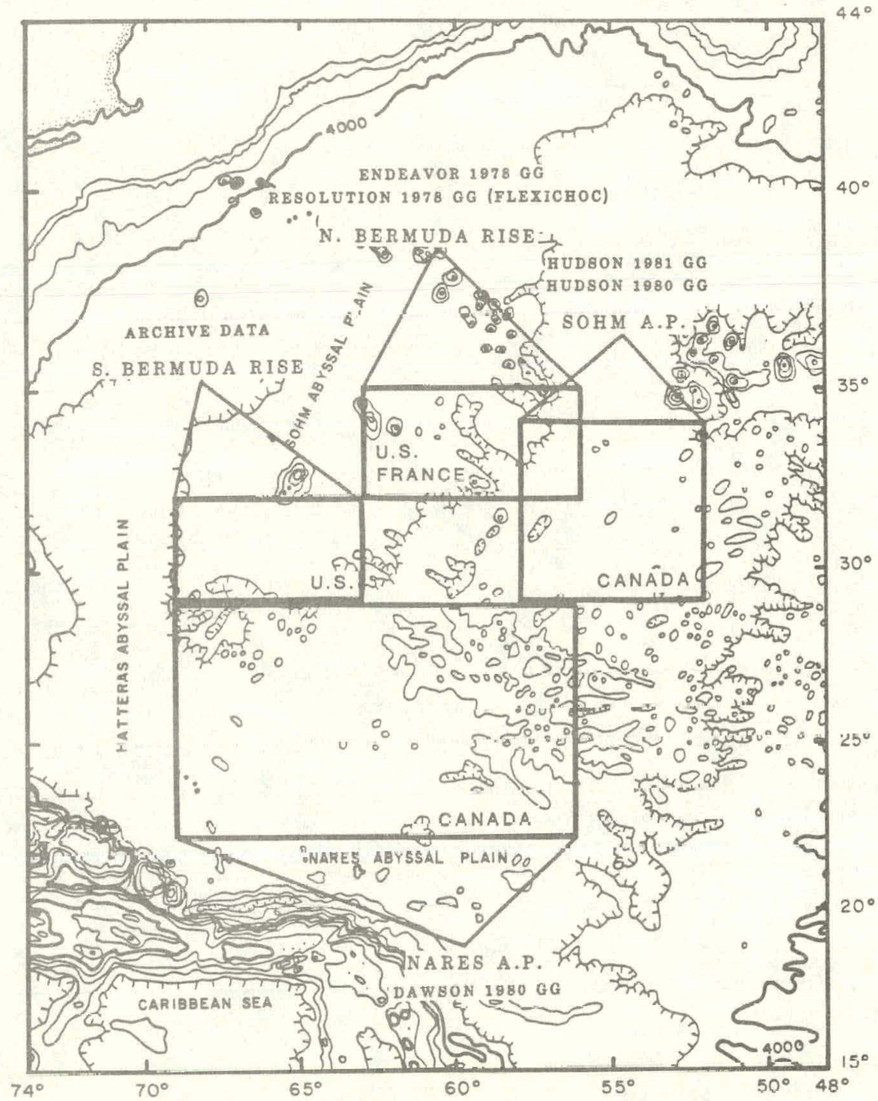


25°
20°
15°
25°
30°
32°
(FLEXICHOC)
N/O RESOLUTION 1979 GG
JEAN CHARCOT 1980 GG
(FRANÇE)
CV2
4000
CAPE VERDE
GAMBIA ABYSSAL
PLAIN

DISPOSAL OPTIONS		REGION	SEDIMENT THICKNESS (m)	CURRENTS	MASS MOVEMENT	SEAMOUNTS	ACOUSTIC UNIFORMITY	LATERAL UNIFORMITY	HIATUSES	SANDS	OTHER
Deep	Shallow										
–	D	Cape Verde CV2	~200-300	+	–	+	0	?	?	–	


CAPE VERDE IS.
15°
4000
GAMBIA
ABYSSAL
PLAIN
10°
4800
4400
7°
25°
20°

DISPOSAL OPTIONS		REGION	SEDIMENT THICKNESS (m)	CURRENTS	MASS MOVEMENT	SEAMOUNTS	ACOUSTIC UNIFORMITY	LATERAL UNIFORMITY	HIATUSES	SANDS	OTHER
Deep	Shallow										
+0	?	Gambia Abyssal Plain	~600	+	+	+	+	?	?	?	



4000
ENDEAVOR 1978 GG
RESOLUTION 1978 GG (FLEXICHOC)
N. BERMUDA RISE
HUDSON 1981 GG
HUDSON 1980 GG
SOHM A.P.
ARCHIVE DATA
S. BERMUDA RISE
SOHM ABYSSAL PLAIN
U.S.
FRANCE
U.S.
CANADA
HATTERAS ABYSSAL PLAIN
CANADA
NARES ABYSSAL PLAIN
NARES A.P.
DAWSON 1980 GG
CARIBBEAN SEA
4000
44°
40°
35°
30°
25°
20°
15°
74°
70°
65°
60°
55°
50°
48°

DISPOSAL OPTIONS		REGION	SEDIMENT THICKNESS (m)	CURRENTS	MASS MOVEMENT	SEAMOUNTS	ACOUSTIC UNIFORMITY	LATERAL UNIFORMITY	HIATUSES	SANDS	OTHE
Deep	Shallow										
-	1	Nares Abyssal Plain	~200	+	+	+	+	+	?	+	
0	?	S. Sohm Abyssal Plain	~400-600	0	+	?	+	?	?	?	
-	?	Southern Bermuda Rise	~200-400	0	?	+	-	?	?	+	
+0	D	Northern Bermuda Rise	>1000	-	-	+	-	-	-	+	

PHASE II

DISPOSAL OPTIONS		REGION
Deep	Shallow	
0	?	S. Sohm Abyssal Plain
+0	?	S. Hatteras Abyssal Plain
0	?	Cape Verde CV3
+0	?	Gambia Abyssal Plain
-	?	Southern Bermuda Rise
-	D	Mad Cap
-	D	King's Trough

LEGEND:

+	Favorable Characteristics
-	Unfavorable Characteristics
0	Available Data Inconclusive
?	No Data
D	Downgrade Study Region

PHASE III

DISPOSAL OPTIONS		REGION
Deep	Shallow	
-	1	Nares Abyssal Plain
-	2	Great Meteor East
+0	D	Cape Verde CV1
-	D	Cape Verde CV2
-	D	Great Meteor West
+0	D	Northern Bermuda Rise

LEGEND:

+	Favorable Characteristics
-	Unfavorable Characteristics
0	Available Data Inclusive
?	No Data
D	Downgrade Study Region

FLOW STUDIES OF THE NORTHWEST PACIFIC POTENTIAL WASTE DISPOSAL SITES

M. Hobart, Lamont-Doberty Geological Observatory

This presentation will include discussions of two additional areas to provide additional data to put our Northwest Pacific analysis in perspective. I will talk about recent studies in the Mariana Trough Back-Arc Spreading Center which combined heat flow and in-situ pore water studies. I will also talk about studies in the distal end of the Nares Abyssal Plain in an area of "transparent domes." This area is of interest because it shows the importance of local outcrops in controlling the thermal regime and also because the Central Nares Abyssal Plain is now being considered as a waste disposal area.

The Mariana Trough Study is along the DSDP leg 60 transect along 18° N. The study area is located between sites 453 and 454, and is on crust a couple of million years old. We have had two heat flow cruises to the area. The second cruise was in early 1981, immediately following a Scripps deep-tow study of the site, and used the same transponder network. We have well over 100 heat flow measurements in an area of a few square miles around several mounds which have been identified as LOCI OG low temperature hydrothermal discharge. Several temperature profiles in the area are non-linear, indicating fluid motion in the sediment. The thermal conductivity of the sediments is fairly uniform, so we can use the simple one-dimensional model of Bredehoeft and Papaoopulos (Water Resources Research, V. 1, 1965). We can use a more elaborate analysis technique if conductivity varies significantly. Analyzing our profiles indicates fluid flow rates of $\sim$ 0.2-2 m/year in areas of outflow, with most in the range of 0.3-0.8 m/year. Measurements of in-situ pore water chemical profiles for cores with non-linear gradients show agreements with our models for some but not all cores. We also found areas of downward flow into the sediment in areas of thin sediments (< 20 m). Here our 5-10 m profiles sampled enough of the sediments to see the curvature at the thermal boundary layer at the base of the sediments (downward flow). Thick sediments provide a problem if the flow is downward, as you see only a linear gradient which is lower than the conductive gradient would be in the absence of flow.

Mapping the areas of flow, we find localized areas of high rate outflow surrounded by larger areas of low rate inflow. This is very similar to the flow patterns predicted by Dave Gartling of Sandia Labs using the finite-element porous media flow program "Mariah." We provided structural data for this program and the permeabilities for the basalt (from DSDP hole 504B, the only in-situ basement permeability value), and the surficial sediments (from measurements by Dallas

Abbott).

The model predicts the surface heat flow and the locations of inflow and outflow of fluids. It also shows that the bulk permeability of the basement cannot be much more than an order of magnitude (at most) lower than our inout value or the agreement with the heat flow pattern is totally lost.

We have presented this data to show that in areas other than the Northwest Pacific we have evidence supporting our aovective interpretation of non-linear temperature profiles. They are not due to conductivity changes, bottom water temperature variation, or biogenic/chemical heat production.

We will now show the results of a study at the distal end of the Nares Abyssyl Plain in the Northwest Atlantic. The site is at about 23° N, 60° W, where the turbidites of the plain are flooding the valleys between abyssal hills. The age of the crust is slightly greater than 80 m.y.; this is near the age where the conductive heat flow averages in the Atlantic approaches the theoretical value for a heating (Hobart et al, in press). This is the boundary where significant convective heat transfer between the curst and the ocean ceases.

This area has been studied in detail because of the presence of what have been termed "transparent domes." These are small knobs sticking up above the level of the abyssal plain turbidites which show very little acoustic energy return on shipboard 3.5 KHZ and single channel seismic systems. Studies have shown that this is due to a very thin covering of smooth red clays, causing just a specular return from one point.

A profile from a pinger on a corner shows the thin covering of sediment from one dome which we cored. The core was 5-6 m long and contained a large amount of hydrothermally altered clays at the bottom of the core. The clay contained Phillipsite (showing long term exposure to sea-water) and Polygorskite (showing interaction of hydrothermal fluids and Montmorillonite). Highly altered basalt was also cored. These domes are in great contrast to the surrounding abyssal plains, with up to 500 m of sediment, and the abyssal hills, with 75-100 m of sediment.

Heat flow profiles are all linear in this study. The heat flow is very close to theoretical values in the abyssal plains. Some of the abyssal hill measurements show variability indicating convective cells in basement under the mud. A detailed heat flow profile across one dome shows an enormous heat flow peak (∿ 700 mW/m^2) localized over the dome (∿ 200-300 m wide) and a surrounding area of heat flow slightly depressed below theoretical expectations (out to at least 2-3 km).

With Dave Gartling's help, a model (again using the Mariah Program) has been developed which explains this pattern as being caused by a convective system "mining" the heat from under the thick abyssal plain sediments surrounding the dome and venting it through the dome. The model predicts that fluid outflow will occur on the dome. We did not observe this but could have missed the flow area by a small amount. We did not necessarily see the highest heat flow on the dome!

This dome has probably been an exit vent for a long time (80 m.y.?) and may have been somewhat rejuvenated as the abyssal plain formed and amplified the thermal resistance contrasts between conductive heat flow through thick valley floor sediments and convective heat flow out through the dome. We have presented this data to illustrate the importance of local outcrops in channeling convective heat transfer. It also provides another example of how the Mariah Program was able to successfully predict heat flow and porous media flow.

Finally, to the Northwest Pacific data from the potential waste disposal sites: Roger Anderson presented this data at the last annual meeting, but the data is now in final form. Several non-linear temperature profiles have been found in these areas. One Vema-32 measurement in area B with a modeled flow rate of about 0.5 m/year. Area C had four non-linear profiles, one from Vema-32 and three from Vema-36, with flow rates fairly uniform at 0.6-0.9 m/year. This area had more basement outcrops and sediment slides and slumps, so it is probably ruled out on other grounds. We do believe the slumping may be related to areas of outflow, as the excess pore pressure to drive the flow will decrease the sediment strength. Area E had one non-linear profile, indicating outflow of about 0.2-0.3 m/year. There were no basement outcrops or sediment disturbances near this core. The conductivity and water content data from these cores do not indicate that this could cause the non-linear temperature profiles. There doesn't appear to be enough organic matter to cause the non-linearity either.

Thus, the curvature is due either to fluid flow or to bottom water temperature changes. The magnitude of the Δ Tw would have to be $\sim$ 0.15° C, and it would have to be a persistent change for a period of about a year. We do not believe that this large a change has occurred. There are some problems that aren't resolved, however. We normally find flow in areas of thin sediments and/or near basement outcrops. There are no known outcrops near this core (V32 DHF 55), the sea floor is very smooth, the sediments are very uniform over a major acoustic horizon (chert?) and sonobuoys indicate a few hundred meters to basement at their nearest measurement sites. How do you get fluid flow through a thick mass of low permeability sediments?

or, is something wrong somewhere?
- bottom water Tw variation?

- flow model wrong?
- permeabilities wrong?
- depth to basement wrong?

---

*Anderson, Hobart and Langseth, 1979. Science, 204, 828-832. As it discusses the model and the limitations.

NORTH ATLANTIC SITE ASSESSMENT STUDIES

Brian E. Tucholke

North Atlantic site assessment studies during 1981 included three topics. 1) For the eastern North Atlantic we interpreted seismic reflection records obtained from three sources (Woods Hole Oceanographic Institution, Lamont-Doherty Geologcial Observatory, Scripps Institution of Oceanography). Reflection times for total sediment thickness and depth to basement were digitized and converted to actual thickness/depth using sonobuoy-derived velocity regression curves. These data are being plotted and contoured to assess sediment distribution and tectonic patterns. Data from European, U.S. Navy, and miscellaneous sources remain to be incorporated. 2) In the western North Atlantic (areas MPG III E, III S) we have completed a compilation of currently available bottom-photograph stations and seafloor samples. Together with our previous compilations of geological/geophysical information, these data indicate that the eastern part of the Nares Abyssal Plain (in area MPG III S) should have high priority for further, detailed evaluation as a candidate site. 3) A pilot computer modelling study was undertaken to evaluate the scales at which geologic discontinuities and sediment inclusions (e.g. cannisters) can be detected beneath the seafloor by use of reflection seismology. The preliminary studies show that inclusions do generate an identifiable reflection pattern and that this pattern should be detectable using recording and source parameters available with present technology.

IV. THERMAL RESPONSE STUDIES

Technical Program Coordinator: C. M. Percival

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C. M. Percival, SNLA 75

Thermal Science
C. E. Hickox, SNLA 80

ISHTE Geotechnical
A. J. Silva, University of Rhode Island 92

ISHTE Engineering
L. Olson, University of Washington Applied Physics Laboratory 101

THERMAL RESPONSE STUDIES

Introduction

C. Mark Percival, SNLA

The general approach being used to develop the ability to predict specific phenomenological response is the same as the general research approach for the Subseabed Disposal Program; that approach is to propose a hypothesis, formulate a model to fit that hypothesis, determine the necessary properties to use the model, and verify the complete system with laboratory and or field experiments. In some respects, the Thermal Transport effort is ahead of other areas in the SDP.

The hypothesis, computational model, and significant property determinations to predict the thermal response have been completed and work has progressed into laboratory and field verification activities. Four experiments are now being developed: two laboratory experiments conducted at Sandia National Laboratory; the In-Situ Heat Transfer Experiment (ISHTE); and the ISHTE Simulation Experiment (ISIMU). The two experiments at SNL are both essentially "bench-marking" type experiments to check the modeling capability of the Mariah computer code used to predict thermal and fluid mechanical responses of the sediment. These experiments will be described by Charles Hickox of SNL. ISHTE is a large, complex experiment requiring the combined efforts of several organizations and the participation by each organization will be discussed by the principal investigators involved. The ISIMU experiment is a 0.287:1.000 scale ISHTE being conducted in the large pressure vessel at the Naval Ship Research and Development Center in Annapolis, Maryland. All principal investigators involved in ISHTE are participating in the simulation experiment. The results of ISIMU will not only have bearing on the successful completion of ISHTE, but will provide laboratory data relevant to the thermal, mechanical and thermal-chemical response of the sediment.

THERMAL TRANSPORT

OBJECTIVE: To develop the capability to predict the thermal response of multi–barrier concept.

GOALS

	MILESTONES					
	Completed Previously	FY81	FY82	FY83	FY84	FY85
Thermal/Fluid Flow Model (MARIAH)	X					
Developed –	X					
Documented –		X				
Property Acquisition						
Predicted –	X					
Laboratory measurements –	X					
Verification						
Laboratory						
Hele-Shaw Experiment –			X			
Porous Media Experiment –			X			
ISIMU –			X			
Field (ISHTF)						
Site survey –	X					
Acoustic test cruise –	X					
Mechanical test cruise –		X				
Ocean test –				X		
Deploy ISHTE –					X	
Recover ISHTE –						X

ISSUES	RESOLUTION	FY
Are existing thermal transport codes adequate to predict the thermal and fluid flow response of the sediments?	Bench tests ISHTE simulation ISHTE	82 82 85
Can laboratory and in–situ tests be used to confirm thermal and fluid flow calculations?	ISHTE simulation ISHTE	82 85
What is the maximum initial acceptable thermal loading?		—

ISHTE

SUITE OF EXPERIMENTS

In-Situ Thermal Conductivity

Temperature Field/Thermal Model

Pore Pressure Measurement

Vane Shear Determination Of Mechanical Properties

Ion Diffusion/Ion Sorption

Pore Water Samples At Temperature

Post Test Analysis Of Cores

ISHTE

SIMULATION EXPERIMENT

(1981)

July 27	Arrive NSRDC Assemble test tank
August 3	Load tank Assemble cold room
August 7	Begin consolidation
October 22	Consolidation complete Prepare for experiment
November	Tank pressurized Preliminary experiments
November	Turn on heater
December	Test complete Begin cool down
December	Depressurize tank Begin post test
December	Clear NSRDC

ISHTE

Simulation Experiment

Laboratory Test To Attempt To Uncover Any Surprises Prior To Ocean Experiment.

- Pressure Buildup In Sediment
- Thermochemical Effects
- Sediment Response
- Convection Along Cylinder

Laboratory Determination Of Thermal Conductivity Of Sediment At High Pressure And Low Temperature

Laboratory Simulation Of ISHTE Will Lend Credence To Laboratory Scale Modeling Of Waste Canister Response

ISHTE Simulation Will Also Provide An Opportunity To Test Available Hardware At Pressure With "Hardwire" Instrumentation And TV Monitoring

ISHTE Participants

Applied Physics Lab -- University of Washington

- Ocean engineering (platform, thermal sensors, microprocessor, acoustic TM, deployment and recovery)

Atlantic Meteorological and Oceanographic Lab (NOAA)

- Pore pressure

Marine Geomechanical Lab -- University of Rhode Island

- Geotechnical science
- Vane shear

Monsanto (Ohio)

- Isotope heater

Sandia National Laboratories

- Project management
- Thermal science
- Geochemistry

Woods Hole Oceanographic Institution

- Geochemistry
- Pore water sampling

THERMAL ANALYSIS
FOR
SUBSEABED DISPOSAL OF NUCLEAR WASTE

C. E. Hickox, SNLA

ABSTRACT

At Sandia National Laboratories (SNL), the Fluid and Thermal Sciences Department (Department 5510) provides support to the Subseabed Disposal Program (SDP) in the areas of heat transfer and fluid mechanics. Additional support is also provided for the mathematical and numerical modeling of both radionuclide transport and sediment response. In this abstract, thermal analyses performed in support of the SDP are summarized. The work described represents a collaborative effort among several individuals in Department 5510.

Current activities are concentrated in the areas of (1) thermal analysis of waste disposal concepts, (2) support of the In Situ Heat Transfer Experiment (ISHTE), (3) participation in laboratory studies of the scaled ISHTE, or ISHTE Simulation (ISIMU), (4) thermal analysis in support of radionuclide transport and chemistry studies, and (5) development of laboratory studies of natural convection in porous media.

Insight into the process of thermally induced convection in porous media can be gained by considering simplified mathematical models. Under certain simplifying assumptions, the thermally induced convective flow field can be described in terms of a non-dimensional parameter called the Rayleigh number. This parameter is physically representative of the relative importance of buoyancy forces, viscous forces, momentum diffusion, and thermal diffusion. For subseabed disposal of nuclear waste, a value of $O(10^{-3})$ is anticipated for the Rayleigh number. For values of the Rayleigh number which are significantly smaller than unity, the temperature distribution in a natural convective flow field is essentially unaffected by the fluid motion and can be adequately predicted by the straightforward application of thermal conduction theory. Hence, it is anticipated that the thermal response associated with the emplacement of nuclear waste in seabed sediment can be predicted from thermal conduction theory. Numerical simulations of the thermal response for proposed emplacement schemes have been accomplished through use of the finite element computer program COYOTE.

A complete description of the natural convective flow field and temperature distribution associated with an emplaced cannister of thermally active nuclear waste can be predicted with the finite element computer program MARIAH. This program was used to analyze

a, so called, reference emplacement configuration. The analysis considered high level waste in a cylindrical container 3m in length with a diameter of 0.3m buried 30m below the sediment-water interface in a layer of sediment 60m thick. The water depth was assumed to be 6000m and the maximum power output of the thermally decaying waste was taken as 1.5kW. Plots of the resulting isotherms and streamlines were produced for selected times. For a point on the surface of the container at the mid-plane, it was shown that the maximum predicted temperature of approximately 220°C decayed to approximately 10°C in 200 years. The corresponding maximum vertical velocity of 20 mm/year decayed to less than 1 mm/year in 100 years. Results of this analysis were used as input for the prediction of radionuclide transport in seabed sediments with the finite difference computer program IONMIG. Results of this prediction indicated that the transport of radionuclides was essentially unaffected by the fluid motion. Hence, it is anticipated that radionuclide transport in the sediment can be adequately described by the processes of diffusion, sorption, and radioactive decay.

A complete thermal analysis of the ISHTE has also been performed. In this experiment, a cylindrical heat source 45 cm long with a diameter of 8.3 cm will be emplaced 60 cm below the sediment-water interface in a region where the water depth is approximately 6000m. The heat source will dissipate 400W, continuously.

Currently, a simulation of the ISHTE is being conducted at the Naval Ship Research and Development Center (NSRDC) in Annapolis, MD. The ISHTE simulation experiment is being conducted in order to (1) verify the methods of analysis employed, (2) provide an opportunity to observe any heretofore unanticipated phenomena, (3) check procedures for data analysis, and (4) check instrumentation proposed for use in the ISHTE. A complete thermal analysis has been performed for the ISHTE simulation experiment and will be used as a guide for the experimental procedure. The predicted temperature distribution in the simulation closely approximates the temperature distribution predicted for the ISHTE in regions where the temperature is greater than 20°C.

Laboratory studies have been initiated at SNL for the dual purposes of guiding the development of computer programs and providing a general understanding of natural convective flows in porous media. Photographs of streamlines produced by natural convection in a Hele-Shaw cell have been obtained and compared with theoretical predictions. An extensive experimental program has been developed for studying natural convection in a vertical porous annulus with accurately controlled boundary conditions. The test rig is under construction and will be operational in a few months.

Planned and continuing activities in the thermal sciences include (1) investigation of approximations and assumptions used in the analyses, (2) thermal analysis for the ISHTE, (3) thermal analysis for the ISIMU, (4) analytical, numerical, and experimental studies of flow in porous media, and (5) interfacing with radionuclide transport and geotechnical studies.

THERMAL ANALYSIS

FOR

SUB-SEABED DISPOSAL OF NUCLEAR WASTE

C. E. HICKOX

SANDIA NATIONAL LABORATORIES

ALBUQUERQUE, NEW MEXICO

CURRENT ACTIVITIES

- THERMAL ANALYSIS OF WASTE DISPOSAL CONCEPTS
- IN-SITU HEAT TRANSFER EXPERIMENT (ISHTE)
- LABORATORY STUDIES OF SCALED ISHTE (ISIMU)
- THERMAL ANALYSIS TO SUPPORT RADIONUCLIDE TRANSPORT AND CHEMISTRY STUDIES
- LABORATORY STUDIES OF NATURAL CONVECTION IN POROUS MEDIA

THERMALLY INDUCED CONVECTION

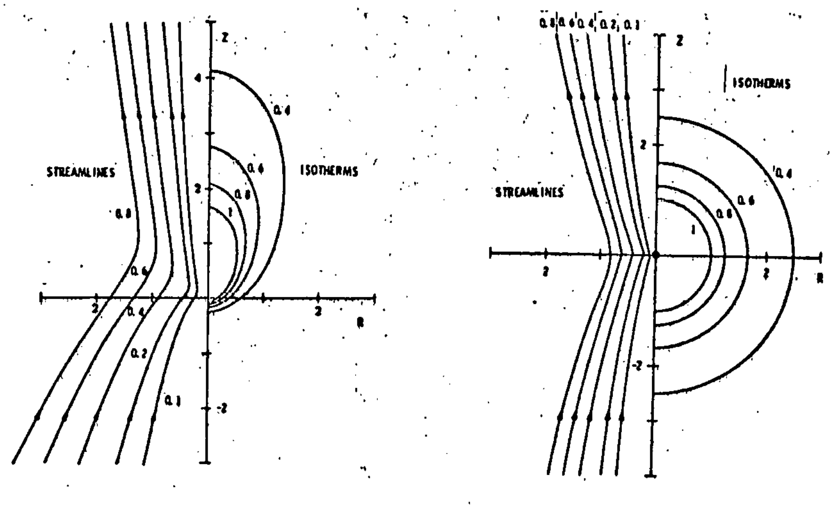
BASIC THEORY:

- RIGID POROUS MATRIX
- INCOMPRESSIBLE FLUID
- SINGLE PHASE FLUID
- BOUSSINESQ APPROXIMATION
- THERMAL EQUILIBRIUM
- DARCY LAW

RAYLEIGH NUMBER:

$$R_A = \frac{\text{BUOYANCY}}{\text{VISCOUS}} \times \frac{\text{MOMENTUM DIFFUSION}}{\text{THERMAL DIFFUSION}}$$

EFFECT OF RAYLEIGH NUMBER



Ra = 10 Ra = 10^{-3}

REFERENCE EMPLACEMENT CONFIGURATION

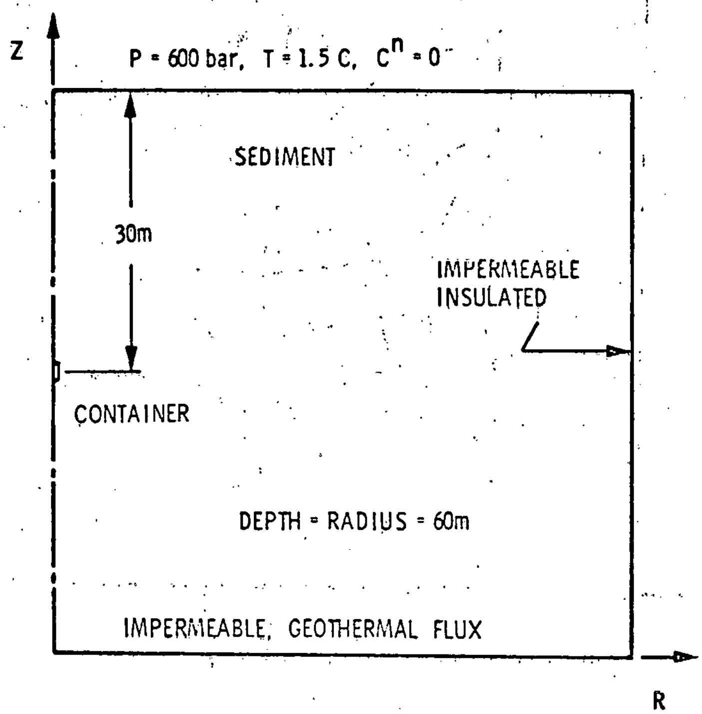
CYLINDRICAL CONTAINER:

LENGTH	3M
DIAMETER	0.3M
BURIAL DEPTH	30M
THICKNESS OF SEDIMENT LAYER	60M
WATER DEPTH	6000M
MAXIMUM THERMAL POWER OUTPUT (HLW)	1.5KW

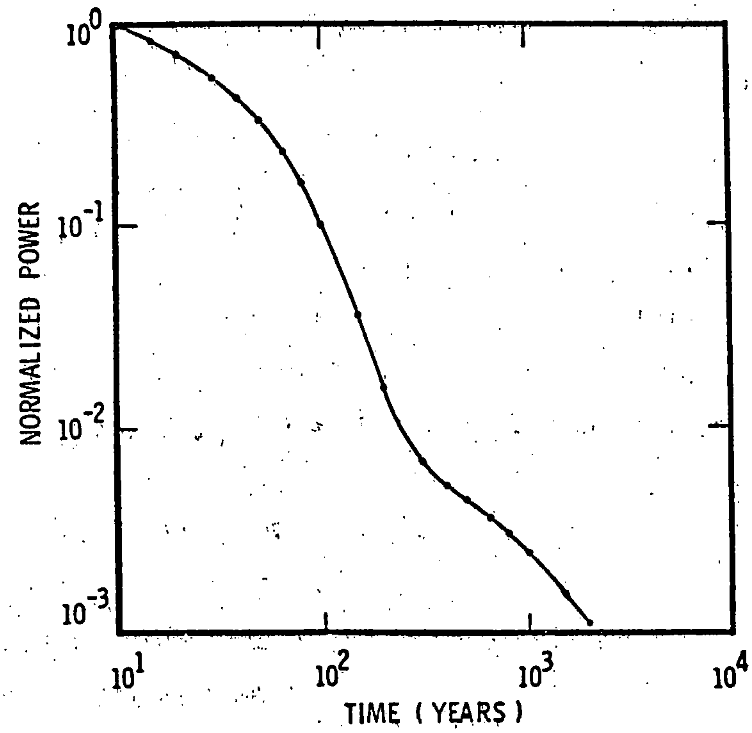
COMPUTATIONAL APPROACH

COMPUTER PROGRAM - MARIAH:

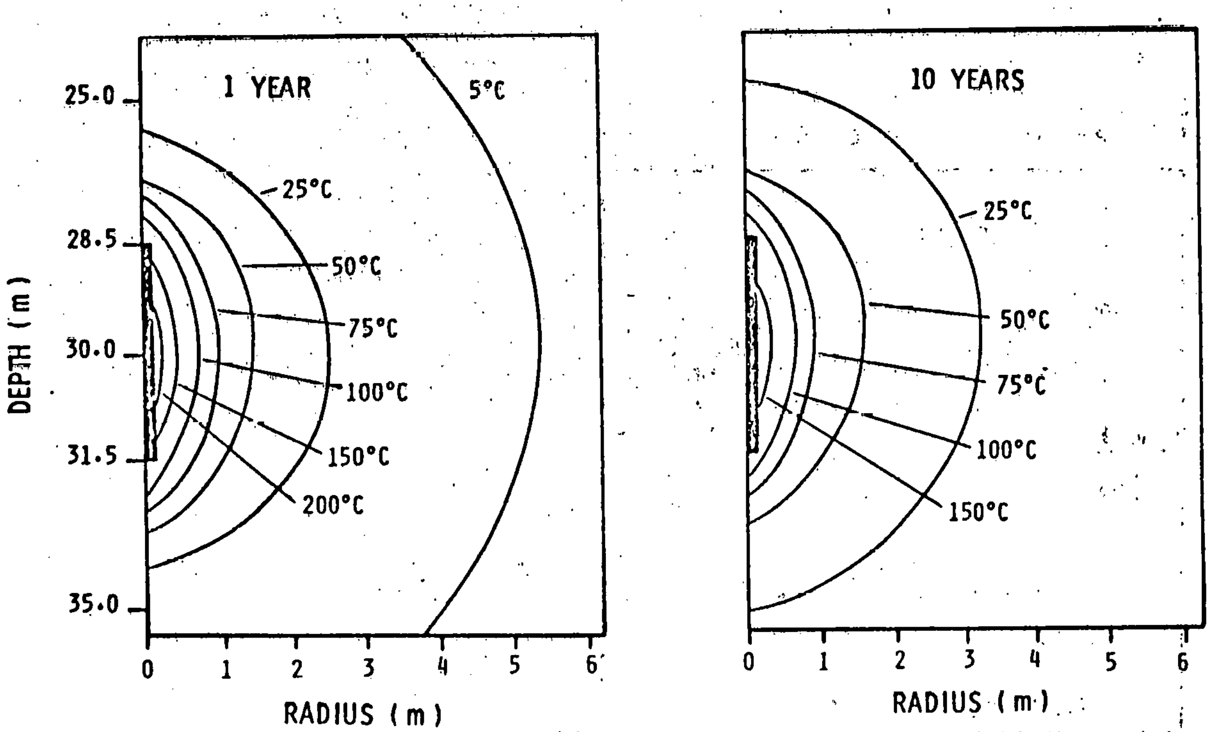
- o BASIC THEORY (PREVIOUS VIEWGRAPH)
- o GALERKIN FORM OF FINITE ELEMENT METHOD
- o PLANAR OR AXISYMMETRIC GEOMETRY
- o TRANSIENT OR STEADY-STATE
- o ISOTHERMAL FLOW, FORCED CONVECTION, OR FREE CONVECTION
- o VARIABLE MATERIAL PROPERTIES
- o ANISOTROPIC MATRIX



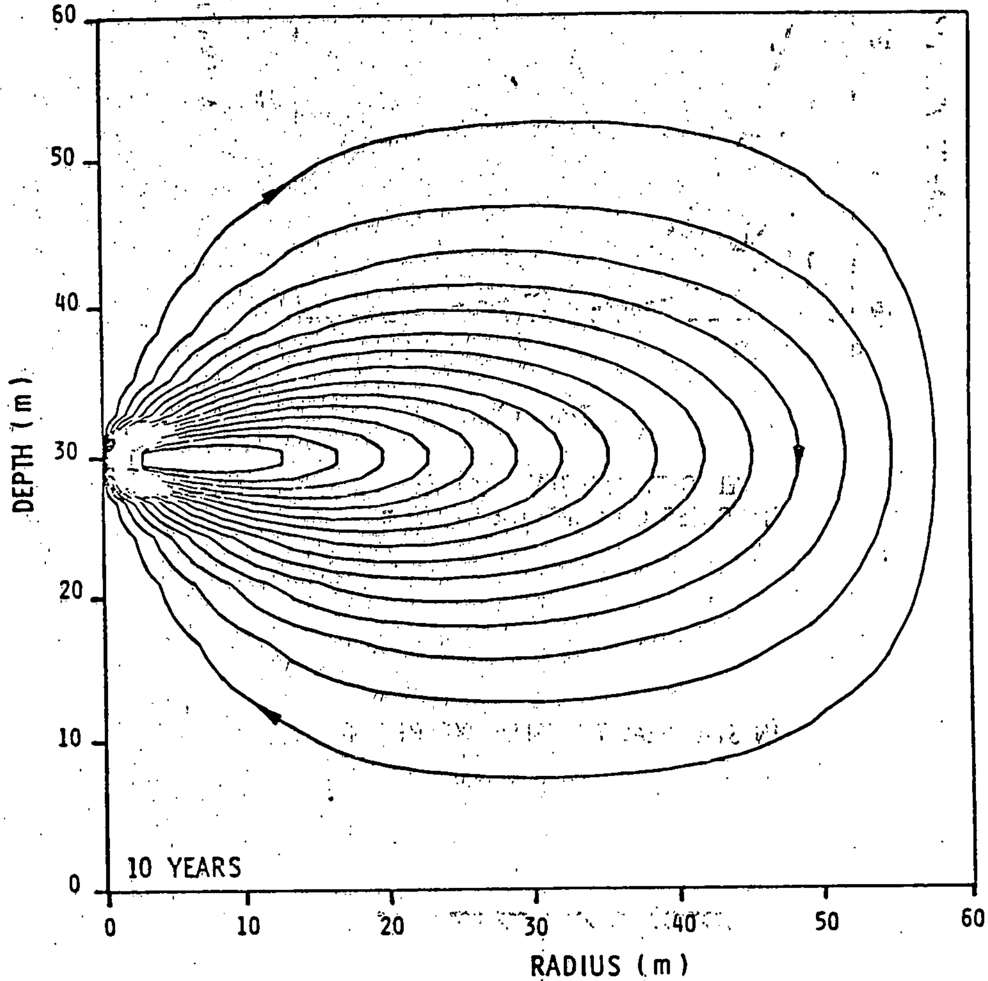
REFERENCE EMPLACEMENT CONFIGURATION



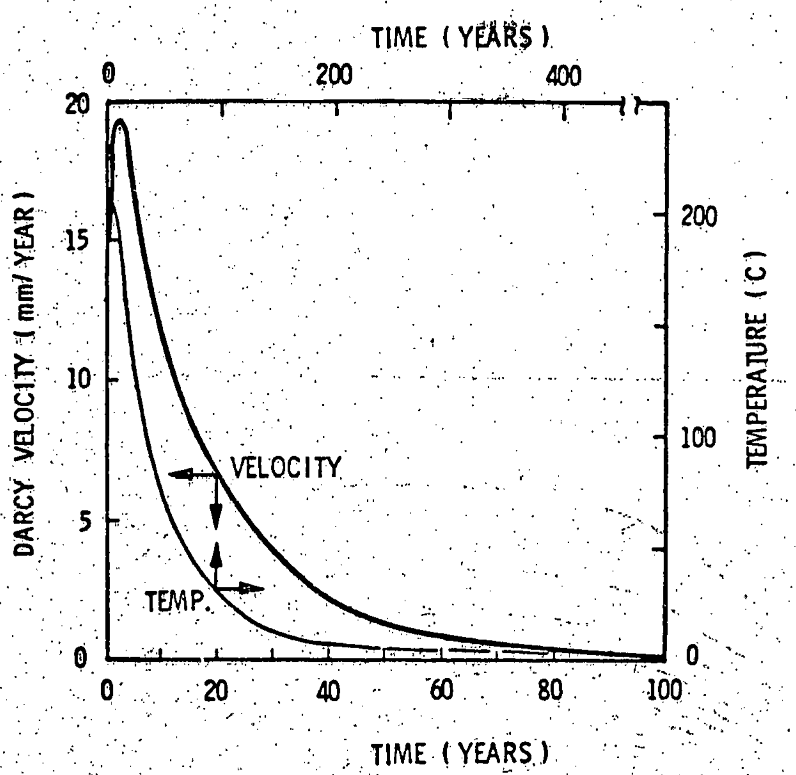
NORMALIZED POWER HISTORY FOR HLW



ISOTHERM PATTERNS NEAR CONTAINER

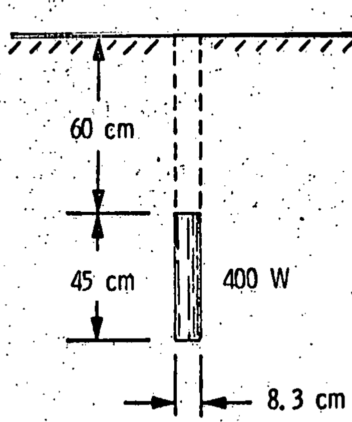


STREAMLINE PATTERN 10 YEARS
AFTER EMPLACEMENT

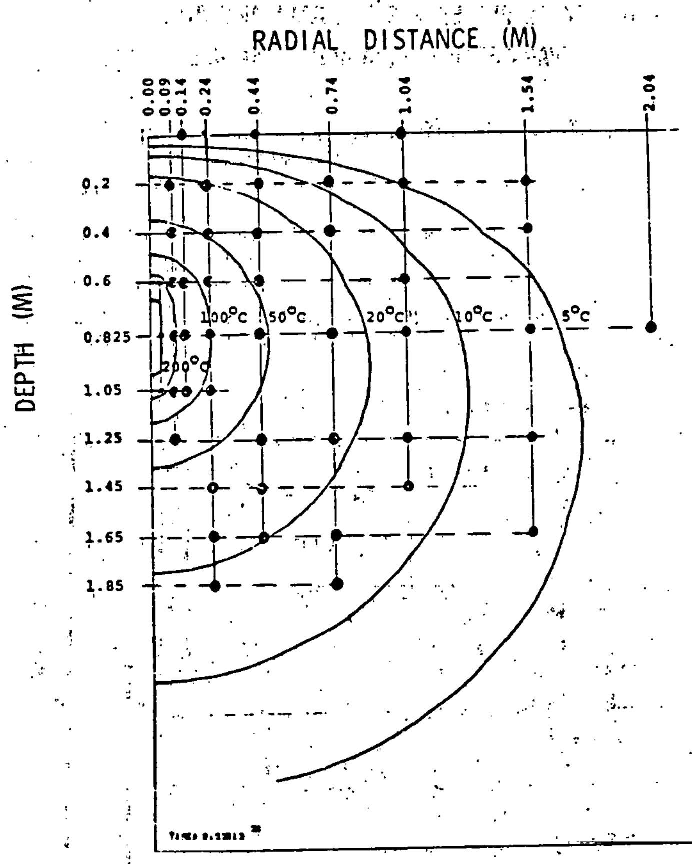


VELOCITY AND TEMPERATURE
HISTORIES ON CONTAINER AT 30m

IN SITU HEAT TRANSFER EXPERIMENT



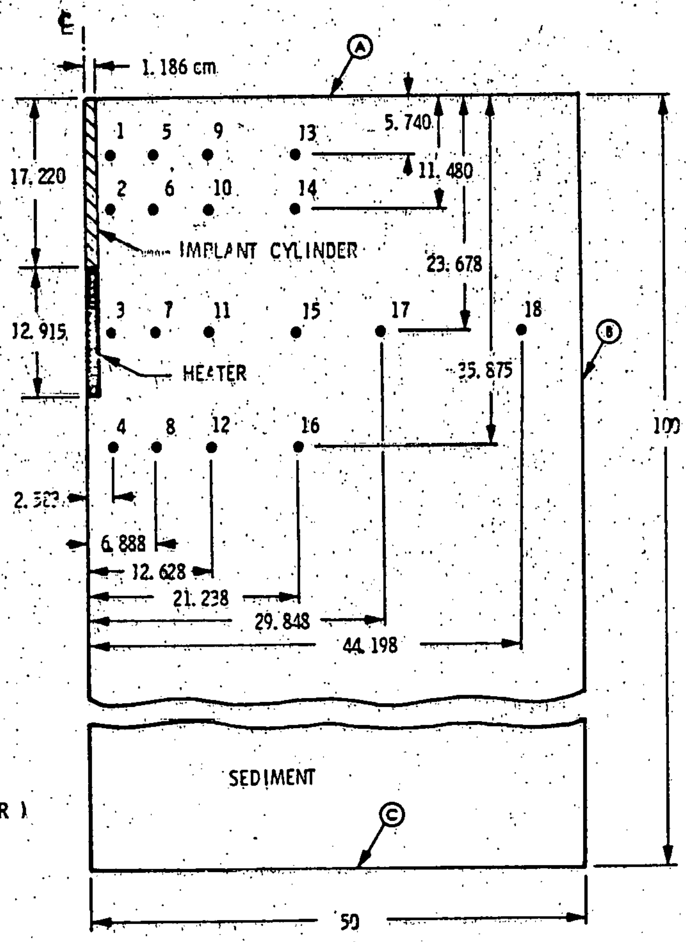
THERMAL FIELD FOR ISHTE



ISHTE SIMULATION

- o VERIFY METHODS OF ANALYSIS
- o OBSERVE UNANTICIPATED PHENOMENA
- o CHECK PROCEDURES FOR DATA ANALYSIS (PARAMETER ESTIMATION TECHNIQUES)
- o CHECK INSTRUMENTATION

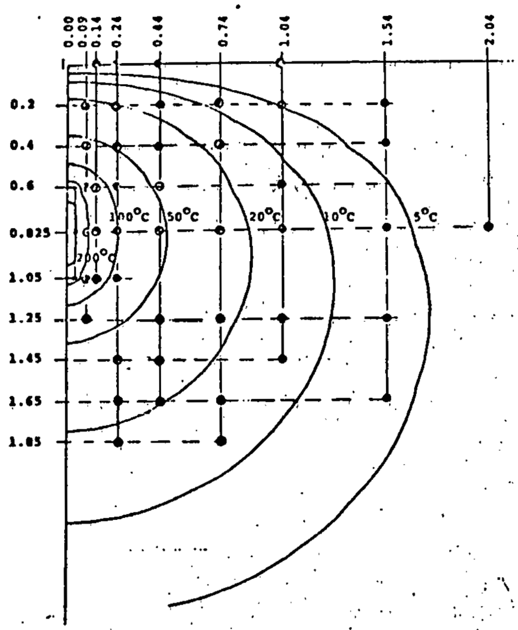
IN SITU HEAT TRANSFER EXPERIMENT SIMULATION (ISIMU)



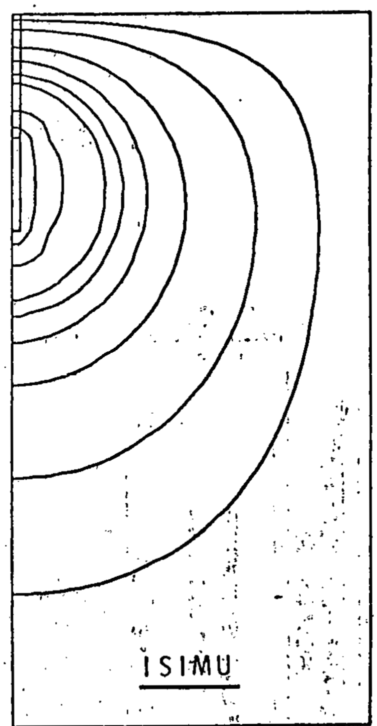
SCALE = 0.287
(30 DAYS = 1 YEAR)

POWER = 115 W

COMPARISON OF THERMAL FIELDS



ISHTE



ISIMU

LABORATORY STUDIES

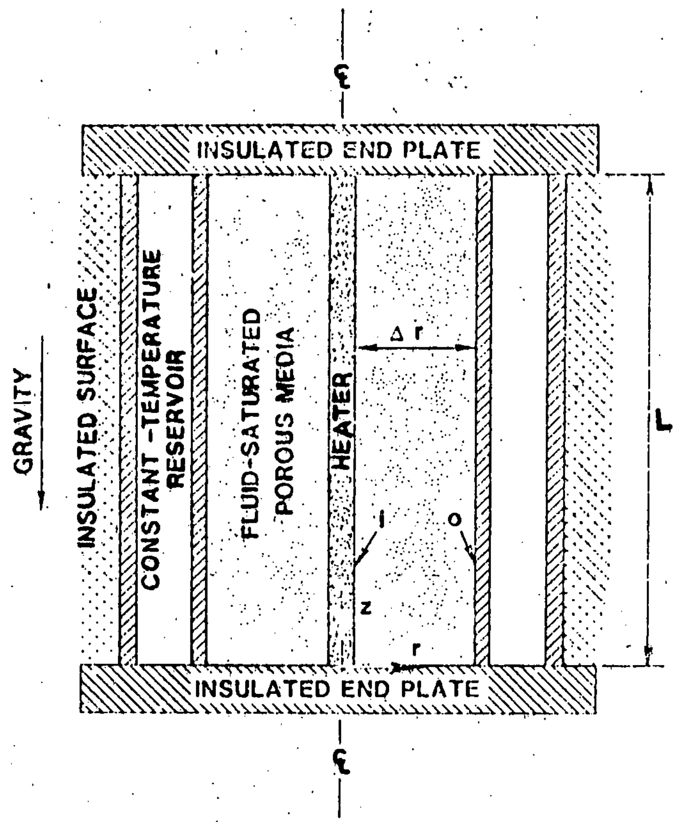
EXPERIMENTS

- o HELE-SHAW CELL
- o NATURAL CONVECTION IN POROUS MEDIA

OBJECTIVES

- o GUIDE DEVELOPMENT OF COMPUTER PROGRAMS
- o CONTRIBUTE TO GENERAL UNDERSTANDING OF NATURAL CONVECTIVE FLOW IN POROUS MEDIA

GEOMETRY AND BOUNDARY CONDITIONS



$L = 89.0$ cm

$r_i = 0.95$ cm

$r_o = 21.91$ cm

$\Delta r = 20.96$ cm (LENGTH SCALE)

$L/\Delta r = 4.25$ (ASPECT RATIO)

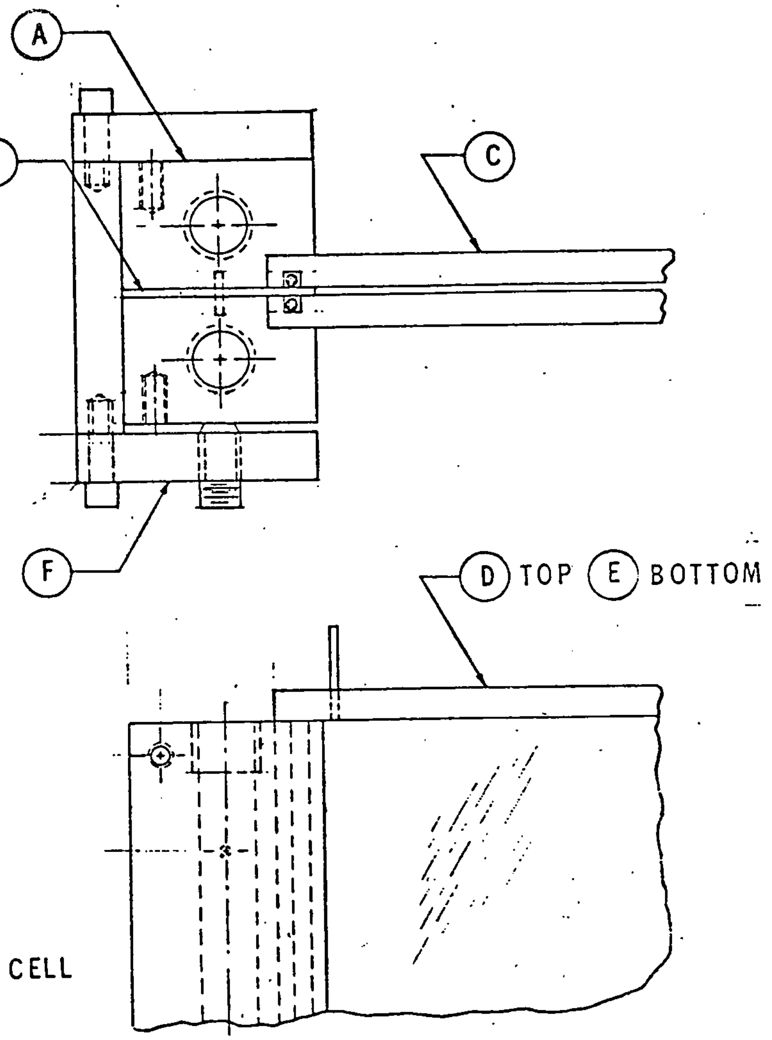
T_i (z) MEASURED

T_o (z) MEASURED (HELD CONSTANT)

T (r, z = o) MEASURED

T (r, z = L) MEASURED

P (r, z = L) HELD CONSTANT AT 1 ATM



ASSEMBLY
HELE - SHAW CELL

CONTINUING / FUTURE ACTIVITIES

- INVESTIGATE APPROXIMATIONS AND ASSUMPTIONS USED IN ANALYSES
- THERMAL ANALYSIS FOR ISHTE
- THERMAL ANALYSIS FOR SCALED ISHTE (ISIMU)
- ANALYTICAL, NUMERICAL, AND EXPERIMENTAL STUDIES OF FLOW IN POROUS MEDIA
- INTERFACE WITH ION TRANSPORT AND GEOTECHNICAL CALCULATIONS

IN SITU HEAT TRANSFER EXPERIMENT (ISHTE)

GEOTECHNICAL PROGRAM - FY 81

UNIVERSITY OF RHODE ISLAND MARINE GEOMECHANICS LABORATORY

A. J. Silva

TASK OUTLINE

- GENERAL GEOTECHNICAL SUPPORT
  - GEOTECHNICAL PARAMETERS AND DESIGN FOR PLATFORM
  - SEDIMENT-STRUCTURE INTERATION TESTS (SSIT)
  - SITE STUDIES

- SIMULATION EXPERIMENT
  - SEDIMENT TANK AND SEDIMENT PREPARATION
  - PRETEST CONSOLIDATION AND ANALYSIS
  - PROJECT COORDINATION, GENERAL INTERFACING OF COMPONENTS

  - TANK AND SEDIMENT SET-UP
  - PARTICIPATE IN OPERATION
  - BREAKDOWN, SAMPLING, GEOTECHNICAL ANALYSIS
  - VANE SHEAR EXPERIMENTS

- IN SITU VANE SHEAR PROBE (ISVSP)
  - DESIGN, FABRICATION, TESTING.
  - MODIFY FOR ISHTE SIMULATION EXPERIMENT

URI/MGL 10/81

ISHTE SIMULATION

TANK CONFIGURATION
CONSOLIDATION PHASE

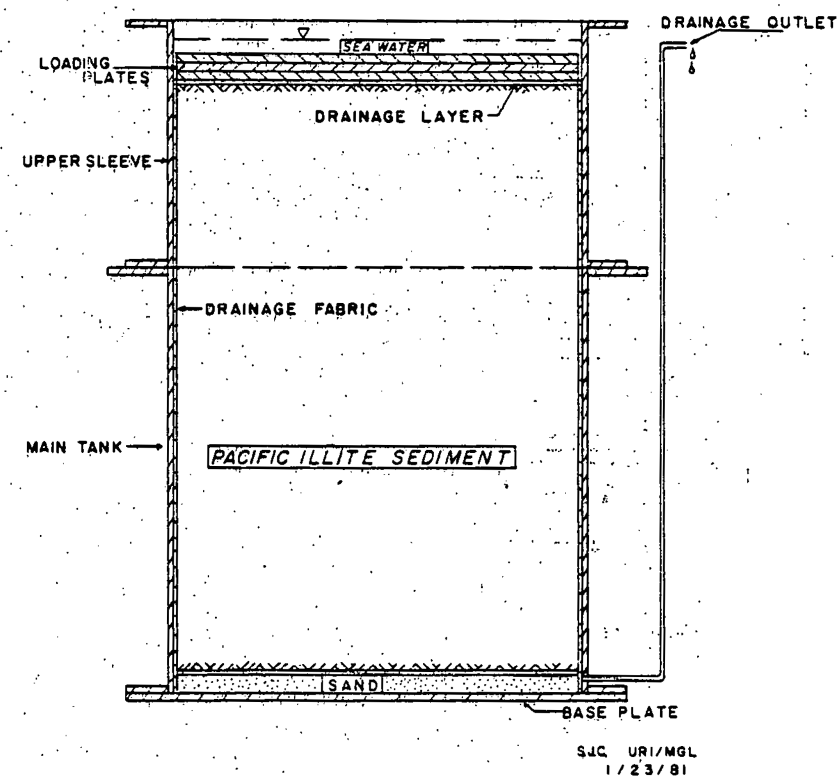


FIGURE 4.3-1

ISHTE SIMULATION

TEST CONFIGURATION

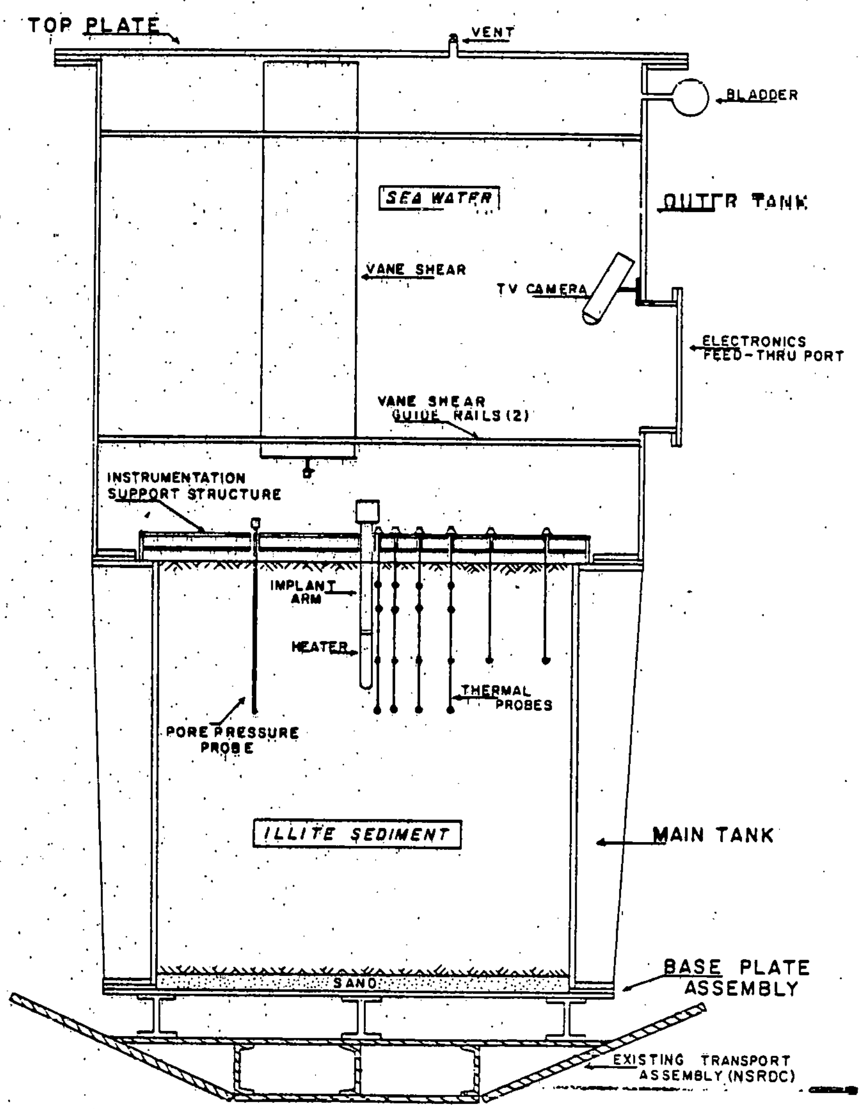
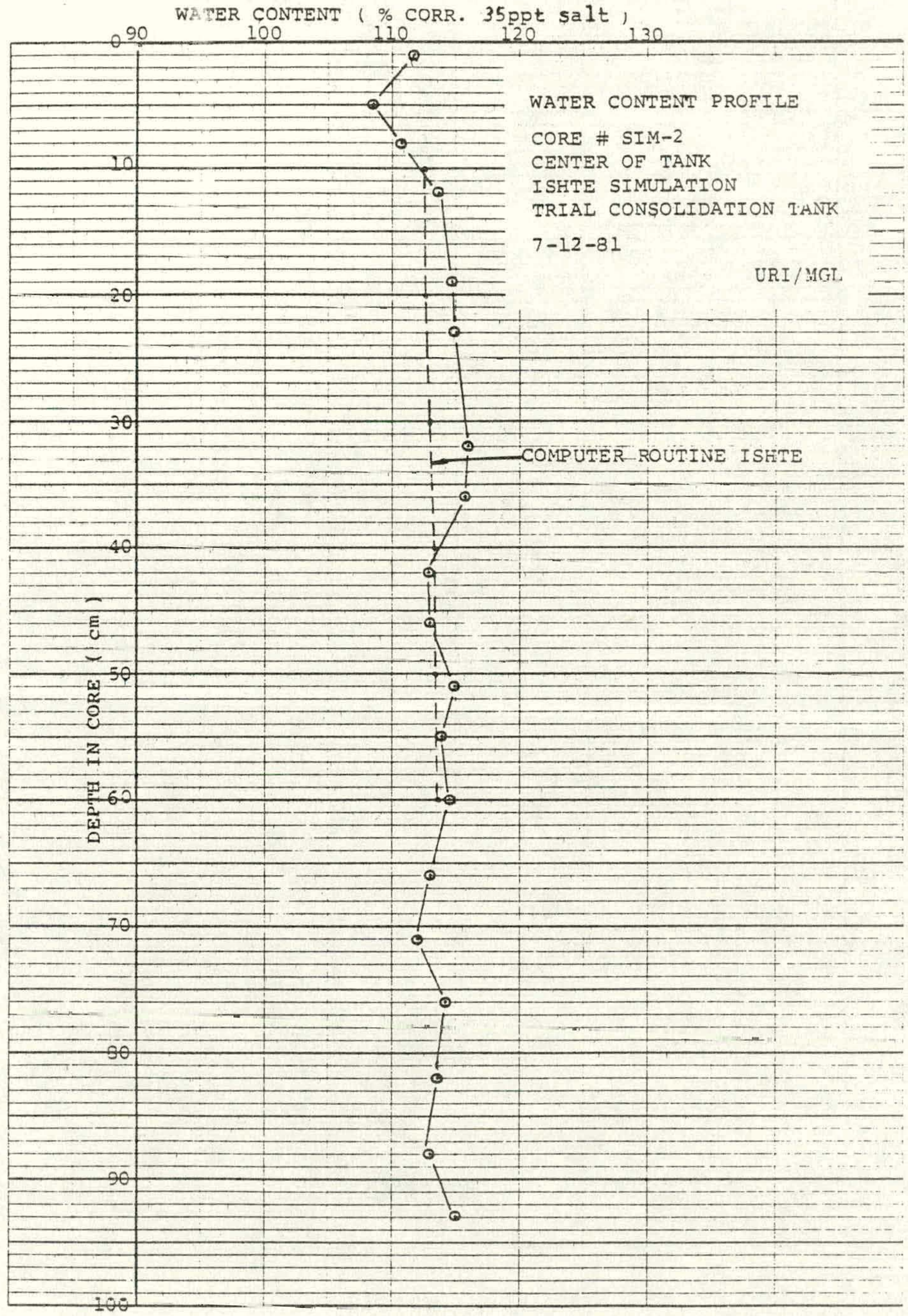
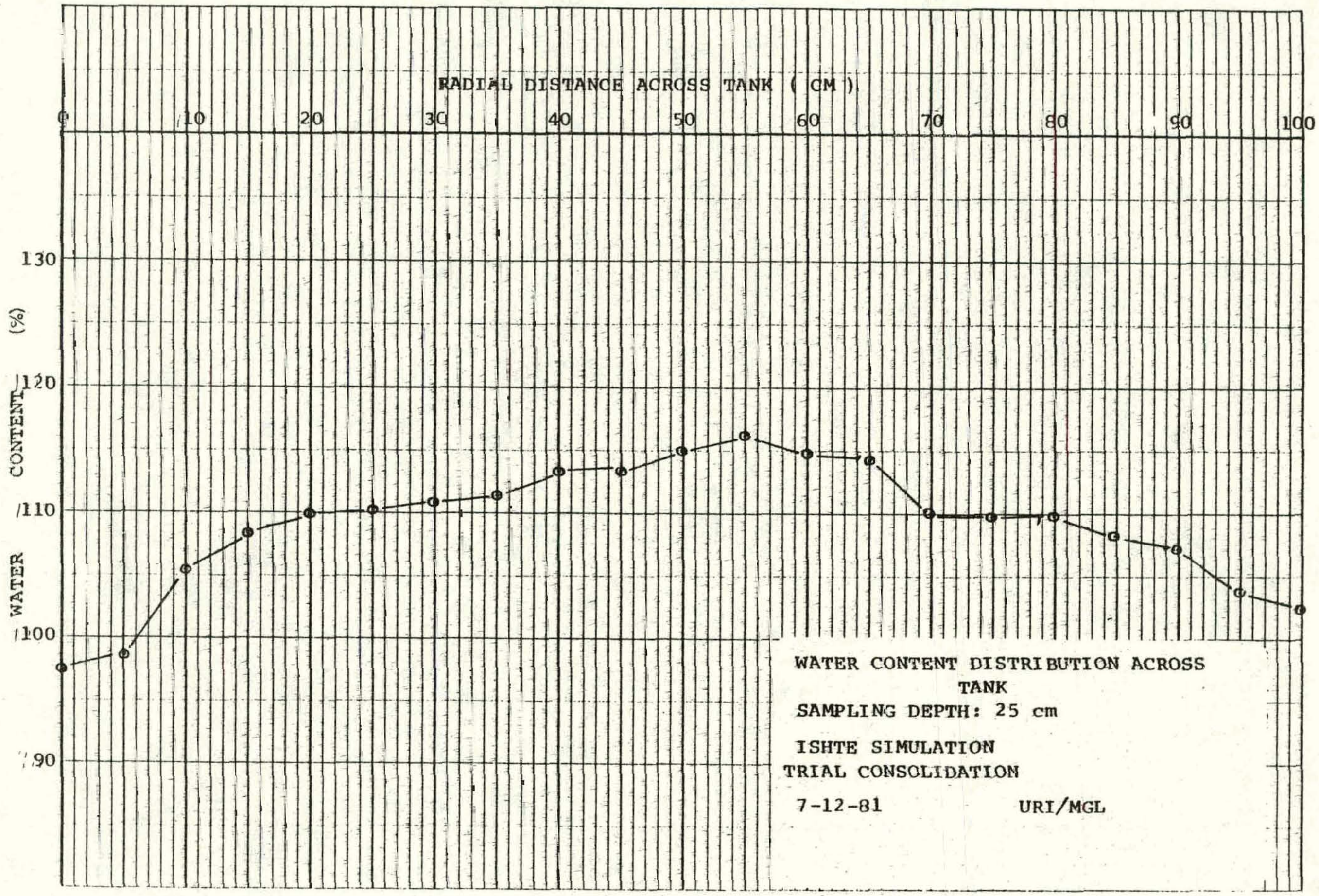
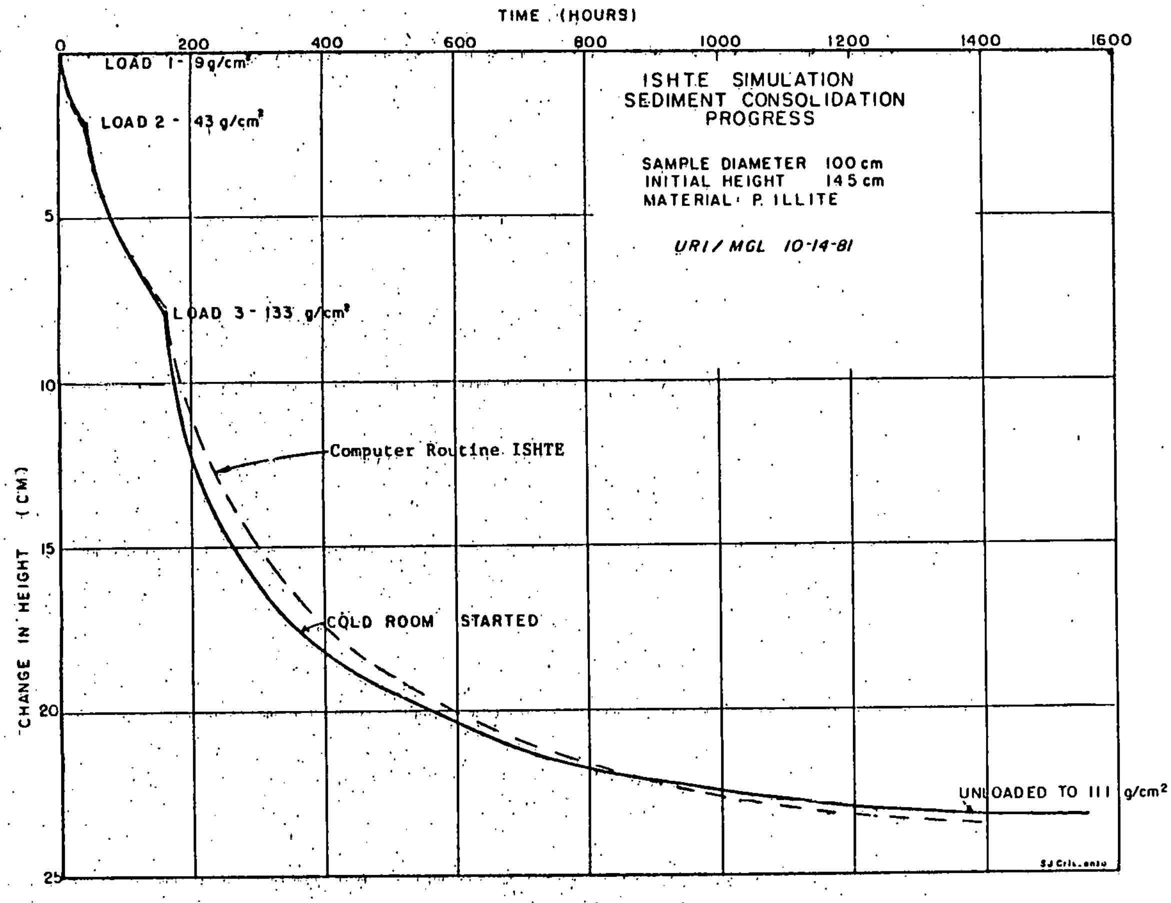


FIGURE 4.3-2

SJC URI/MGL
1/23/81


WATER CONTENT (% CORR. 35ppt salt)
0
90
100
110
120
130
WATER CONTENT PROFILE
CORE # SIM-2
CENTER OF TANK
ISHTE SIMULATION
TRIAL CONSOLIDATION TANK
7-12-81
URI/MGL
10
20
30
COMPUTER ROUTINE ISHTE
40
50
60
70
80
90
100
DEPTH IN CORE (cm)


RADIAL DISTANCE ACROSS TANK (CM)
0
10
20
30
40
50
60
70
80
90
100
WATER CONTENT (%)
130
120
110
100
90
WATER CONTENT DISTRIBUTION ACROSS TANK
SAMPLING DEPTH: 25 cm
ISHTE SIMULATION
TRIAL CONSOLIDATION
7-12-81
URI/MGL



ISHTE SIMULATION EXPERIMENT
STATUS (AS OF 10/13/81)

URI INVOLVEMENT:

- TRIAL CONSOLIDATION COMPLETED AND SUCCESSFUL
- SEDIMENT TANK AT NSRDC-CONSOLIDATION "COMPLETE"
- UPPER TANK- COMPLETED
- ANCILLARY SEDIMENT TANKS (2) - COMPLETED
- PRESSURIZATION TEST WITH ANCILLARY TANK - SCHEDULED
- POST-TEST CORERS - BEING FABRICATED.
- ETC. - UPDATE AT MEETING

ISHTE SIMULATION EXPERIMENT

Effects of Pressurization to 3000 psi.

Saturation:

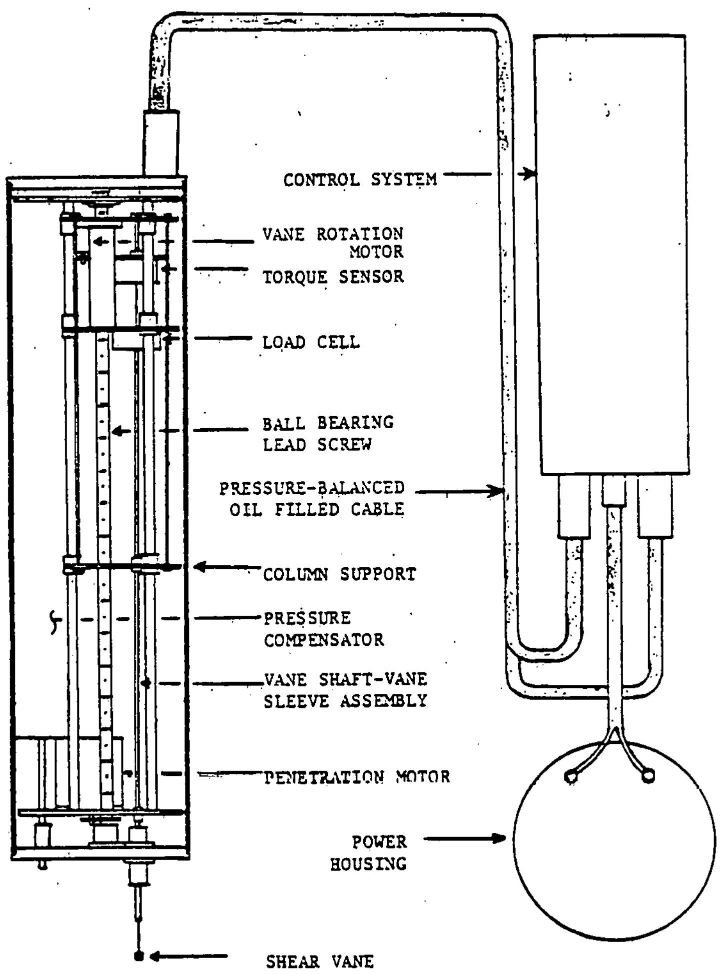
1. Sediment voids contain 2 to 3% air.
2. Gas will be forced into solution.
3. Due to low permeability, a volume change will occur.
4. Upper bound settlement is 2.3 cm (for 97% sat.) actual will be somewhat less.
5. For 98% saturation; settlement is 1.5 cm.

Compression:

1. Sediment volume decrease due to compressibility of water-sediment system.
2. Estimates:
   a) Based on two laboratory tests at URI/MGL
      Bulk compressibility = 2.15 to 2.68×10^{-6}/psi.
      Settlement = 1.7 to 2.1; Ave = 1.9 cm
   b) Based on published compressibility data:
      Settlement = 2.4 cm.
   c) Estimate by R. Bennett
      Settlement = 1.7 cm
3. Summary:

	Settlement Estimates, cm	
	Maximum	Minimum
Saturation	2.3	1.5
Compression	2.1	1.7
Total	4.4	3.2

IN SITU VANE SHEAR PROBE SYSTEM
(ISVSP)



GEOTECHNICAL ANALYSIS AND DESIGN
ISHTE PLATFORM

- AN ANALYSIS TO DETERMINE THE REQUIRED PAD SIZES AND ESTIMATE THE TOTAL SETTLEMENT BASED ON ONE YEAR DEPLOYMENT HAS BEEN COMPLETED.
- A RECTANGULAR SHAPED PAD IS RECOMMENDED BASED ON SETTLEMENT CALCULATIONS FOR VARIOUS PAD SHAPES.
- FOR A RECTANGULAR PAD A TOTAL SETTLEMENT OF 2.0 CM HAS BEEN ESTIMATED NEGLECTING THE EFFECTS OF IMPACT, UNEVEN LANDING, LATERAL STRESSES, AND THE UPPER 15 CM OF SEDIMENT.
- THE ANALYSIS AND DESIGN WILL BE REVIEWED AGAIN USING ANY NEW INFORMATION FROM THE 1981 DESTEIGER CRUISE.

DESTEIGER CRUISE - MPG-1
DS-1208-81

GEOTECHNICAL EVALUATION OF HYDROSTATIC CORER (HC-1)

- SHIPBOARD COMPARISONS BETWEEN HC-1 AND COMPANION GRAVITY CORE GC-5 ARE COMPLETE. THE TWO CORES HAVE NEAR IDENTICAL PROFILES OF BULK DENSITY, WATER CONTENT AND SHEAR STRENGTH MEASURED BY MINIATURE VANE.
- LABORATORY OEDOMETER TESTS OF UNDISTURBED SAMPLES FROM EQUIVALENT DEPTHS IN HC-1 AND GC-5 ARE UNDERWAY TO GIVE AN INDICATION OF DEGREE OF DISTURBANCE. PRELIMINARY RESULTS SHOW THE HYDROSTATIC CORER TO TAKE A SUPERIOR QUALITY SAMPLE COMPARED TO THE GRAVITY CORER.

REMAINING WORK

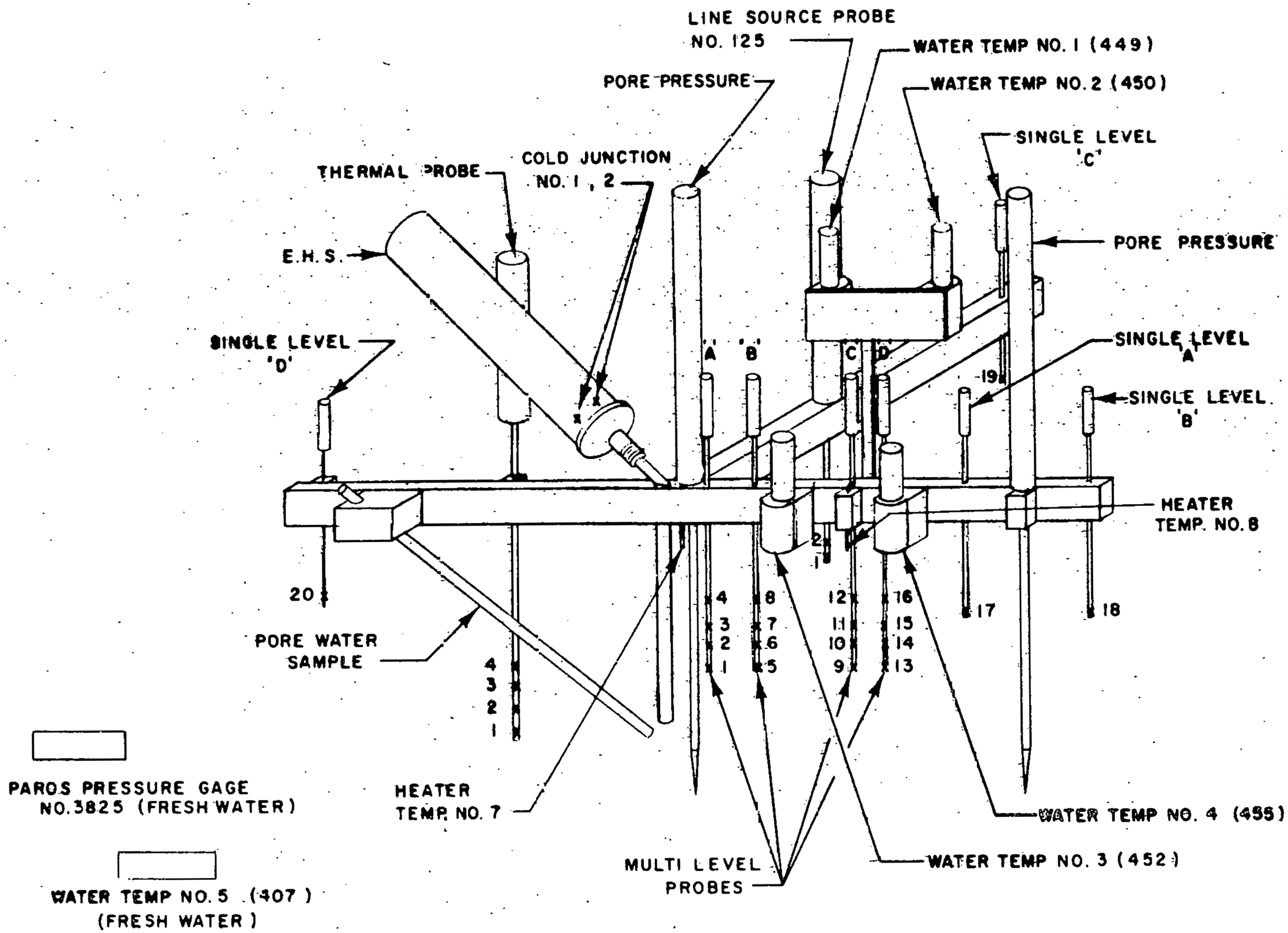
- CORE PROCESSING OF THE REMAINING FIVE GRAVITY CORES IS PRESENTLY UNDERWAY.

LeRoy O. Olson
APL University of Washington
Progress Briefing

The applied Physics Lab at the University of Washington is building and testing equipment to support ISHTE which will operate for one year at 8800 psi ambient pressure in the ocean. Major tasks this year have focused on two activities. The first was an oceanographic cruise aboard USNS DeSteiguer at MPG-1 during May. The second activity is an ISHTE approximation in a pressure chamber at the David Taylor Naval Ship Research and Development Center at Annapolis during October, November, and December, 1981.

APL is supplying all thermal instrumentation including the associated support structure for the ISHTE chamber test (ISIMU). A sketch shows the three member, support structure which rests one inch above the sediment tank. The sketch shows all the thermal sensor locations as numbers except for the 8 thermocouples associated with the electric heat source (EHS). The EHS is attached to the system heater with a bent tube. The heater is physically located in the center of the bottom end of the tube, below the support structure. A back-up heater is located next to the primary heater, but off center in the tube. A photo shows the sensor array resting on vertical posts during a mock-up at APL. A table shows a simulated sample computer printout of the ISIMU data. This data will be printed every 2-1/2 minutes for the first 4 hours of the test, every 5 minutes for the next 16 hours and then every 20 minutes for the remaining month. The data is also stored on magnetic tape.

The purpose of the oceanographic cruise was to test the following systems: a hydrostatic corer (sea pressure driven corer), and an acoustic data link. Secondary objectives were to exercise the acoustic tracking system, recover a mooring deployed the previous year, and obtain gravity cores of undisturbed sediment. All objectives were successfully met. Pictures include USNS DeSteiguer, a map of the operation area, a sketch of the long-term mooring, a photo of the hydrostatic corer next to a person, a photo of the hydrostatic coring platform being launched, a photo of the corer's cutter positioned above the manganese nodule covered seafloor in 5850 m of water, and a photo of the corer driven 170 cm into the seafloor.

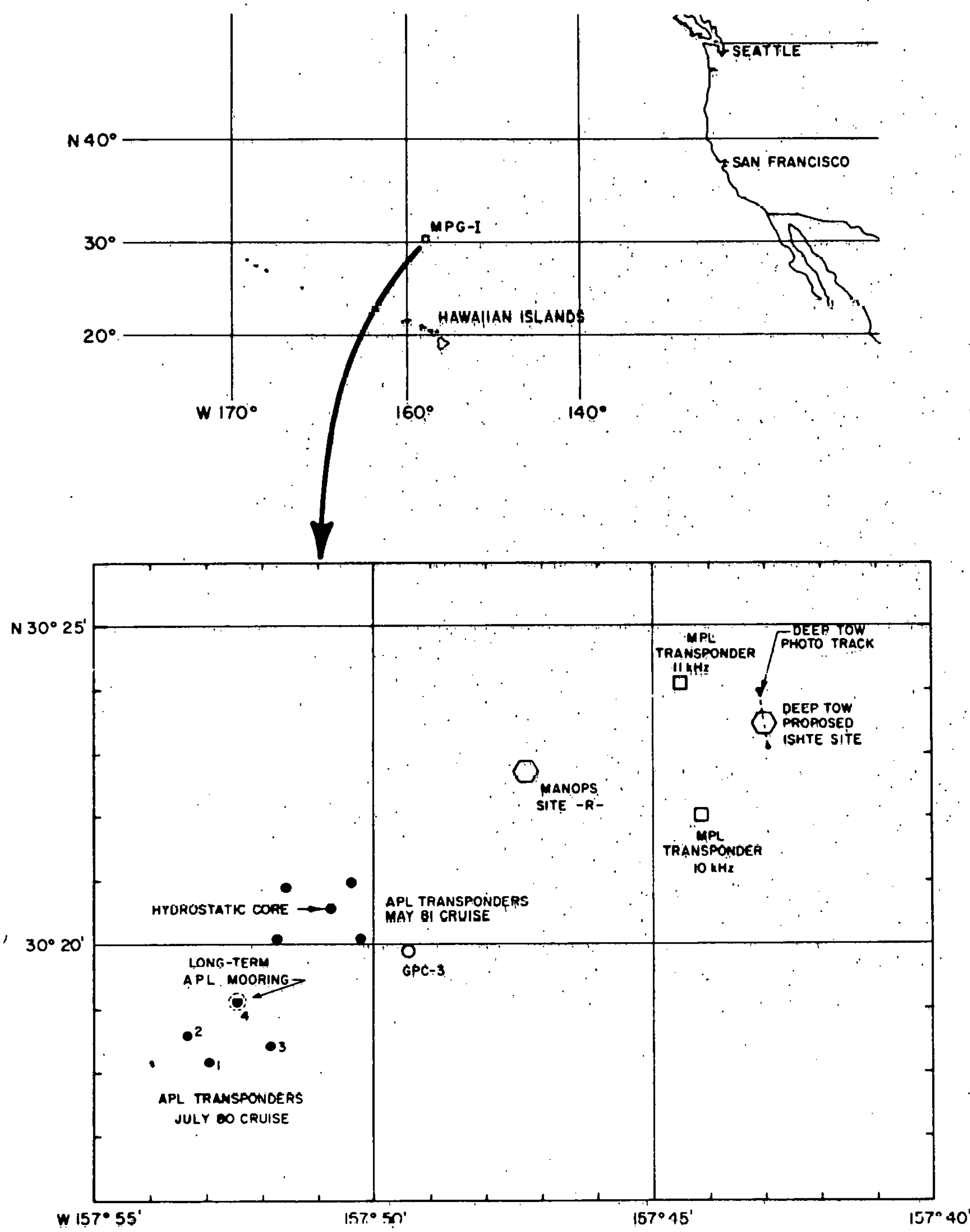

LINE SOURCE PROBE
NO. 125
WATER TEMP NO. 1 (449)
WATER TEMP NO. 2 (450)
PORE PRESSURE
COLD JUNCTION
NO. 1, 2
THERMAL PROBE
SINGLE LEVEL
'C'
E.H.S.
PORE PRESSURE
SINGLE LEVEL
'D'
'A'
'B'
'C'
'D'
SINGLE LEVEL
'A'
19
SINGLE LEVEL
'B'
HEATER
TEMP. NO. 8
20
2
1
4
3
2
1
8
7
6
5
12
11
10
9
16
15
14
13
17
18
PORE WATER
SAMPLE
4
3
2
1
PAROS PRESSURE GAGE
NO. 3825 (FRESH WATER)
HEATER
TEMP. NO. 7
WATER TEMP NO. 4 (455)
WATER TEMP NO. 3 (452)
MULTI LEVEL
PROBES
WATER TEMP NO. 5 (407)
(FRESH WATER)

Computer Printout

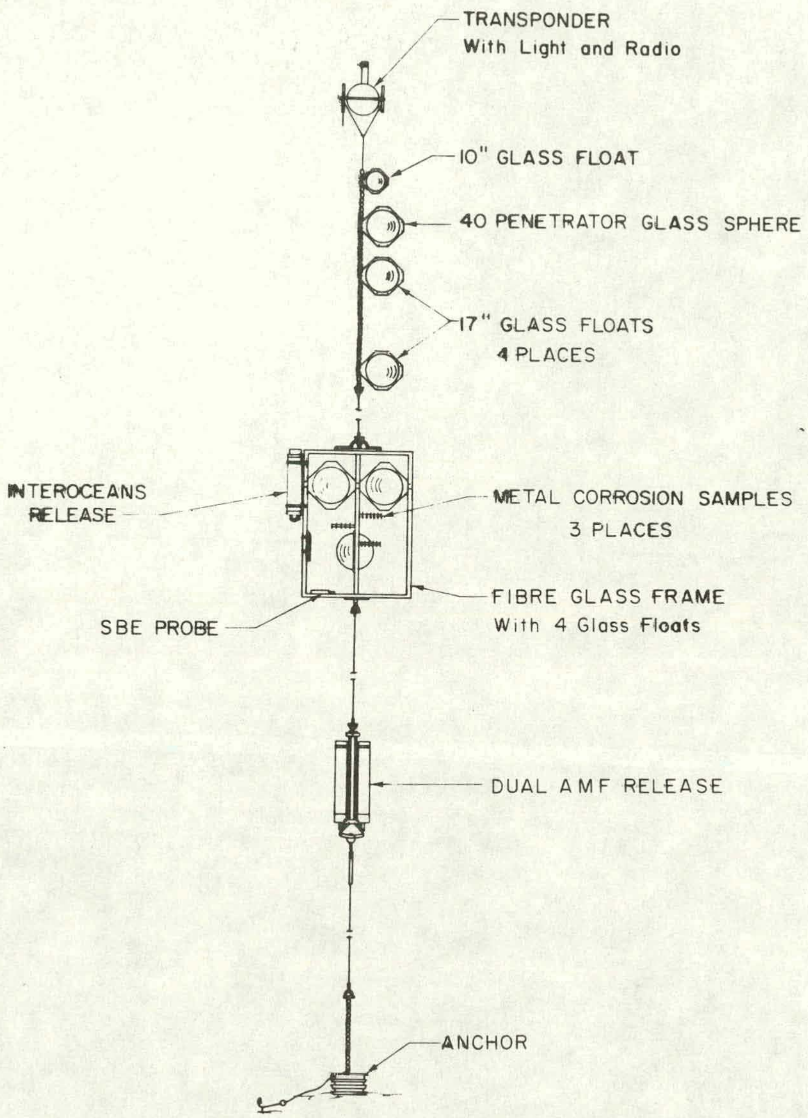
ISIMU Data Monitor

```
SAMPLE 0001              000 00:02:30

Heater Temp(1)=    20 deg C
Heater Temp(2)=    21 deg C
Heater Temp(3)=    20 deg C
Heater Temp(4)=    20 deg C
Cold Jn Temp(1)=   25.8 deg C
Heater Temp(5)=    20 deg C
Heater Temp(6)=    20 deg C
Heater Temp(7)=    20 deg C
Heater Temp(8)=    18 deg C
Cold Jn Temp(2)=   25.8 deg C
Sediment Temp( 1)= 208.2 deg C
Sediment Temp( 2)= 208.1 deg C
Sediment Temp( 3)= 207.4 deg C
Sediment Temp( 4)= 208.3 deg C
Sediment Temp( 5)= 208.3 deg C
Sediment Temp( 6)= 208.3 deg C
Sediment Temp( 7)= 208.2 deg C
Sediment Temp( 8)= 208.2 deg C
Sediment Temp( 9)= 208.2 deg C
Sediment Temp(10)= 208.3 deg C
Sediment Temp(11)= 208.1 deg C
Sediment Temp(12)= 208.1 deg C
Sediment Temp(13)= 202.0 deg C
Sediment Temp(14)= 202.1 deg C
Sediment Temp(15)= 202.1 deg C
Sediment Temp(16)= 201.6 deg C
Sediment Temp(17)= 193.5 deg C
Sediment Temp(18)= 193.6 deg C
Sediment Temp(19)= 193.5 deg C
Sediment Temp(20)= 193.6 deg C
Water Temp(1)=  25.75 deg C
Water Temp(2)=  19.84 deg C
Water Temp(3)=  20.30 deg C
Water Temp(4)=  28.00 deg C
Water Temp(5)=  20.23 deg C
Thermal Probe(1)=  19.45 deg C
Thermal Probe(2)=  19.53 deg C
Thermal Probe(3)=  19.62 deg C
Thermal Probe(4)=  19.68 deg C
Line Src Probe(1)=  19.04 deg C
Line Src Probe(2)=  19.03 deg C
Pressure=   -3.5 psia
```

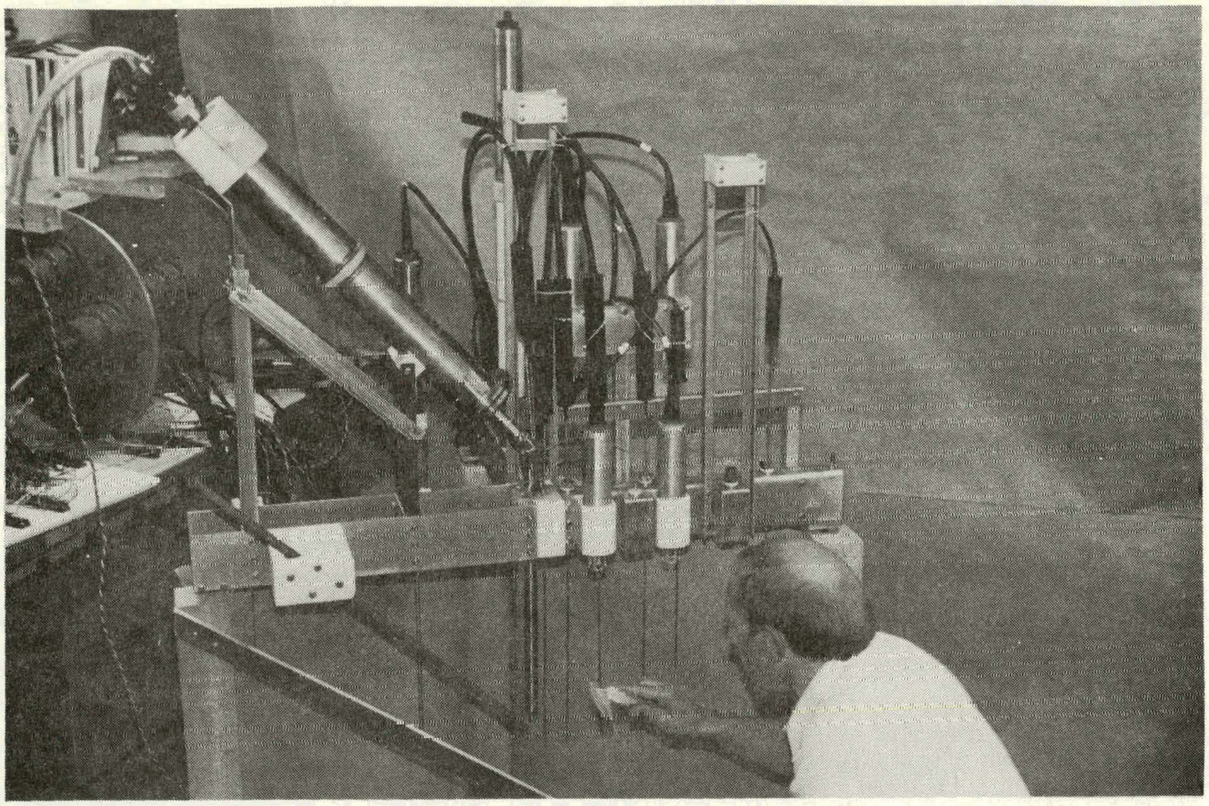


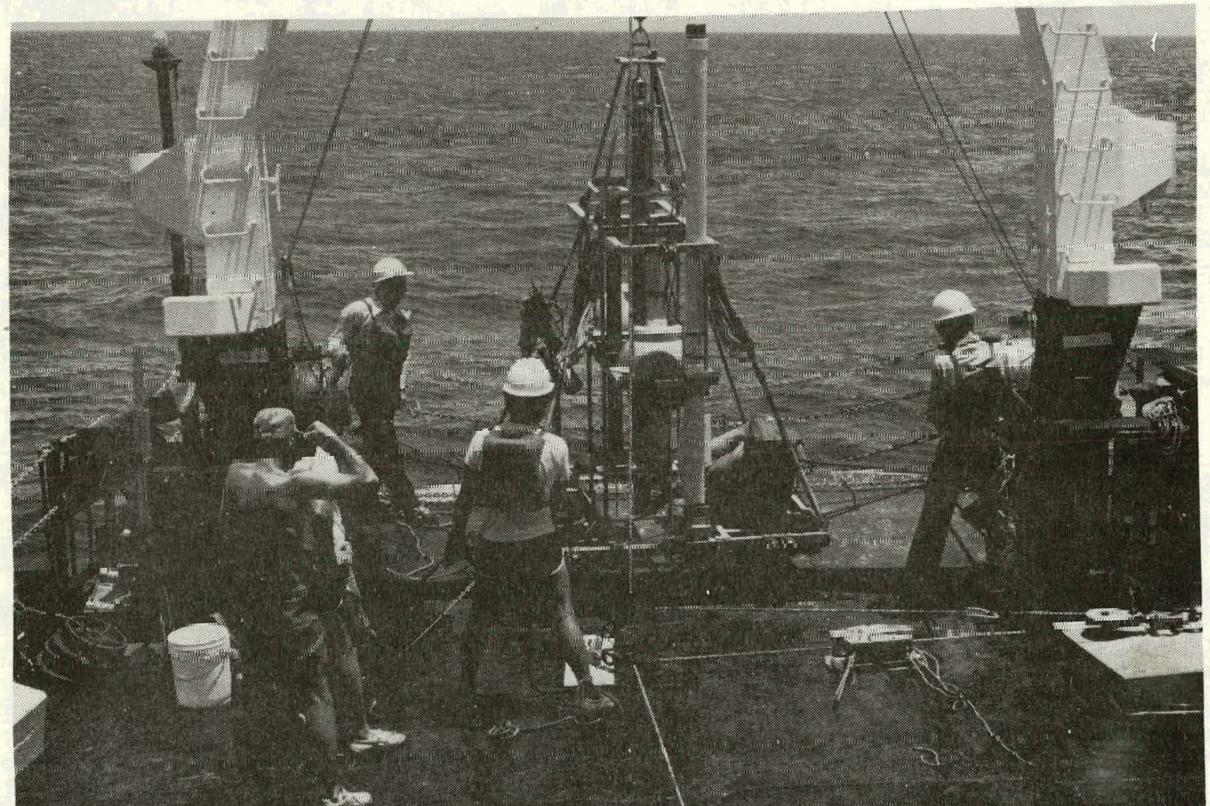
N 40°
30°
20°
W 170°
160°
140°
SEATTLE
SAN FRANCISCO
MPG-I
HAWAIIAN ISLANDS
N 30° 25'
30° 20'
W 157° 55'
157° 50'
157° 45'
157° 40'
MPL TRANSPONDER 11 kHz
DEEP TOW PHOTO TRACK
DEEP TOW PROPOSED ISHTE SITE
MANOPS SITE -R-
MPL TRANSPONDER 10 kHz
HYDROSTATIC CORE
APL TRANSPONDERS MAY 81 CRUISE
GPC-3
LONG-TERM APL MOORING
APL TRANSPONDERS JULY 80 CRUISE

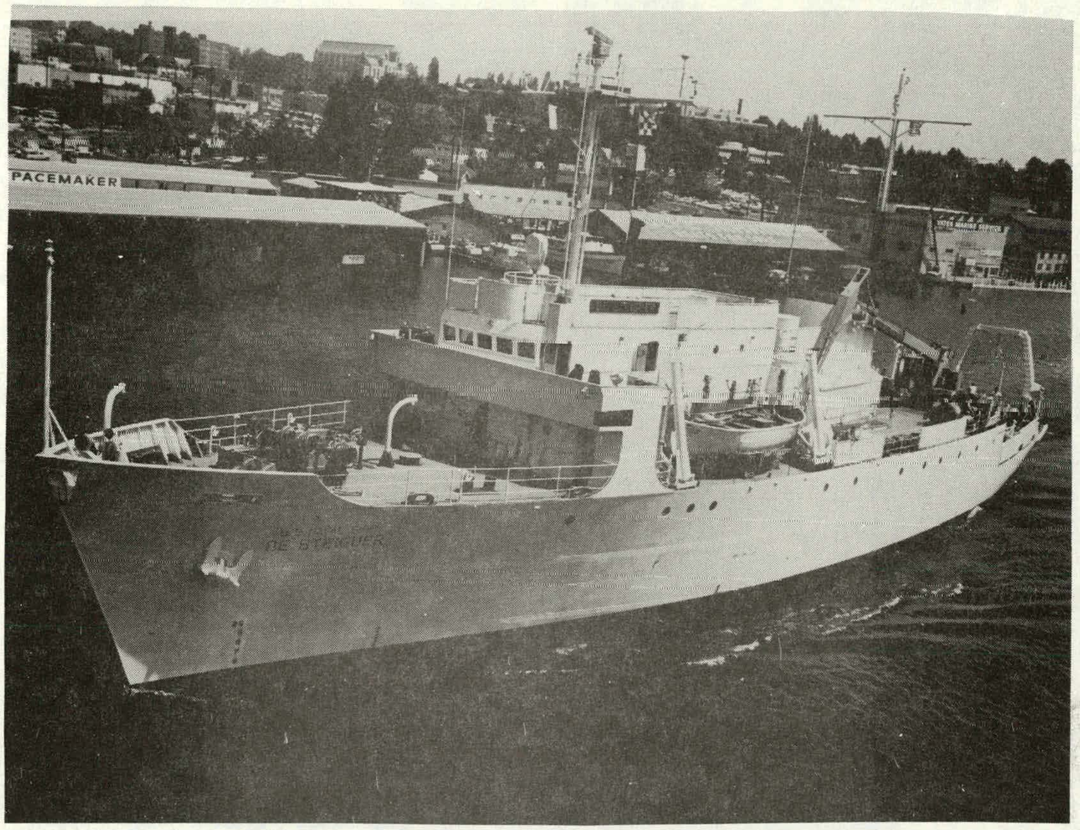


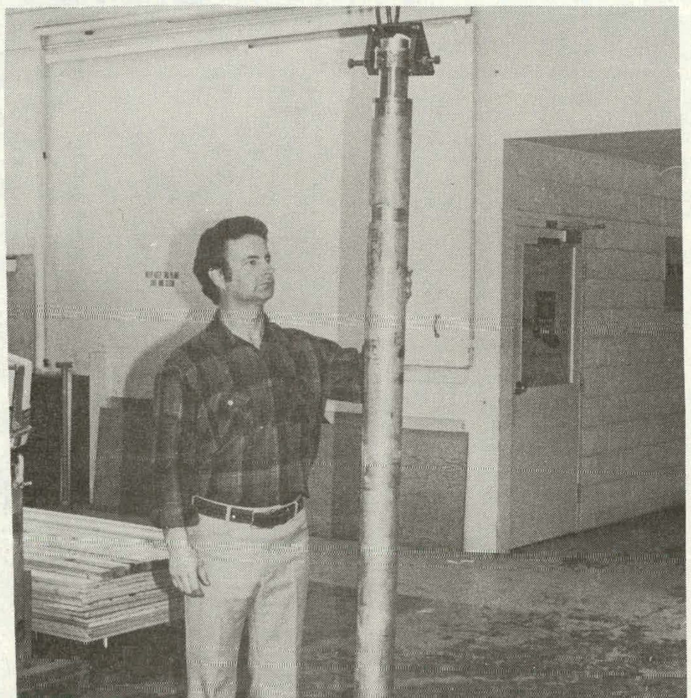
LONG TERM CORROSION
MOORING

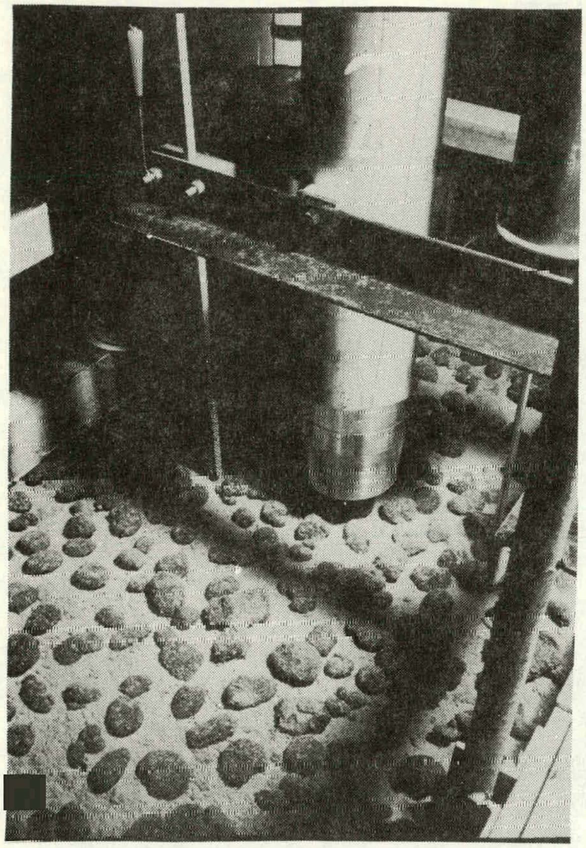
APL Applied Physics Laboratory University of Washington

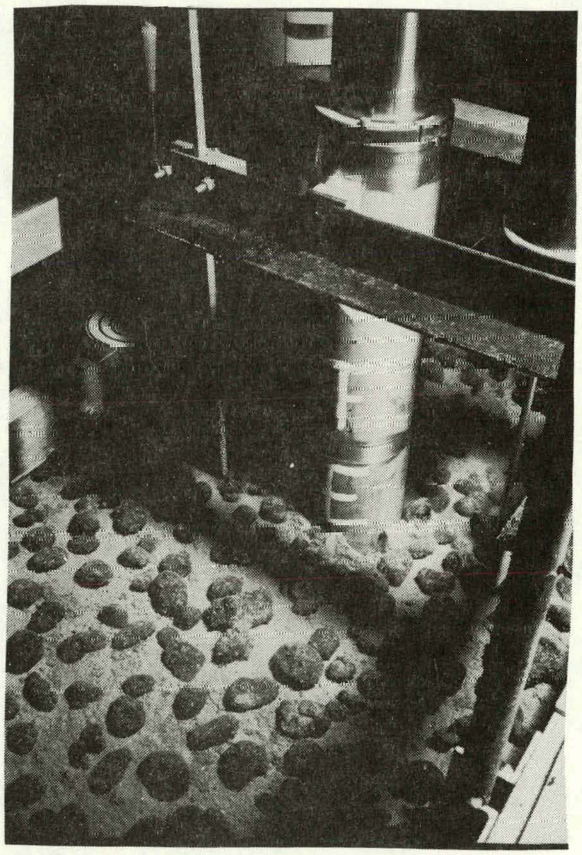





PACEMAKER







V. MECHANICAL RESPONSE STUDIES

Technical Program Coordinator: J. Lipkin

Introduction
J. Lipkin, SNLA — 111

Sediment Geotechnical Properties
A. J. Silva, University of Rhode Island — 118

Thermal Effects on Sediment Properties
W. N. Houston, N. D. Williams, University of California at Berkeley — 140

Creep Modeling
P. R. Dawson, Cornell University; J. Lipkin, SNLA — 151

Dynamic Properties and Modeling of Seabed Sediment
B. Rohani, US Army Engineer Waterways Experiment Station — 161

INTRODUCTORY COMMENTS

MECHANICAL RESPONSE STUDIES SESSION

SUBSEABED ANNUAL WORKSHOP--October 27-29, 1981

Joel Lipkin, SNLA

Several aspects of the SDP require a detailed understanding of the response of marine sediments to thermal and mechanical loading. For example, the first vu-graph illustrates a scenario beginning with waste canister emplacement using a penetrator concept, and continues through what might be termed "repository operation." Appropriate time frames and the corresponding sediment response characteristics that must be modeled are also indicated on this figure. From this scenario it is evident that an understanding of sediment behavior is required under quite varied mechanical and thermomechanical loading conditions. It is especially noteworthy that the relevant time scales shown range from 10^{-3} s to perhaps 10^{9} s (i.e., 50 years), which is another indication of the extreme requirements being placed on our laboratory and modeling efforts. The second vu-graph summarizes the distinctions between the modes of sediment behavior that are relevant in this program. The first three of the following four presentations deal primarily with the long-term problem of canister/sediment stability which involves characterizing the creeping motion of the sediment. The third vu-graph summarizes the objectives of this part of the program and the major milestones expected thru FY'85. The final presentation involves the mechanical response studies underway in support of the SDP emplacement activities. The fourth vu-graph summarizes this aspect of the program using the same format as the third vu-graph. The final vu-graph briefly highlights the accomplishments of the Subseabed Geotechnical Program in FY'81. It should be noted that efforts are being made throughout this program to integrate laboratory results and modeling requirements.

EVENT SEQUENCE :

Initial Stages of Waste Canister Penetration

Impact Velocity ~30m/s

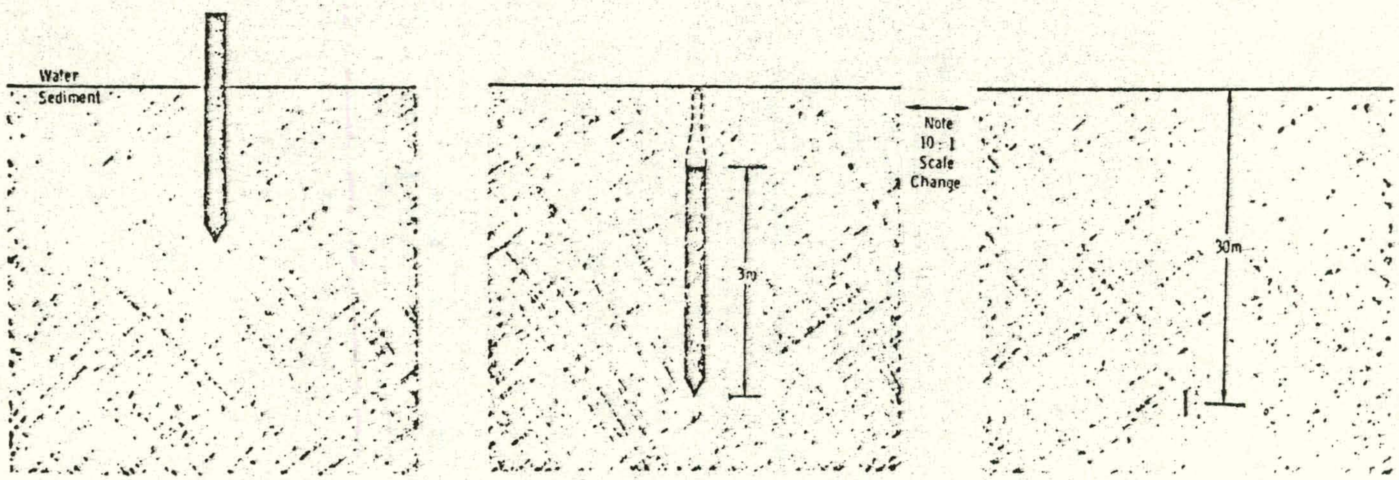
Relevant Time Scale $10^{-3} - 10^{-2}$ s

Late Stages of Penetration and Initial Hole Closure

Relevant Time Scale $10^{-1} - 10^{2}$ s

Late Time -- Canister Emplaced, Hole Sealed

Relevant Time Scale Days — Years...



PHENOMENA TO BE MODELED :

Penetrator Vehicle Dynamics

Penetration Mechanics in Saturated Medium

Dynamic Sediment Response

Coupling of Thermal Field and Sediment / Pore-Water Motion

Canister / Sediment Stability in Convective Cell

DEFINITIONS

Seabed Sediment Deformation

CREEP

Time-dependent deformation under thermal and/or mechanical loading with the following characteristics:

1. Very Slow Rates, No Inertia Effects
2. Predominantly Non-recoverable
3. Relative Motion of Sediment Skeleton and Pore Water

DYNAMIC

Mechanically-induced deformation with the following characteristics:

1. Relatively High Rates with Possible Inertia Effects
2. Combination of both Recoverable and Non-recoverable
3. No Relative Motion of Sediment Skeleton and Pore Water

NEAR FIELD / FAR FIELD SEDIMENT THERMOMECHANICAL RESPONSE

OBJECTIVE: To determine the long-term stability of a waste canister buried in the sediment and provide boundary conditions for radionuclide migration from a canister.

GOALS	MILESTONES					
	Completed Previously	FY81	FY82	FY83	FY84	FY85
Models						
COUPLEFLO –	X					
NEPTUNE –			X			
STEALTH –		X				
Property Acquisition						
Permeabilities –	X					
Porosities –	X					
Lo-temp. shear strength –	X					
Lo-temp. creep –		X				
Hi-temp. creep –			X			
Hi-temp. shear strength –		X				
Effect of radiation and temperature on shear strength –				X		
Verification						
Simulate laboratory triaxial experiments –			X			
ISHTE simulation –			X			
Centrifuge experiment –				X		
ISHTE					X	

SEDIMENT RESPONSE MODELING FOR EMPLACEMENT

OBJECTIVE: Develop the methodology for predicting large sediment motions during emplacement activities.

GOALS	MILESTONES					
	Completed Previously	FY81	FY82	FY83	FY84	FY85
Models						
HONDO –		X				
STEALTH –		X				
EURDYN –			X			
Property Acquisition						
Failure envelope –		X				
Elastic bulk and shear moduli –		X				
Dynamic failure strength –			X			
Shear strength at high hydrostatic pressure –			X			
Verification						
Field penetrometer experiment –			X			
Laboratory simulation of hole closure –						X

GEOTECHNICAL PROGRAM - FY 81

UNIVERSITY OF RHODE ISLAND - MARINE GEOMECHANICS LABORATORY

A.J. SILVA

TASK OUTLINE

- STRESS-STRAIN BEHAVIOR: TRIAXIAL COMPRESSION EXPERIMENTS.
  ISOTROPIC (CIU), ANISOTROPIC (CAU),
  HIGH PRESSURE, EXTENSION,
  RADIATION HISTORY EFFECTS.

- CREEP BEHAVIOR: TRIAXIAL-DRAINED-CONSTANT STRESS TESTS.
  ROOM TEMPERATURE
  THERMAL EFFECTS (4°C - 150°C)
  LONG TERM (ONE-DIMENSIONAL AND TRIAXIAL)

- COMPRESSIBILITY STUDIES: STANDARD AND BACK-PRESSURED
  TESTS, STRESS HISTORY ANALYSES.
  MPG-1 (N.C. PAC.), MPG-IV (N.W. PAC.)

- PERMEABILITY STUDIES: BACK-PRESSURED TESTS.
  ROOM TEMPERATURE, NOMINAL PRESSURE (MPG-1,IV).
  HIGH TEMPERATURE EFFECTS (20°C TO 220°C).
  HIGH PRESSURE EFFECTS (TO 9000 PSI-60 MPA)

- SEDIMENT CHARACTERIZATION STUDIES (GEOTECHNICAL ASPECTS):
  MPG-1 (N.C. PAC.), MPG-III N (ATL.ABYS. PL.),
  MPG-IV (N.W. PAC.).

FY81 HIGHLIGHTS OF SUBSEABED GEOTECHNICAL PROGRAM

Laboratory Efforts

- Completed triaxial test series on irradiated samples of remolded smectite - URI
- Obtained preliminary data on thermal consolidation phenomenon - UCB
- Obtained hi-temperature shear strength data - UCB
- Initiated long-term room temperature creep test - URI
- Obtained new undisturbed illite cores from MPG I - WES

Modelling Efforts

- Successfully incorporated WES effective stress model into SNLA computer codes suitable for penetration/hole closure calculations - SNLA/WES
- Completed 1-D and 2-D simulations of dynamic hole closure incorporating pressure drop in penetrator wake, and initiated sensitivity study of model parameters for this problem - SNLA/ARA
- Completed fit to isotropic consolidation data suitable for NEPTUNE porous media calculation - CU/SNLA

GEOTECHNICAL PROGRAM - URI/MGL - FY 81

Progress and Milestones during past 12 months.

- Room Temperature Creep Program-
  - First phase testing completed - M.S. Thesis by Kate Moran completed. Companion Tech. Rep. by K. Moran & A. Silva issued.
  - Additional tests and analysis underway.
- Variable Temperature Creep Program -
  - Preliminary test program completed (4°C to 150°C) M.S. Thesis By Jan Wildman completed.
  - Testing being continued, repeated, extended.
- Triaxial: Anisotropically Consolidated (K_0) Tests
  - First Phase Testing Completed - M.S. Thesis by Sylvie Schwartz completed.
  - Additional companion tests underway.
- Site Characterization: MPG-IV (N.W. Pac.)
  - First Phase Testing and Analysis Completed - M.S. Thesis by Greg Walker completed.
  - Additional Tests and Analysis Underway.
- Radiation History Triaxial Tests -
  - Testing and Analysis Completed.
- High Pressure/High Temperature Permeability and Conductivity
  - First Phase Testing Program Completed.

GEOTECHNICAL PROGRAM - URI/MGL - FY 81

OUTLINE OF PRESENTATION

1. STATIC STRESS-STRAIN BEHAVIOR.
2. STRESS-STRAIN-TIME (CREEP) BEHAVIOR.
3. EFFECTS OF HIGH PRESSURE AND HIGH TEMPERATURE ON PERMEABILITY AND CONDUCTIVITY PROPERTIES.
4. SITE CHARACTERIZATION STUDIES OF MPG-IV.
5. GEOTECHNICAL COMPARISON OF SDP SITES.

STATIC STRESS-STRAIN BEHAVIOR OF DEEP SEA SEDIMENTS

- EFFECTS OF RADIATION HISTORY
  - RECONSTITUTED-RECONSOLIDATED SMECTITE
  - STATUS: TESTING COMPLETED
- EFFECTS OF HIGH CONSOLIDATION STRESS
  - RECONSTITUTED-RECONSOLIDATED ILLITE
  - STATUS: INITIAL TEST SERIES TO 1770 KPA COMPLETED
- EFFECTS OF ANISOTROPIC CONSOLIDATION
  - UNDISTURBED ILLITE
  - RECONSTITUTED-RECONSOLIDATED ILLITE AND SMECTITE
  - STATUS: FIRST STAGE TESTING COMPLETED
- EFFECTS OF VARYING OVERCONSOLIDATION RATIO
  - RECONSTITUTED-RECONSOLIDATED ILLITE
  - STATUS: SERIES AT OCR 1, 2, 4, 8 COMPLETED
- EFFECTS OF VARYING STRESS PATH
  - RECONSTITUTED-RECONSOLIDATED ILLITE
  - STATUS: PRELIMINARY EXTENSION SERIES COMPLETED

Sediment Geotechnical Properties

A. J. Silva
University of Rhode Island

GEOTECHNICAL PROGRAM - URI/MGL - FY 81

SITE CHARACTERIZATION STUDIES OF MPG-IV (NO. WEST PACIFIC)

OBJECTIVE AND PROGRAM OUTLINE

OBJECTIVE: ESTABLISH GENERAL GEOTECHNICAL DATA BASE FROM MPG-IV CORE SAMPLES FOR USE AS SITE QUALIFICATION ANALYSES AND COMPLETE PRELIMINARY ANALYSES TO HELP EVALUATE THE SITES IN TERMS OF ESTABLISHED SDP CRITERIA.

PROGRAM OUTLINE

PARTICIPATE IN VEMA 36-12 CRUISE.
GEOTECHNICAL PROCESSING OF CORES.
PERFORM LABORATORY TESTS - COMPRESSIBILITY,
PERMEABILITY, ATTERBERG LIMITS,
SPECIFIC GRAVITY, GRAIN SIZE DISTRIBUTION.
INTERPRETATION OF CORING RESULTS.
ANALYSIS WITH SDP IMPLICATIONS.

STATUS

FIRST PHASE COMPLETED - M.S. THESIS BY G. WALKER.
ADDITIONAL TESTS AND ANALYSES UNDERWAY.

MPG-IV (No. West Pacific)

Sediment Loss and Recalculated Sedimentation Rates[1]

Using Two Methods (from G. Walker, 1981)

CORE	METHOD I[2] SED. RATE MM/KY	METHOD I[2] SED. LOSS CM	METHOD II[3] SED. RATE MM/KY	METHOD II[3] SED. LOSS CM
PC 35	5.5	80	7.9	253
PC 45	10.6	70	14.9	379
PC 46	10.3	150	8.1	-9
PC 47	9.4	165	9.9	198
PC 48	9.9	195	9.9	195
PC 49	7.3	110	9.6	275
PC 51	8.8	250	9.2	278

[1] Rate since B/M boundary to present.

[2] From water content profile matching.

[3] Using sedimentation rate for period between B/M and U/J boundaries.

GEOTECHNICAL PROPERTIES COMPARISONS: N.W. Pacific and N.C. Pacific

AREA	CORE	Sand %	Silt %	Clay %	W_L %	W_P %	OCR	COEFFICIENT OF PERMEABILITY cm/sec.
E_2	All Cores	2	49	49	120	46		5.0×10^{-7} to 5.0×10^{-6}
	PC 49	2	52	46	120	47	1.3 (@ 12 m)	
	PC 51	3	45	52	120	46	1.1 (@ 12 m)	
B_1	All Cores	7	56	37	110	45		1.6 x 10-6 to 6.0×1.0^{-6}
	PC 43	4	57	39	126	50		
	PC 45	11	54	35	94	39	1.9 (@ 13 m)	
C_1	All Cores	7	53	40	85	44	2.7 (@ 11 m)	1.0×1.0^{-6} to 5.4×10^{-6} (<3 m)
MPG-1	LL-44 GPC 3	1	25	74	106 to 240	45 to 97	1.1 (@ 14 m)	1.0×10^{-7} to 7×10^{-6} (< 2 m) 1.0×10^{-7} to 8×10^{-7} (> 2 m)
MPG-2	YALUC	1	43	57	84	38		2.2×10^{-7} to 7.0×10^{-7} (< 3 m)

GEOTECHNICAL PROGRAM - URI/MGL, FY 81

SITE CHARACTERIZATION STUDIES: MPG-IV, (N.C. PAC.)

SUMMARY

- LOCATIONS E_2, B_1, C_1: SIMILAR GENERAL GEOTECHNICAL PROPERTIES. SOME ZONES OF HIGH WATER CONTENT INDICATE SILICEOUS AND/OR SMECTITE.
- CORES: ALL CORES MISSING SEDIMENT FROM UPPER METERS - AS MUCH AS 250 CM TO 400 CM MISSING (DEPENDING ON ANALYSIS METHOD USED).
- GRAIN SIZE:

	E_2	B_1	C_1
SILT	48	56	53
CLAY	49	37	40

- SHEAR STRENGTHS: GENERALLY LOW

  UPPER 3 M: 10 KPA FOR E_2, C_1

  DEEPER: <20 KPA, PEAKS TO 30 KPA
- CONSOLIDATION:

  SOME OVERCONSOLIDATION (AT DEPTH) FOR ALL THREE LOCATIONS. REASON UNKNOWN. HIGHER COMPRESSION INDEX IN E_2, C_1.
- PERMEABILITY: HIGHER PERMEABILITY THAN MPG-1.

COMPARISON OF GEOTECHNICAL PROPERTIES FOR SITES MPG-I, III, & IV

INTRODUCTION

Geotechnical properties are necessary for characterizing and predicting behavior of deep sea sediments. These properties aid in the assessment of the site sediment as related to the feasibility of subseabed disposal of radioactive wastes. The following is a summary of specific property determination, comparison and evaluation of SDP sites MPG-I, III, IV. (See table)

Highlights

- MPG-I, North Central Pacific; MPG-III, Atlantic Abyssal Plain; MPG-IV, North Western Pacific.
- MPG-I and IV contain sediments of sub-group illite, transitional (illite/smectite) and smectite identified with depth, where as, MPG-III is classed primarily illitic.
- Water contents are typical higher as concentration of smectite increases. MPG-IV shows higher water contents for the same mineral group.
- Undrained shear strengths typically increase with depth. Noticeably, profiles of water content and undrained shear strength trend decrease in water content is a associated with increase in undrained shear strength and vice versa.
- All three sites show grain sizes primarily less than 2 μm (clay) with small percentages of silt and fractions of sand.
- Liquid and plastic limits classically increase with greater concentrations of smectite.
- Activity is the ratio of plastic index (LL-PL) to % clay fraction and is used to separate the type and amount of clay influencing the properties. The higher the activity the more important the influence of the clay fraction on the properties. Here, as expected, the higher values of activity are associated with an increase in smectite minerals.
- Specific gravities for illite and smectite clays generally fall between 2.6 and 3.0. All sites respect this range.
- Overconsolidation of surficial sediments is generally associated with erosion and has been discussed numerous times. The OCR values greater than 1.0 indicates over consolidation, however, "apparant" for the MPG-sites and attributed to cementation and/or interparticle bonding rather than erosion.
- The compression indexes shown are strictly averaged values and should be used with caution. The compression index is highly dependent on in situ void ratio. Typically, higher void ratios are linked with higher water contents as is the case with smectite and show larger compression indexes.
- The permeability is essentially the same for the MPG-I and III sites at comparable depths. Site MPG-IV indicates higher magnitudes.

SITE	MPG-I			MPG-III		MPG-IV	
Depth (m)	0 to 3	3 to 10	10 to 24	0 to 2	2 to 5	0 to 2	3 to 12.5
Class.	Illite	Transi-tional	Smectite	Illite	Illite	Illite	Ill./Smc
Water Content w_c (%)	110	135	200	100	120	140	145
Und. Shear Strength S_u (KPa)	0→ 6	6→ 18	18→ 30	0→ 5	1→ 5	0→ 10	5→ 10
% Clay	70	74	68	68	74	50	43
Liquid Limit LL	95	175	240	73	75	85	120
Plastic Limit PL	45	65	100	27	32	42	45
Activity A	0.7	1.7	2.1	0.7	0.6	1.1	1.7
Specific Gravity G_s	2.78	2.82	2.90	2.77	2.77	2.76	2.73
Overconsol. Ratio OCR	25→ 1.8	1.8→ 1.0	1.0	10→ 1.5	≈1.0	36→ 2.3	2.0
Compression Index C_c	.95	.95→ 2.9	2.9	1.7	1.6	2.1	2.0
Permeability k (cm/sec)	$3x10^{-6}$	$5x10^{-7}$	$3x10^{-7}$	$5x10^{-6}$	$5x10^{-7}$	$5x10^{-6}$	$1x10^{-6}$

Geotechnical Properties of Deep Sea Sediments

In Study Areas MPG-I, III & IV

EFFECTS OF RADIATION HISTORY ON STRESS-STRAIN PROPERITES: Pacific Smectite

INTRODUCTION

The effects of possible changes in soil stress-strain behavior to exposure to high level radiation is of great interest to the Subseabed Disposal Program. Five triaxial sub-samples of reconstituted-reconsolidated smectite were exposed to a cobalt-60 radioactive source at various dosages at SNL. Four samples were then isotropocally consolidated, tested and analyzed at URI/MGL. One sample was too dried out to be tested.

HIGHLIGHTS

- Three samples were exposed to 8,100 and 1000 hr. dosages of radiation and tested at approximately the same consolidation stress ($\sim$134 kPa) to isolate any radiation effects. As seen on the p-q plot (see figure) these three samples follow almost identical stress paths.

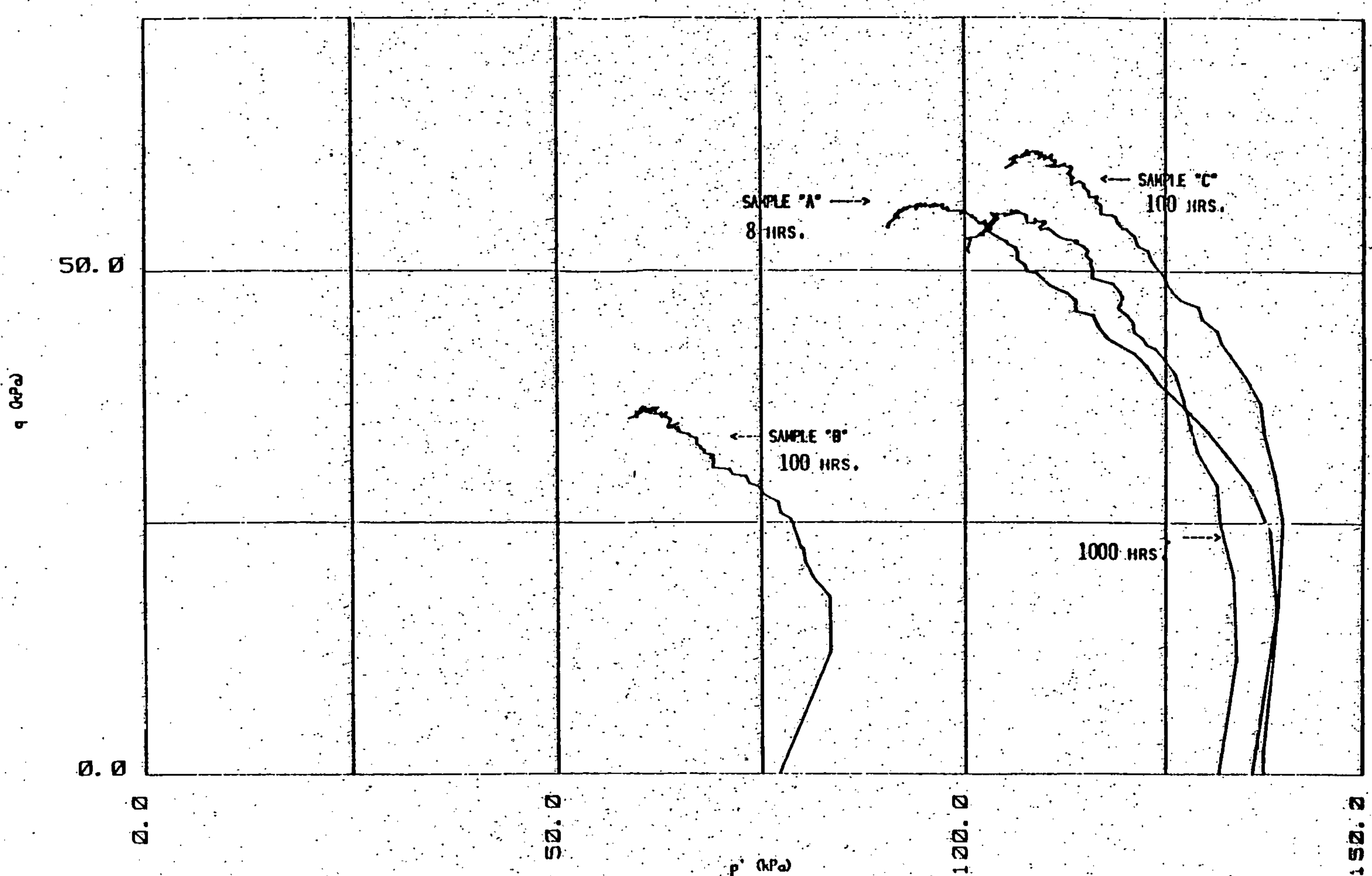
- Two 100 hr. dosage samples were tested at different consolidation stresses and a simple two point determination of the effective angle of internal friction ($\bar{\phi}$) and effective cohesion ($\bar{c}$) was made.

Control series	$\bar{\phi} = 33.5^{o}$	$\bar{c} = 1.11$ kPa
Irradiated series	$\bar{\phi} = 31.4^{o}$	$\bar{c} = 6.13$ kPa

These values compare relatively well in view of the fact that the control series data is based on 4 tests while the irradiated, only 2.

- Most other tests parameters including stress ratio, A-factor, peak deviator stress, and axial strain at failure did not differ significantly from the control series of non-radiated smectite (see Summary Table)

CONCLUSIONS (See figure)



q vs. p'
PS-9 "IRRADIATED"
URI/HCL

EFFECTS OF RADIATION HISTORY
ON STRESS - STRAIN PROPERTIES

EXPOSURE TIME (HRS)	W_I (%)	W_F (%)	$\bar{\sigma}_C$ (KPA)	ϵ_{AF} (KPA)	$(\sigma_1-\sigma_3)_F$ (KPA)	$\bar{\sigma}_1/\bar{\sigma}_{3F}$	A_F
RECONSTITUTED- RECONSOLIDATED SMECTITE: PS-9							
8	174	119	136	11	113	3.8	.86
100	180	128	77	14.8	73	4.1	.73
100	160	115	137	13.2	124	3.7	.74
1000	130	118	131	9.4	112	3.2	.73
RECONSTITUTED-RECONSOLIDATED SMECTITE: PS-18 (AKERS AND SILVA, 1980)							
0	128	112	9.5	10.2	26	3.8	.01
0	134	131	28	10.4	42	4.1	.32
0	126	123	78	9.8	66	3.4	.73
0	133	117	134	16.0	123	3.6	.68

EFFECTS OF RAIDATION HISTORY
ON STRESS-STRAIN PROPERTIES
(PACIFIC SMECTITE)

CONCLUSIONS

- RADIATION HISTORY HAS NO SIGNIFICANT EFFECT ON STRESS-STRAIN PROPERTIES.
- RADIATION DOSAGE HAS NO SIGNIFICANT EFFECT ON STRESS-STRAIN PROPERTIES.
- FUTURE STUDIES SHOULD EXAMINE STRESS STRAIN BEHAVIOR DURING ACTUAL RADIATION EXPOSURE.

EFFECTS OF HIGH CONSOLIDATION STRESS ON STRESS STRAIN BEHAVIOR: RECONSTITUTED RECONSOLIDATED ILLITE.

INTRODUCTION

The objective of these tests is to observe any change in the stress-strain behavior of deep sea sediment due to increasing consolidation stress. This first series is being done using reconstituted-reconsolidated illite, the next series will use undisturbed samples from the 1981 DeSteiger cruise. URI/MGL is tasked to go to approximately 2.7 MPa to provide overlap with testing at even higher consolidation pressures being done at WES on the same type samples.

HIGHLIGHTS

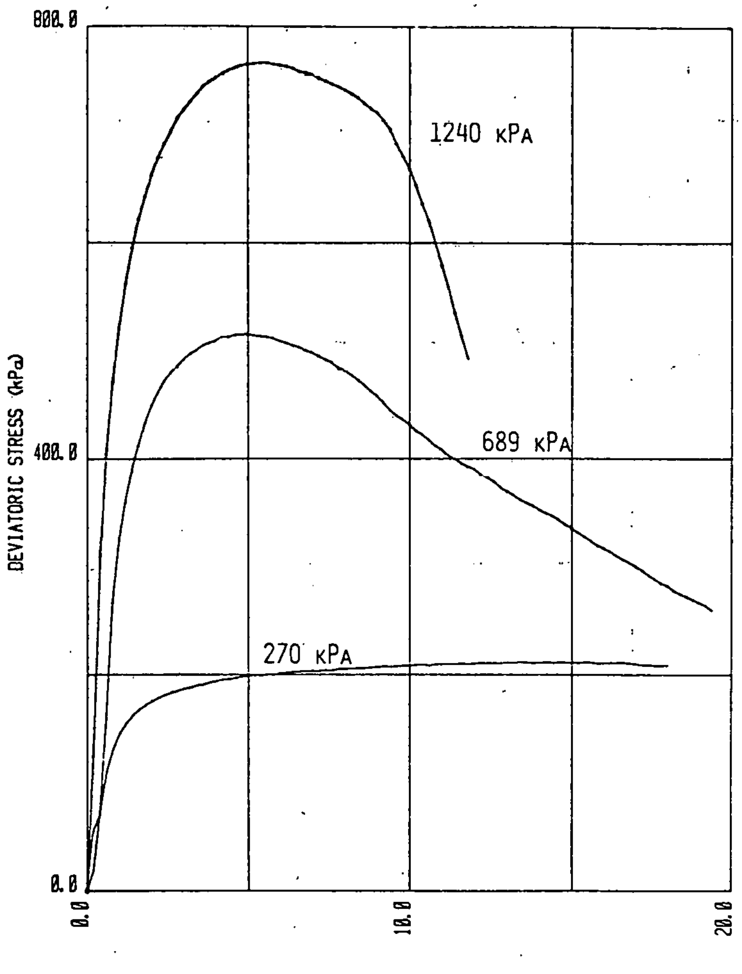
- An initial series at consolidation stresses of 270, 689 and 1240 kPa has been recently completed. As can be seen in the stress-strain curves (see figure) a change in mode of failure is observed above 270 kPa.

- At these consolidation stresses a preliminary analysis shows that some flattening of the Mohr-Coulomb failure envelope is occurring. A decrease in $\bar{\phi}$ with increasing consolidation stress is common in soils.

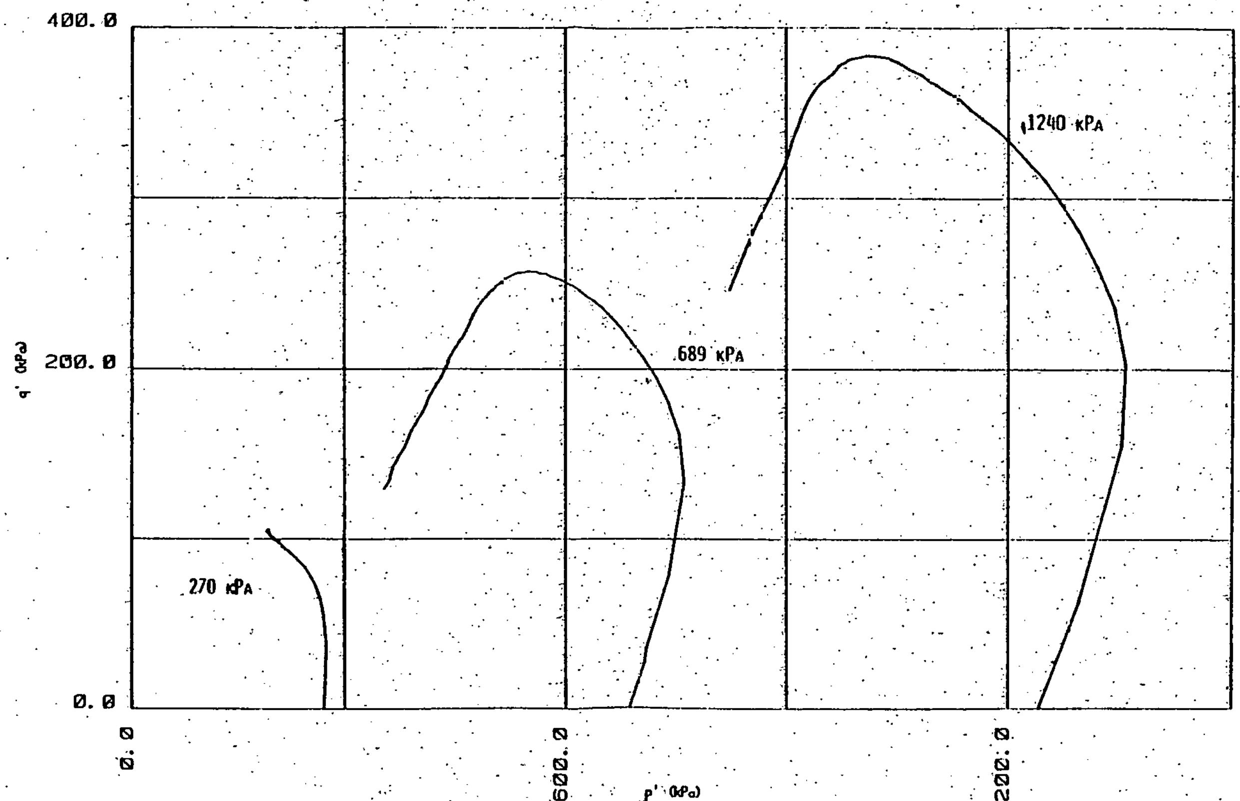
- After 689 kPa consolidation stress, the amount of additional water that can be squeezed out of a sample is almost insignificant.

- Preliminary results of a new test at a consolidation stress of 1770 kPa point to a trend where all three high pressure tests (689, 1240 and 1770 kPa) all reach peak deviator stress at approximately 5% axial strain.

SUMMARY AND REMAINING WORK (See Figure)



DEVIATORIC STRESS vs. STRAIN
PI-5-8; HIGH PRESS.
URI/MGL



q' vs. p'
PI-5-8-1 HIGH PRESS.
UNI/HGL

Sediment Geotechnical Properties con't.

EFFECTS OF HIGH CONSOLIDATION STRESS

SUMMARY AND REMAINING WORK

- AT CONSOLIDATION STRESSES GREATER THAN 270 KPA THE FAILURE MODE CHANGES FROM "BARREL SHAPED" TO A SINGLE DEFINED SHEAR PLANE
- SAMPLES REACH A "CRITICAL" VOID RATIO AT PRESSURES GREATER THAN 689 KPA AFTER WHICH INSIGNIFICANT DECREASE IN VOLUME IS OBSERVED WITH INCREASING CONSOLIDATION STRESS
- FURTHER TESTING WILL CONTINUE INCREASING CONSOLIDATION STRESSES TO NO GREATER THAN 2640 KPA
- FURTHER TESTING WILL ATTEMPT TO BETTER DEFINE THE TRANSITION IN MODE OF FAILURE BETWEEN 270 AND 689 KPA
- FURTHER ANALYSIS WILL INCORPORATE PREVIOUSLY REPORTED CIU RESULTS FOR RECONSOLIDATED RECONSTITUTED ILLITE AND DETERMINE ANY CHANGES IN THE MOHR-COULOMB FAILURE ENVELOPE

CREEP PROGRAM

INTRODUCTION

Creep properties and behavior of deep sea sediments has been investigated at URI/MGL under three conditions; room temperature, variable temperature and long-term. A constant loading stress is applied on a fully drained triaxial specimen in all tests, (except in the long-term drained uniaxial, experiment), with continuous measurements of appropriate deformations and test conditions. The following is a summary of our findings.

ROOM TEMPERATURE

This aspect of the program is complete. See attached table.

VARIABLE TEMPERATURE - See attached table and figure.

- Instabilities occurred at all temperatures.

- Brittle structure developed during 100 and 150°C tests. Insignificant increase in axial strain with increase in stress level.

- In the 150°C test, sample failure occurred at 210% stress level. The 100°C test is currently at 70% stress level with no significant change in axial strain. The 75°C test failed at 10% stress level; 20°C at 50% and 4°C at 40%.

- From the figure it appears that a cooling (4°C) or heating (75, 100, 150°C) of the specimen results in a decrease in axial strain under comparable loading. However, the 150°C test does not conform since it has an initial strain several magnitudes greater than the other tests. It is suspected that this high initial strain could be partially due to some seating of the piston on the sample prior to true straining.

- Current and future tests include - the 100°C test which is near completion; substantiating the previous 75°C and 150°C by rerunning on similar material; conducting two tests (75 and 150°C) on remolded smectite varying the procedure by consolidating first then heating.

LONG-TERM-UNIAXIAL - See attached table and figure

- Two areas of secondary creep (constant $\dot{\varepsilon}$) can be identified on each curve of constant applied stress. The latter $\dot{\varepsilon}$ being of lesser magintude in each curve. It is suspected that an instability occurred between the two areas of secondary creep because this behavior is precisely the same as the room temperature triaxial series completed by K. Moran.

- Magnitude of strain rate in the second region of secondary creep increases with stress level.

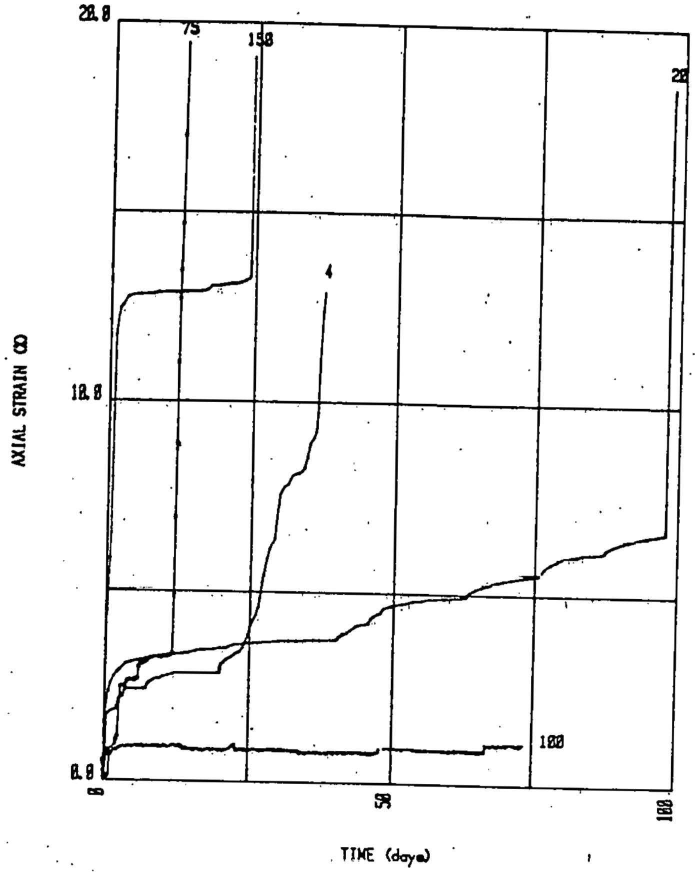
LONG-TERM-UNIAXIAL (Continued)

- Tests are continuing examining uniaxial creep behavior under increasing stress level on this specimen.

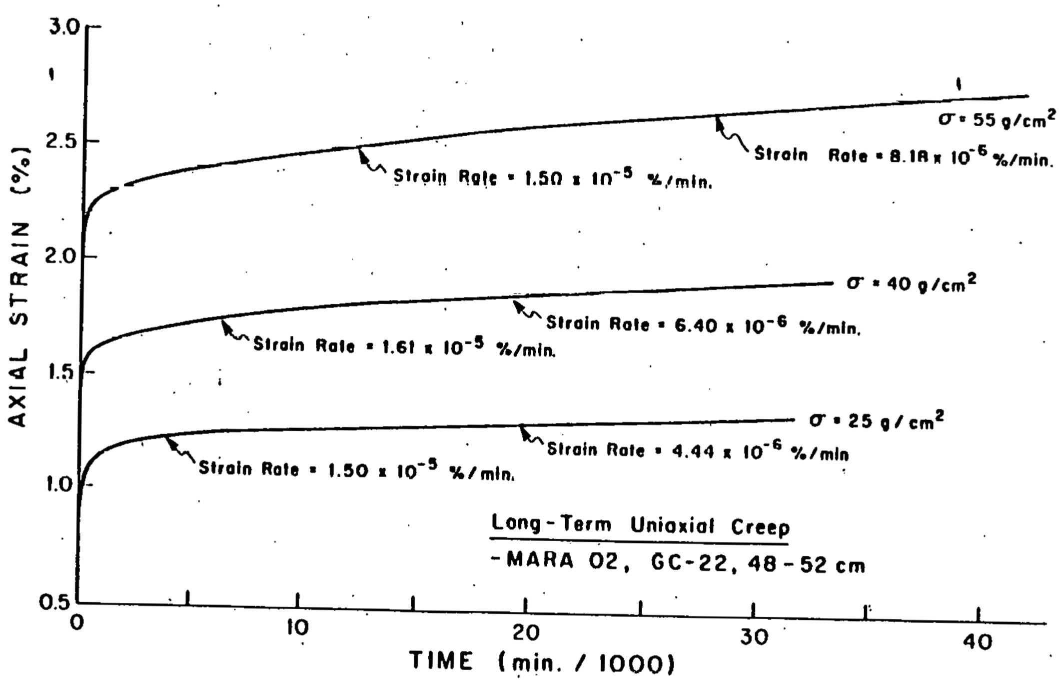
LONG-TERM: TRIAXIAL - See attached table and figures.

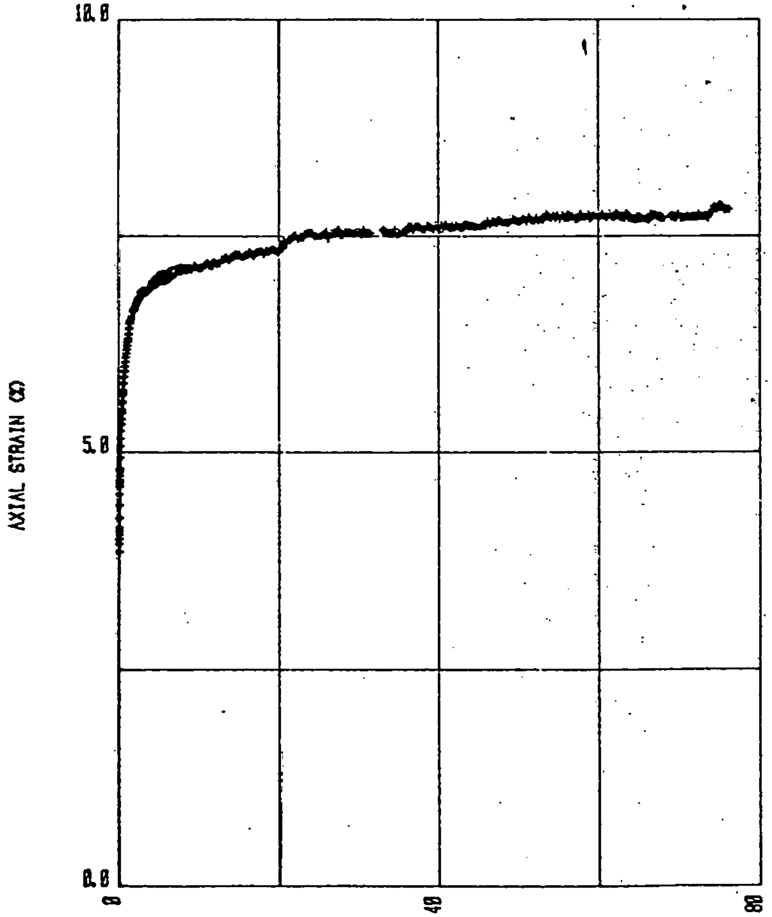
- Two areas of secondary creep can be identified (before and after 20,000 min.). Magnitude of strain rate, $\dot{\varepsilon}$, less for second area.

- Instability occurs at approximately 20,000 min. Noticeable in axial and volumetric strain vs. time curves.

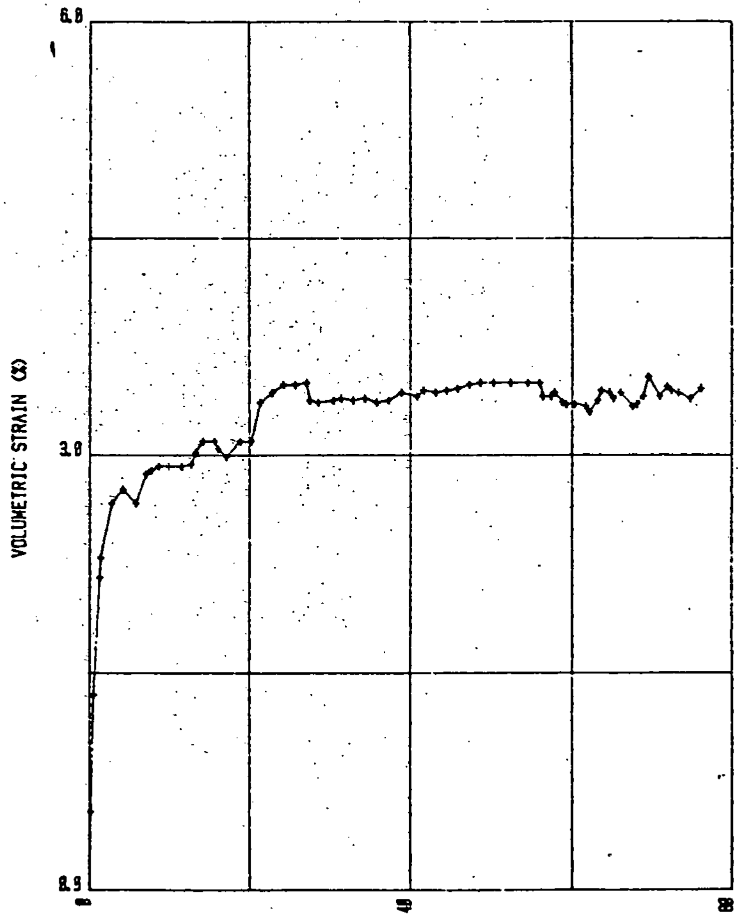


AXIAL STRAIN vs. TIME
VARIABLE TEMP. CREEP
URI/HGL





AXIAL STRAIN vs. TIME
LONG TERM
URI/MGL
MARA-02, GC-08, 66-73 cm



VOLUMETRIC STRAIN vs. TIME
LONG TERM, UI-8
URI/MGL
MARA-02, GC-08, 66-73 cm

CREEP PROGRAM

Room Temperature

- Identify and analyze creep properites and behavior of deep sea sediments.
- Conduct constant stress drained tests on undisturbed illite and smectite and remolded smectite material at various stress levels.
- Testing and analysis complete - Thesis by K. Moran available.

Long-Term

- Assess long-term (1 year) creep properties and behavior.
- Carry out drained uniaxial and triaxial tests on undisturbed illite.
- 1-D, uniaxial; 150 days; 25, 40, 55, 85, g/cm^2 stresses.
- 2-D, triaxial; 95 days; 25% stress level.

Variable Temperature

- Investigate temperature effects on creep properies and behavior of deep sea sediments.
- Perform constant stress drained tests on undisturbed illite and remolded smectite material at temperatures expected in the canister vicinity.
- Phase 1 - Temp. 4, 20, 75, 150°C Complete - Thesis by J. Wildman available.
- Phase 2 - Temp. 100°C near completion; 75, 150°C (Remolded Smectite) FY 82; Substantiate Phase 1.

ROOM TEMPERATURE CREEP

CONCLUSIONS

- Deep-sea sediments exhibit larger axial strains than their terrestrial and "bay" counterparts.
- Tertiary creep (Rupture) occurs at lower stress levels than counterparts.
- Instabilities occurred on undisturbed specimens only.
- Proposed phenomenological equation $\log \dot{\varepsilon} = mts + bs + k$ accounts for nonlinear axial strain rate vs. time.

High Pressure/High Temperature

Thermophysical Properties Program:

This task was initiated in order to determine the thermophysical properties of deep-sea sediments as a function of void ratio at in situ conditions of hydrostatic pressure and temperature. The sediments chosen were two clay types obtained from the MPG-1 study area.

The initial effort primarily focussed on the design, fabrication, and calibration of the laboratory apparatus. The device has the capability of consolidating a sample to simulate compaction through the sediment column. At various void ratios, permeability and thermal conductivity can be directly measured, while exposing the sample to hydrostatic pressures up to 65 MPa and temperatures up to 220° C.

A systematic test program has been performed in order to analyze the effects of large hydrostatic pressures on sediment physical properties. The clay samples exhibited a gradual increase in thermal conductivity with increasing pressure. This behavior simply reflects the variation of the thermal conductivity of water alone as a function of pressure. There was no detectable change in sediment permeability with increasing hydrostatic pressure. A small variation in the kinematic viscosity of water with pressure was within the accuracy of the test (∓ 10%), and, therefore, did not discernibly influence the results.

The change in the viscosity of the permeating medium did, however, affect the results of the variable temperature tests. In this series of experiments, the clay samples were exposed to a constant hydrostatic pressure of 58.6 MPa, and the temperature was increased in stages from 22° C to 220° C. The results of the permeability tests show that the variation can be accounted for by the change in viscosity of the sea water with temperature.

As in the case of the variable pressure test, the variable temperature tests illustrate that the change in the sediment thermal conductivity closely reflects the behavior of this property for water alone as a function of temperature.

HIGH PRESSURE/HIGH TEMPERATURE
THERMOPHYSICAL PROPERTIES PROGRAM

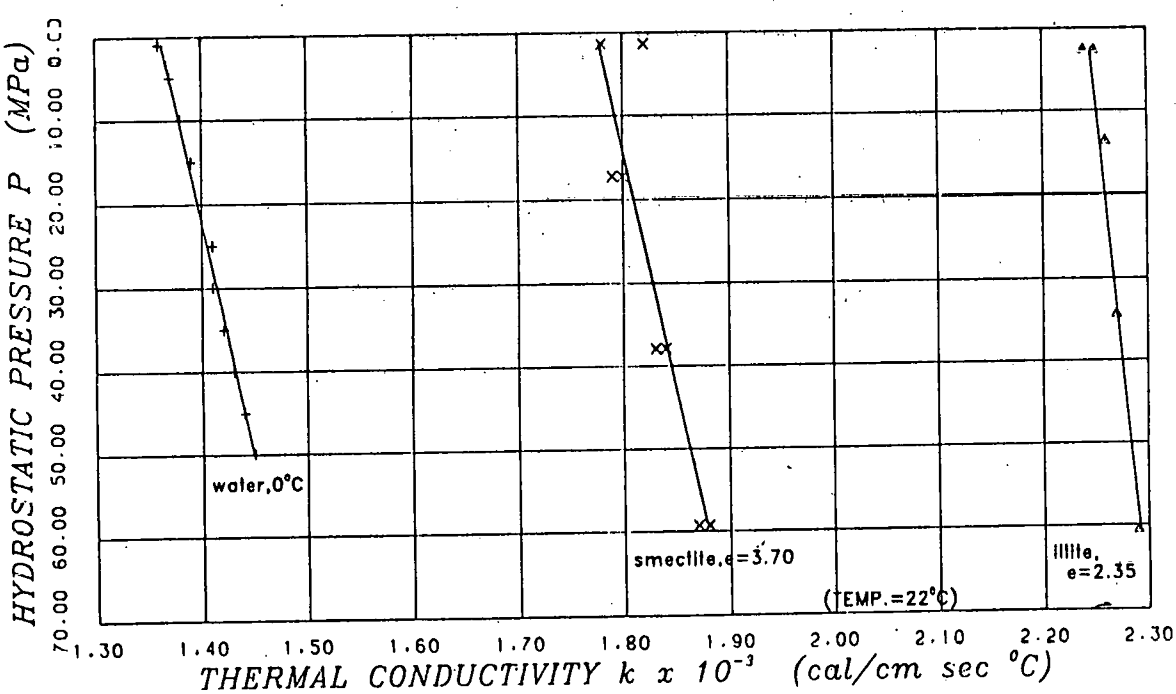
1. PURPOSE -

TO DETERMINE THE PERMEABILITY AND THERMAL CONDUCTIVITY OF DEEP-SEA CLAYS AS A FUNCTION OF VOID RATIO AT *IN SITU* CONDITIONS OF HYDROSTATIC PRESSURE AND TEMPERATURE.

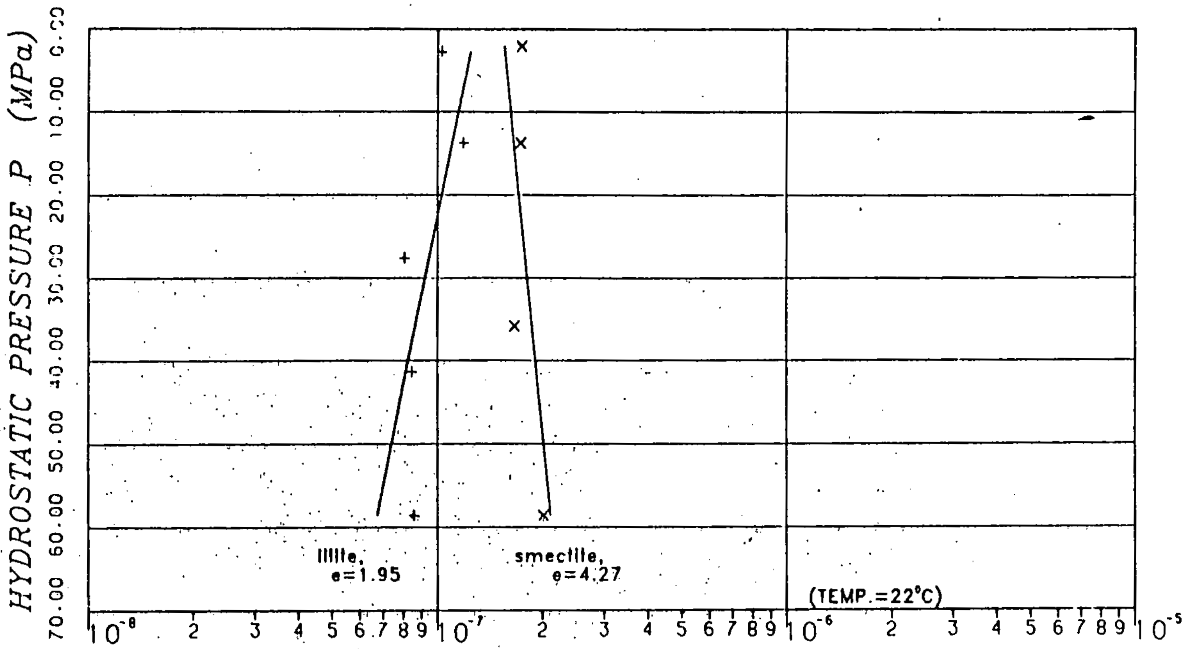
2. SCOPE -

A) DESIGN AND BUILD A LABORATORY APPARATUS CAPABLE OF CONSOLIDATING A SEDIMENT SAMPLE AND DIRECTLY MEASURING THE ABOVE PROPERTIES, WHILE EXPOSING IT TO HYDROSTATIC PRESSURES UP TO 65 MPA AND TEMPERATURES UP TO 220°C.

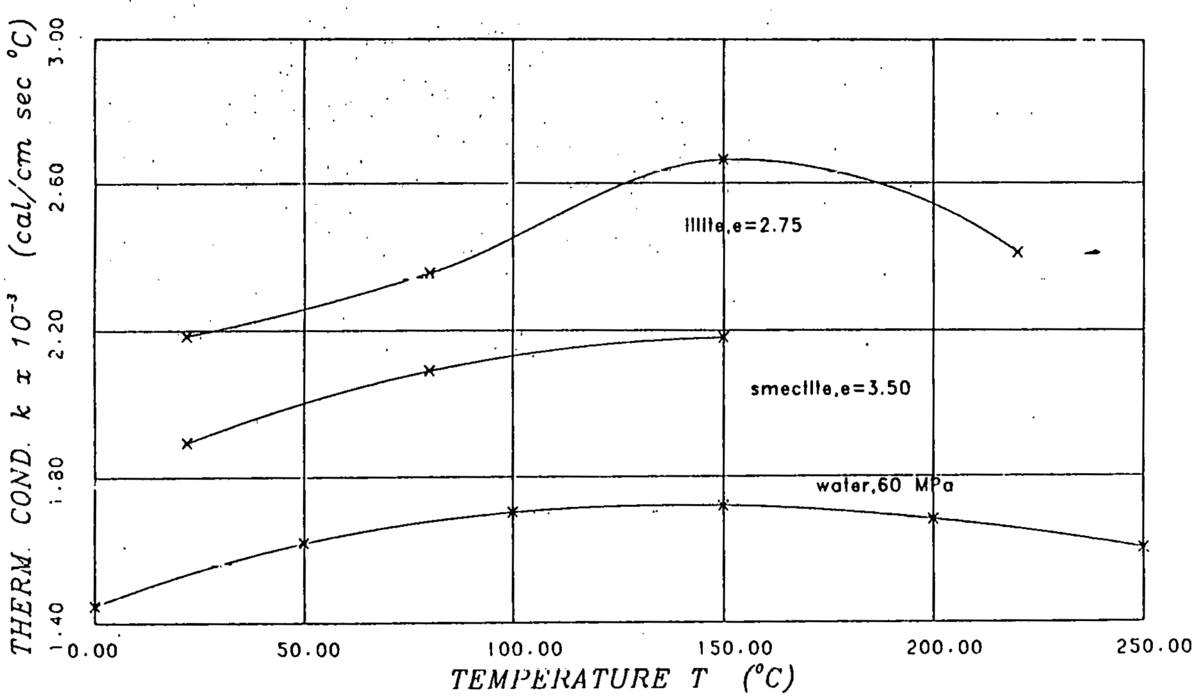
B) PERFORM A SYSTEMATIC TEST PROGRAM WITH BOTH ILLITE AND SMECTITE SAMPLES IN ORDER TO DETERMINE THE THERMOPHYSICAL EFFECTS OF HIGH HYDROSTATIC PRESSURE AND TEMPERATURES.



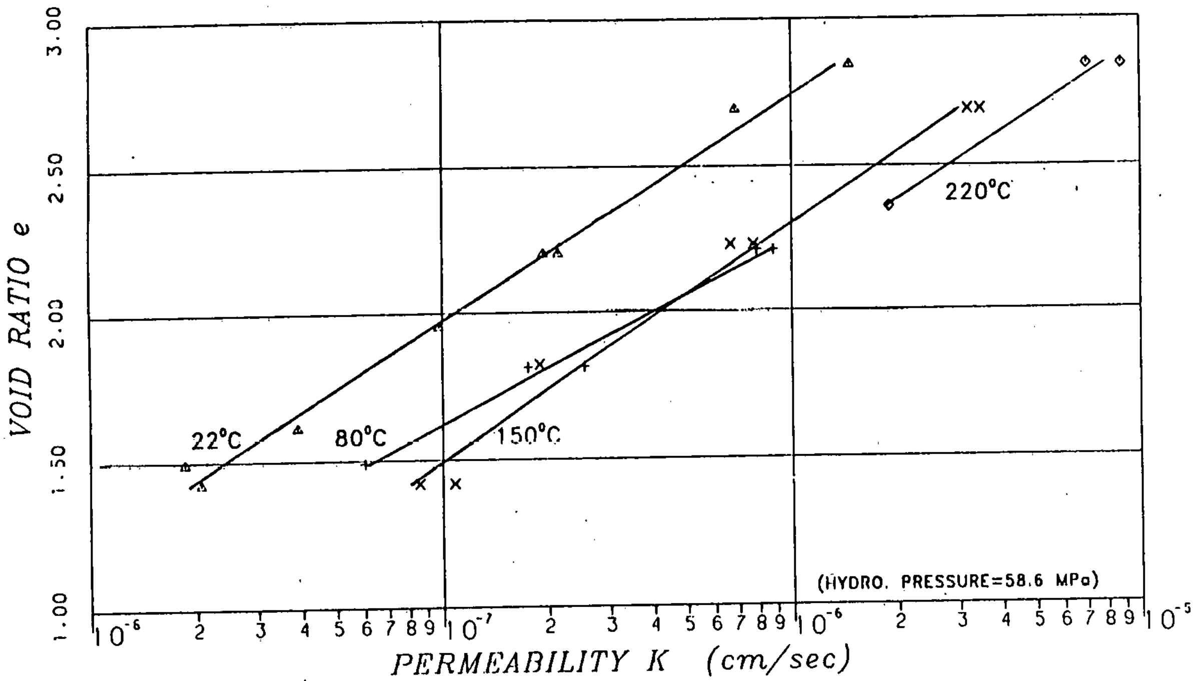
k vs. P


HYDROSTATIC PRESSURE P (MPa)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Illite, e=1.95
smectite, e=4.27
(TEMP.=22°C)
PERMEABILITY K (cm/sec)

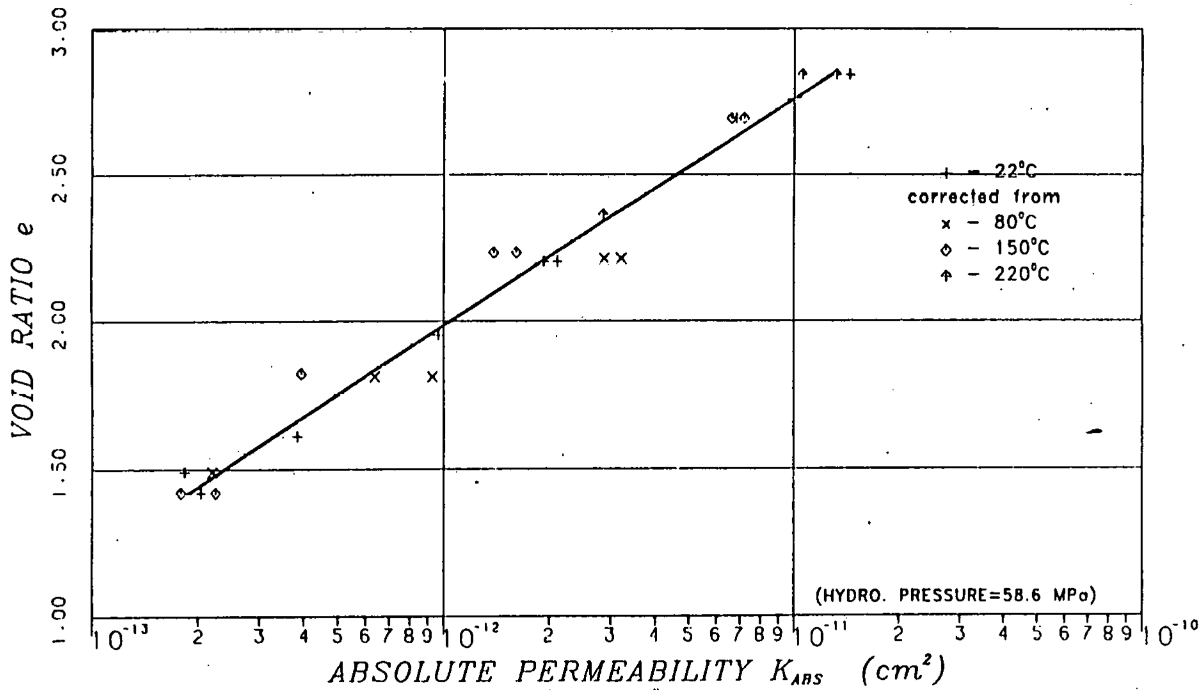
K vs. P


THERM. COND. k x 10⁻³ (cal/cm sec °C)
1.40
1.80
2.20
2.60
3.00
Illite,e=2.75
smectite,e=3.50
water,60 MPa
0.00
50.00
100.00
150.00
200.00
250.00
TEMPERATURE T (°C)

k vs. T



ILLITE, K vs. e vs. T



ILLITE, K_{ABS} vs. e

RESULTS

1. PRESSURE EFFECTS:

   A) THERMAL CONDUCTIVITY -
   VARIATION REFLECTS BEHAVIOR OF WATER ALONE.

   B) PERMEABILITY -
   NO DISCERNIBLE CHANGE. SMALL VARIATION IN WATER VISCOSITY IS WITHIN ACCURACY OF TEST.

2. TEMPERATURE EFFECTS:

   A) THERMAL CONDUCTIVITY -
   VARIATION REFLECTS BEHAVIOR OF WATER ALONE.

   B) PERMEABILITY-
   VARIATION REFLECTS CHANGE IN THE KINEMATIC VISCOSITY OF THE PERMEATING MEDIUM -SEA WATER.

Thermal Effects on Sediment Properties

William N. Houston, Neil D. Williams
University of California at Berkeley

At UC Berkeley, we have been doing an experimental study of the thermomechanical properties of subject soils, measuring the response to shear and compressive loading over a temperature range of 4° - 200° C. The emphasis of this work is on undrained response. Tests include both isotropic and anisotropic consolidation, constant-rate-of-strain strength tests, constant stress creep tests, thermal consolidation tests, and permeability tests at more than one shear stress level.

Some Preliminary Observations

Most of the tests to date have been on remolded-reconsolidated illite. This material exhibits an essentially elastic-plastic stress-strain curve at moderate temperatures, but becomes more brittle at higher temperatures and after creep loading, significant secondary compression (high C_α), secondary compression rates which are a strong function of temperatures and are essentially independent of effective confining pressure, and a time for any degree of consolidation that is a strong function of temperature (see table).

There is also a strong relationship between undrained shear strength and water content at failure--regardless of whether water content decrease was induced by mechanical consolidation or by thermal consolidation, and whether water content decrease was caused by primary consolidation or prolonged secondary compression. There is positive pore pressure with a low stress level, then a fairly steady pore pressure with a high shear stress level.

Temperature (°C)	Approx. t_{100} (min.)
21	$\approx$ 400
40	$\approx$ 120
100	$\approx$ 10
200	$\gtrsim$ 1

WHEN A SOIL MASS OF KNOWN STATE $(\bar{3}, (\frac{I_\sigma}{3})_c, \omega, T)$ IS SUBJECTED TO CHANGES IN THE STATE OF STRESS $(\Delta \bar{3}, \Delta(\frac{I_\sigma}{3})_c)$ A/O CHANGES IN THE TEMPERATURE (ΔT), DEFORMATIONS OF THE SOIL MASS WILL ENSUE.

AN EQUATION DESCRIBING THE DEFORMATION OF THE SOIL MASS IS AS FOLLOWS:

$$\Delta \varepsilon_{TOT} = \Delta(\varepsilon_v^e) + \Delta(\varepsilon_v^p) + \Delta(\varepsilon_v^c) + \Delta e^e + \Delta e^p + \Delta e^c$$

WHERE,

$$\Delta(\varepsilon_v^e) = \Delta(\varepsilon_v^e)_m + \Delta(\varepsilon_v^e)_T + \Delta(\varepsilon_v^e)_{TE}$$

$$\Delta(\varepsilon_v^p) = \Delta(\varepsilon_v^p)_m + \Delta(\varepsilon_v^p)_T$$

$$\Delta(\varepsilon_v^c) = \Delta(\varepsilon_v^c)_m + \Delta(\varepsilon_v^c)_T$$

PRELIMINARY RESULTS AND CONCLUSIONS

1) CERTAIN TERMS ARE SMALL WHEN COMPARED TO OTHER TERMS IN THE DEFORMATION EQUATION AND MAY BE NEGLECTED. THESE TERMS ARE : $(\varepsilon_v^e)_m$, $(\varepsilon_v^e)_T$, e^e

2) THE UNDRAINED SHEAR STRENGTH OF THE SOIL IS A FUNCTION OF THE WATER CONTENT AT FAILURE AND THE STRESS HISTORY. THEREFORE, THE ULTIMATE STRENGTH OF THE SOIL, FOR A GIVEN STRESS PATH, CAN BE ESTIMATED FROM THE WATER CONTENT AT FAILURE, AND IS UNAFFECTED BY TEMPERATURE, EFFECTIVE STRESS DURING CONSOLIDATION, AND THE TIME THE SOIL HAS CREEPED.

3) THE BEHAVIOR OF THE SOIL CAN BE DESCRIBED AS ELASTIC-PLASTIC FOR LOW TO MODERATE TEMPERATURES AND MODERATE TO HIGH WATER CONTENTS. STRAIN SOFTENING OCCURS AT HIGH TEMPERATURES AND LOW WATER CONTENTS.

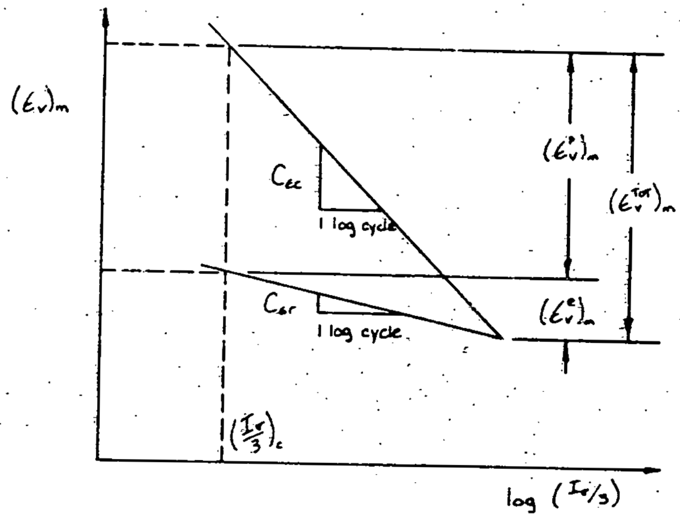
4) PRIMARY CONSOLIDATION OCCURS VERY FAST AT HIGH TEMPERATURES. THE ASSUMPTION OF UNDRAINED BEHAVIOR MAY NOT BE VALID AT HIGH TEMPERATURES.

5) THE BEHAVIOR OF THE SOIL AFTER COOLING HAS YET TO BE ADDRESSED. SAMPLES SHOULD BE THERMALLY CONSOLIDATED THEN COOLED AND TESTED IN AN UNDRAINED TRIAXIAL COMPRESSION TEST.

6) INCREASES IN TEMPERATURE INCREASE THE VOLUMETRIC CREEP, CAUSE THERMAL CONSOLIDATION, AND INCREASE SOIL STRENGTH AND DENSITY.

1) TRIAXIAL CONSOLIDATION TESTS

T = REFERENCE TEMPERATURE
$t = t_p$



$$\Delta(\epsilon_v^{Tot})_m = C_{\epsilon c} \log \left[\frac{(I_\sigma/3)}{(I_\sigma/3)_c}\right]$$

$$\Delta(\epsilon_v^{e})_m = C_{\epsilon r} \log \left[\frac{(I_\sigma/3)}{(I_\sigma/3)_c}\right]$$

$$\Delta(\epsilon_v^{p})_m = \Delta(\epsilon_v^{Tot})_m - \Delta(\epsilon_v^{e})_m$$

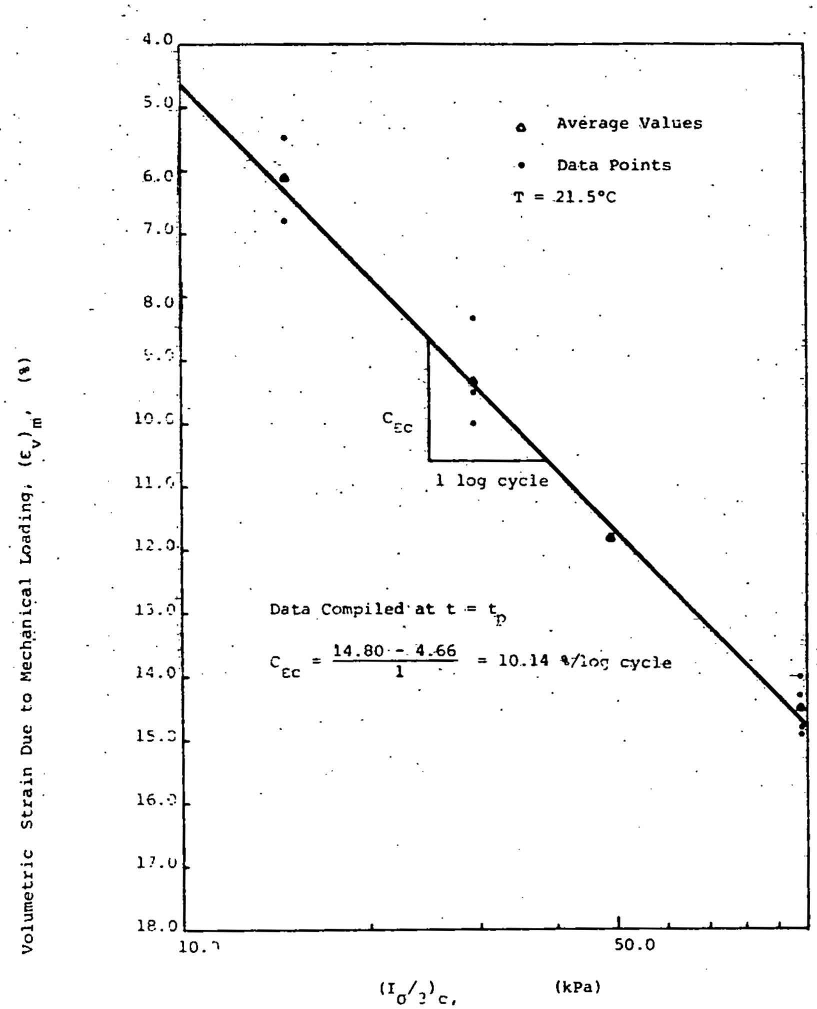
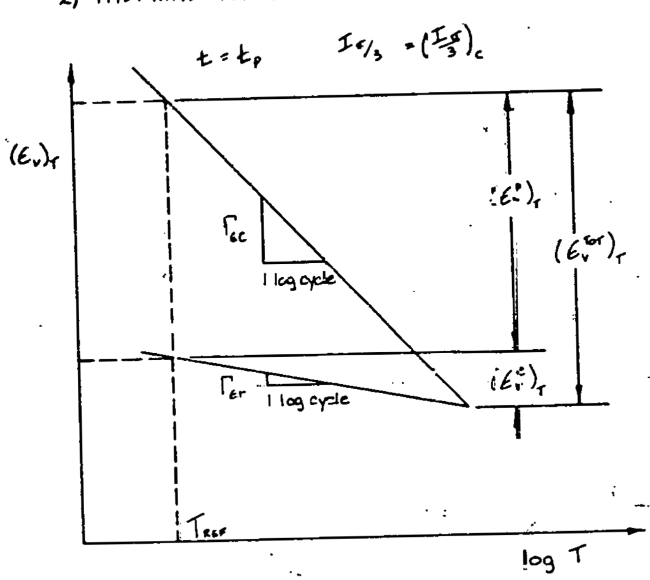


Figure . The Strain Consolidation Index for hydrostatic stress increments.

2) THERMAL TRIAXIAL CONSOLIDATION TESTS



$$\Delta(\varepsilon_v^{tot})_T = \Gamma_{\varepsilon c} \log\left(\frac{T}{T_{ref}}\right)$$

$$\Delta(\varepsilon_v^{e})_T = \Gamma_{\varepsilon r} \log\left(\frac{T}{T_{ref}}\right)$$

$$\Delta(\varepsilon_v^{p})_T = \Delta(\varepsilon_v^{tot})_T - \Delta(\varepsilon_v^{e})_T$$

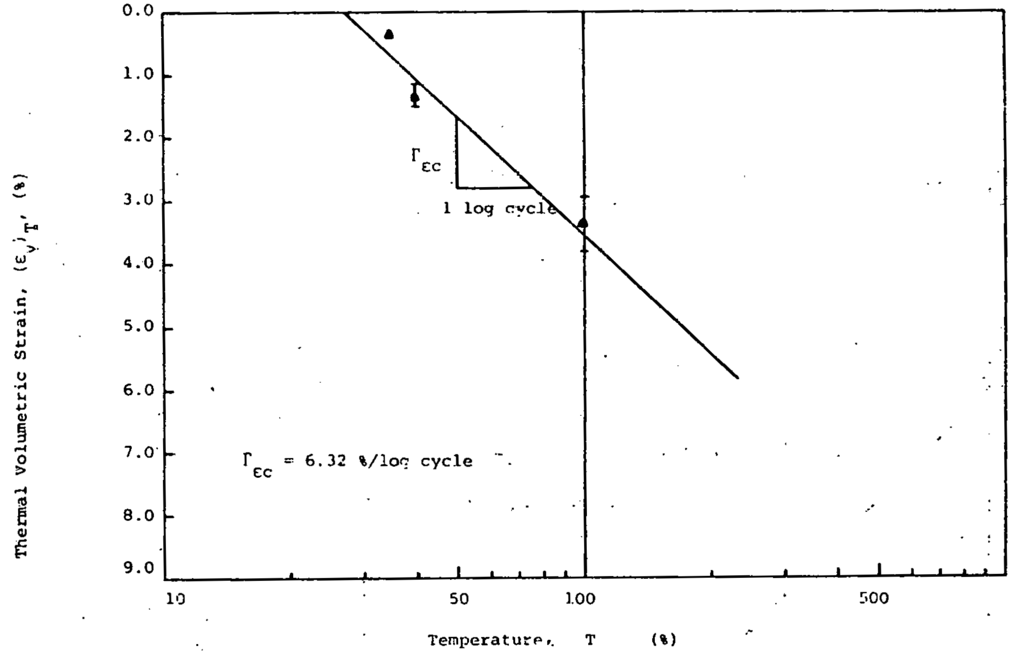
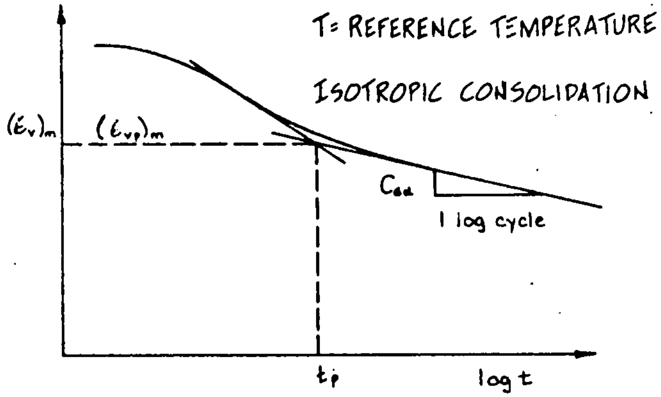


Figure . Thermal Consolidation Index.

4) TRIAXIAL CONSOLIDATION TEST :

VOLUMETRIC CREEP



$$\Delta(\epsilon_v^c)_m = C_{\epsilon\alpha} \log(t/t_p)$$

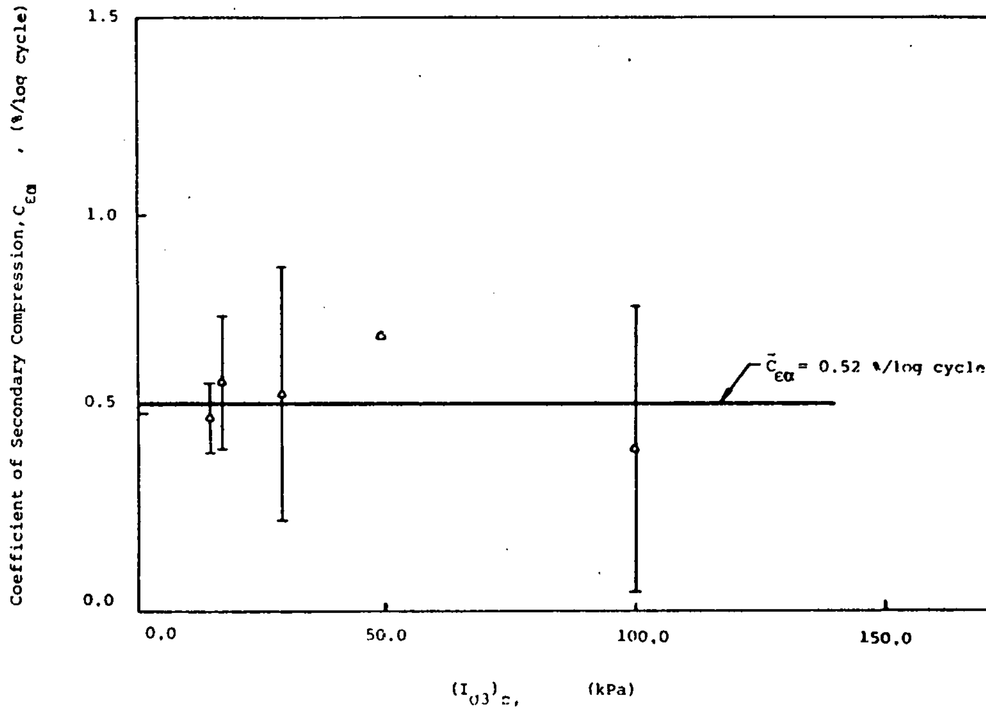
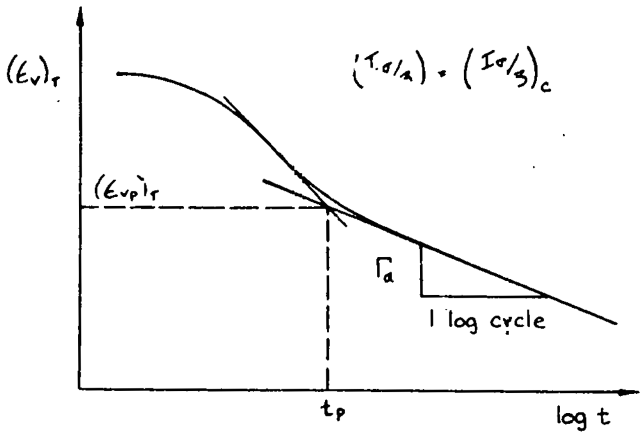


Figure . Average Coefficient of Secondary Compression.

5) THERMAL TRIAXIAL CONSOLIDATION TEST:

THERMAL VOLUMETRIC CREEP



$$\Delta(\epsilon_v^c)_T = \Gamma_\alpha \log\left(\frac{t}{t_p}\right)$$

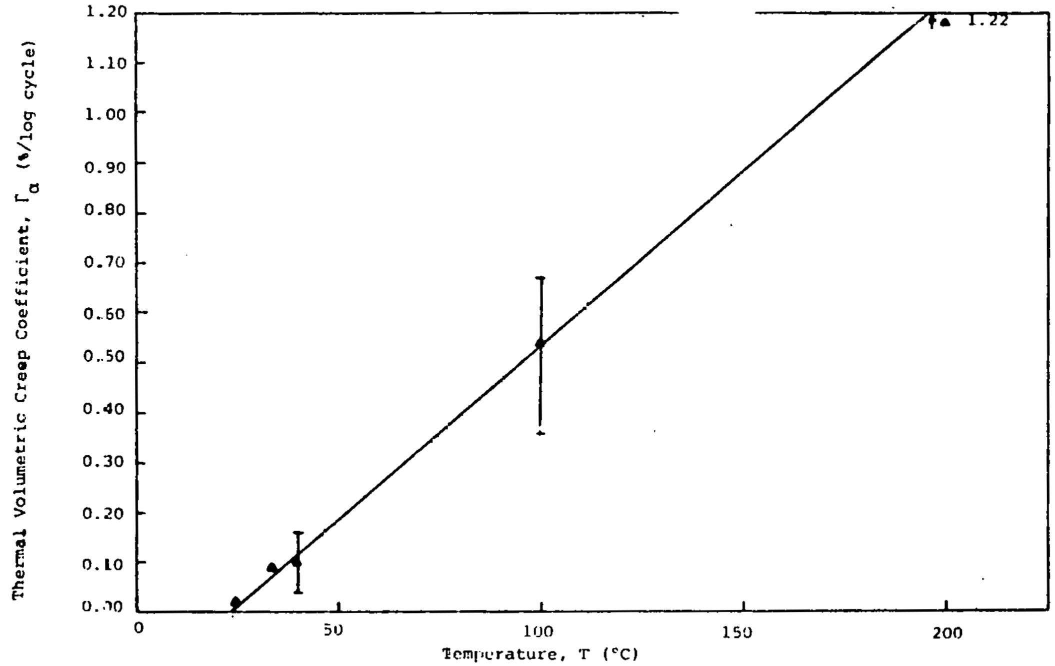
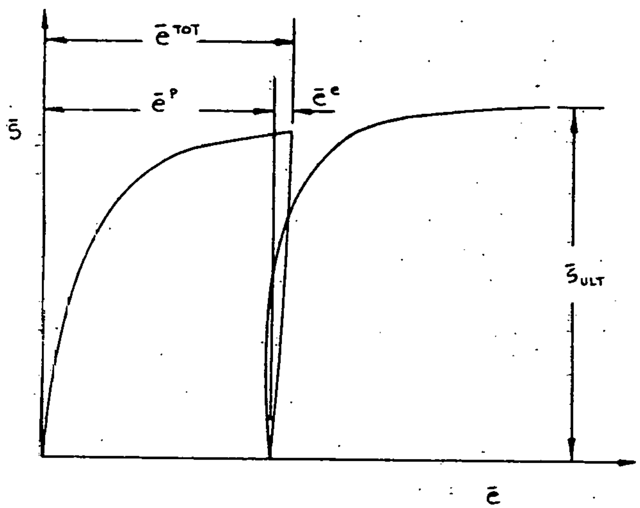


Figure . The Thermal Volumetric Creep Coefficient as a function of temperature.

6) UNDRAINED TRIAXIAL COMPRESSION TEST

$\sigma_2 = \sigma_3 = $ CONSTANT

σ_1 INCREASED



$\bar{s}$ = EFFECTIVE STRESS PARAMETER

$\bar{s} = (3 J_{2D})^{1/2}$

$\bar{e}$ = EFFECTIVE STRAIN PARAMETER

$\bar{e} = (\frac{4}{3} II_e)^{1/2}$

$\bar{s} = \bar{s}\left(\bar{e}, \left(\frac{I_\sigma}{3}\right)_c, T, w_f, t^c, \text{STRESS HISTORY}\right)$

$\bar{s}_{ULT} = \bar{s}_{ULT}(w_f, \text{STRESS HISTORY})$

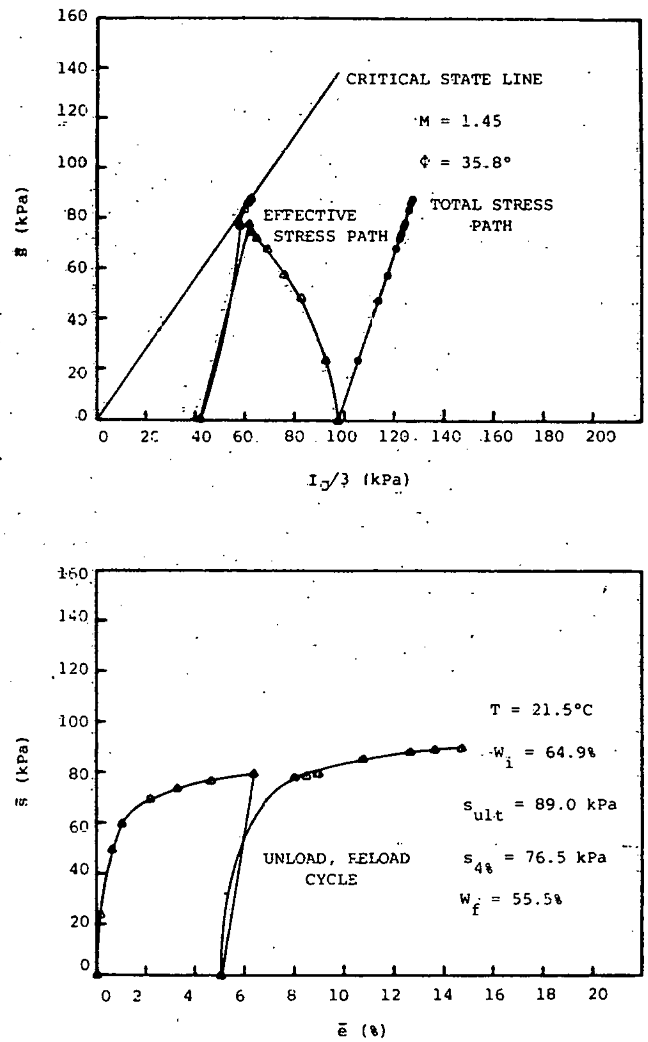
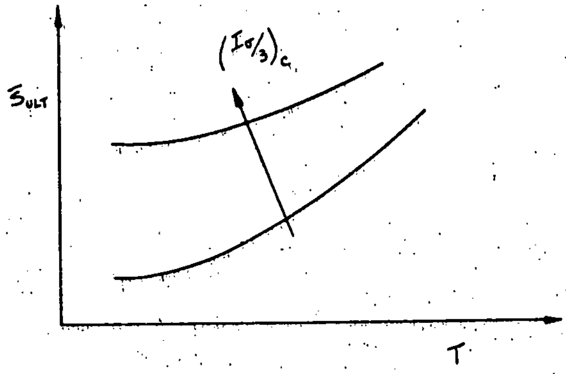
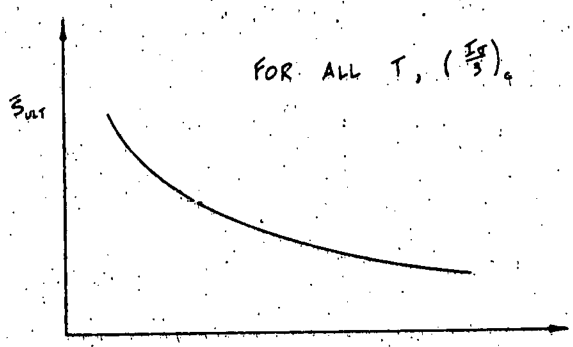


Figure . Stress Paths and Strength Behavior for Test SS 12 in Terms of Effective Stress and Strain Parameters.

6A) PARAMETERS INFLUENCING $\bar{s}_{ULT}$





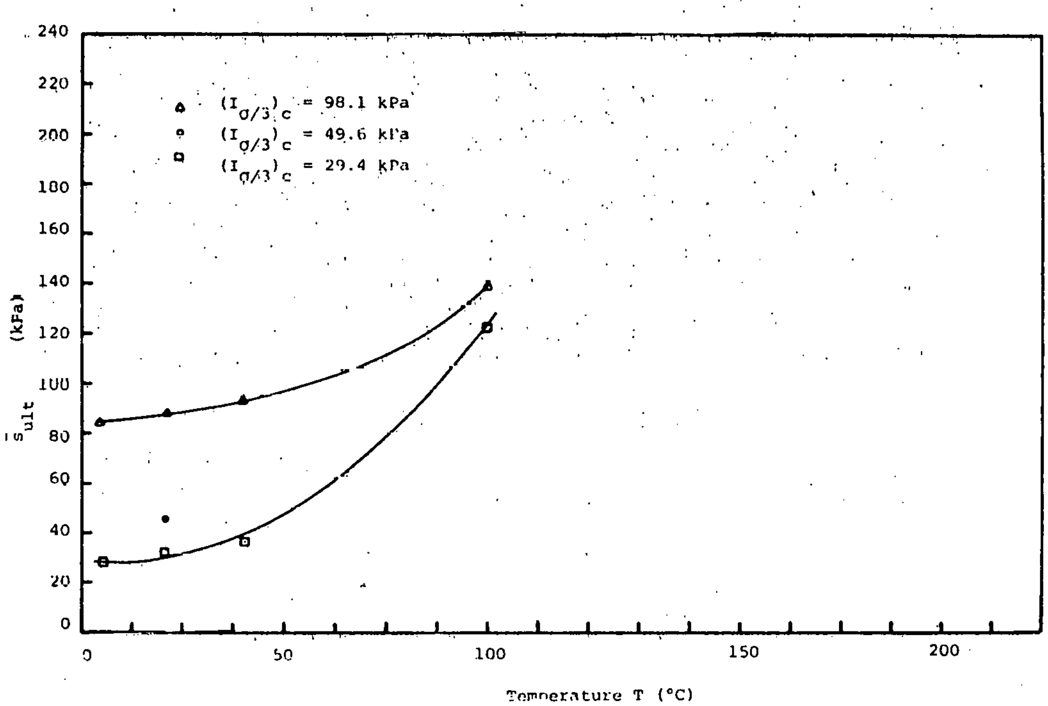


Figure . The undrained Shear Strength as a function of temperature and hydrostatic stress during consolidation.

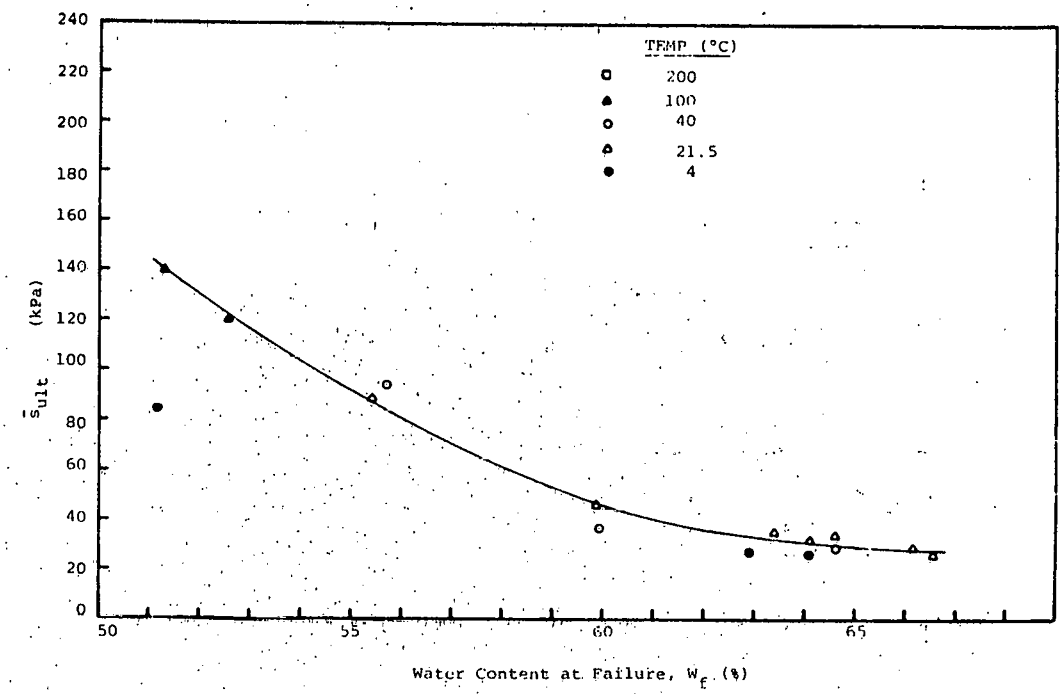


Figure . The undrained Shear Strength as a function of the water content at failure.

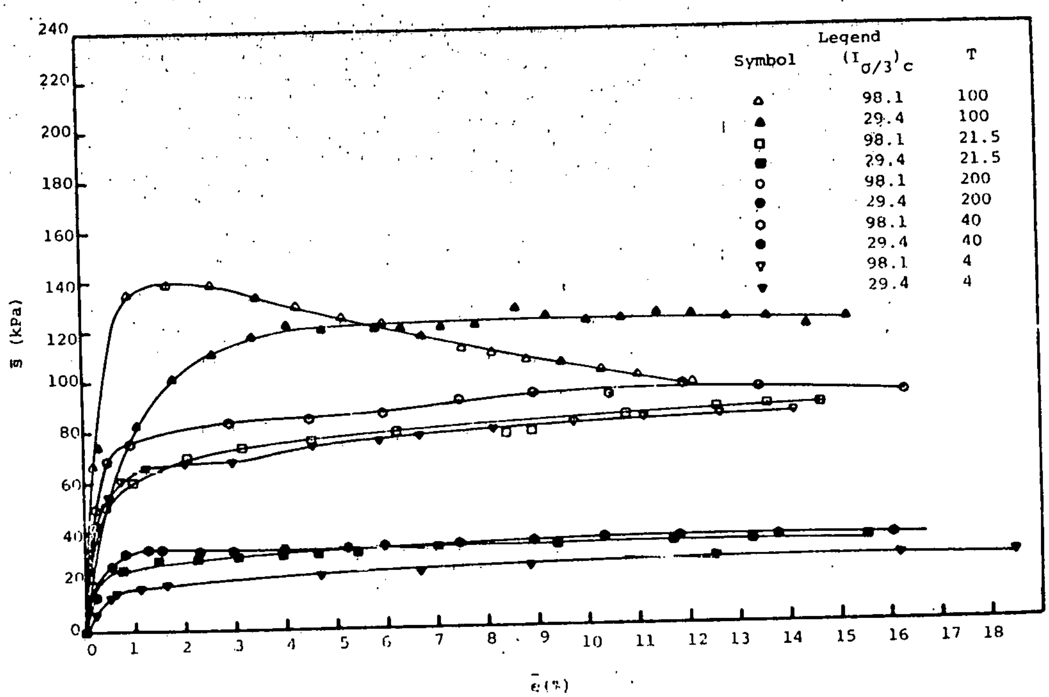
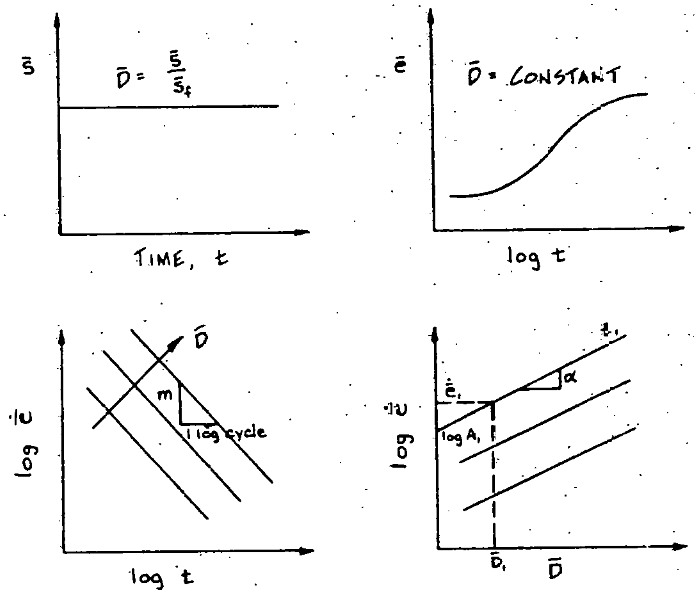


Figure . Stress-Strain behavior as a function of temperature and hydrostatic stress during consolidation.

7) CONSTANT DEVIATOR STRESS, UNDRAINED

CREEP TEST $\qquad$ T = CONSTANT



POSSIBLE DEVIATORIC CREEP MODELS:

1) SINGH - MITCHELL: $\dot{\varepsilon} = A\left(\frac{t_1}{t}\right)^m \operatorname{Exp}(\alpha \bar{D})$

2) HYPERBOLIC SINE: $\dot{\varepsilon} = \dot{\varepsilon}_0 \sinh\left[\frac{\phi(F)}{u_f \; \bar{s}_f}\right]$

WHERE, $\phi(F) = 0$ IF $F \leq 0$

$\phi(F) = F$ IF $F > 0$

F = EQUATION OF FAILURE SURFACE

$F = F(\bar{s}, I_1/3)$

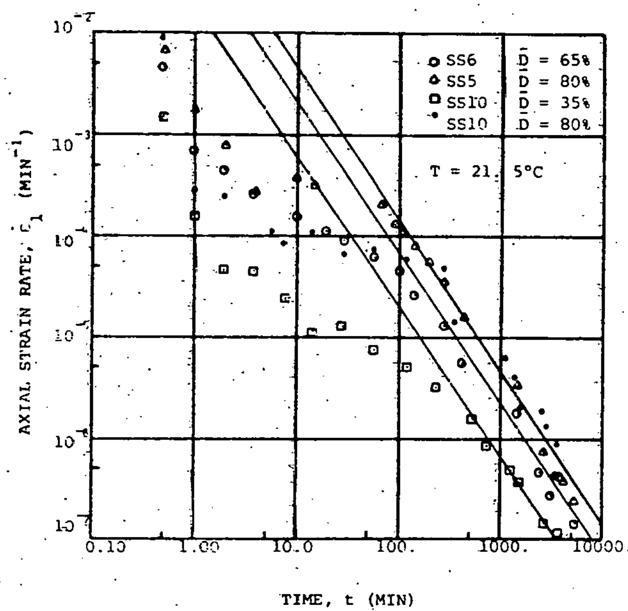


Figure . Axial strain rate - time relationship for creep tests at stress levels, $\bar{D}$ = 35, 65, 80%.

Creep Modeling Activities

Paul R. Dawson, Cornell University; Joel Lipkin, SNLA

The development of creeping deformation simulation tools has centered on the NEPTUNE computer code. Over the past year several activities have been directed at improving NEPTUNE's ability to model accurately the thermomechanical response of deep-ocean sediments. These activities are enumerated in Figure 1. One major activity is related to generalizing the field equations solved by NEPTUNE, as well as improving the computational algorithm for obtaining a solution. A second activity has been directed toward the constitutive equations that mathematically describe the mechanical response of saturated sediment to applied loads, possibly in the presence of complicated thermal histories. Both the form of the constitutive equations and the paramters within the equations must be derived from the analysis of laboratory and field tests. The development of analytical modeling also involves experimentation with the simulation tools themselves. This third activity is necessary to develop a better understanding of the tools' performance when applied to problems of importance to the SDP.

The general capabilities of the NEPTUNE code have been summarized in Figure 2, so that the discussion that is to follow might be placed in better context. Briefly, NEPTUNE is a finite element code that numerically solves the field equations for creeping (nonlinear) viscous flow of a porous cohesive matrix (skeleton). Concurrent movement of the pore water relative to the skeleton is directly coupled to the skeleton motion through sharing of the total applied stress and through continuity of the skeleton and pore fluid motions. The thermal response, which is central to many SDP applications, is also simulated in NEPTUNE and coupled to the saturated system motions through temperature-dependent material properties, thermally induced density gradients, energy transfer by material convection, and changing geometries from system deformations. NEPTUNE has been written to allow simulation of arbitrary two-dimensional geometries. The creeping flow formation permits changes in the geometry that are quite large (large strain and displacement) by integrating the particle velocities through the region.

A number of physically important assumptions have been made in arriving at the equations that are solved by NEPTUNE. The major assumptions are listed in Figure 2. These assumptions include the soil mechanics concept of effective stress, and the concept that the motions are sufficiently slow that inertia of the constituents may be neglected. The fluid and solid components are assumed to be locally incompressible, and their macroscopic structure is assumed to be isotropic and homogenous. The shear stresses in the fluid are negligible except a they contribute to the drag forces between the solid and fluid that arise which relative motion occurs. Local equilibrium of temperatures is also assumed. The governing equations and solution procedure on which NEPTUNE is based are summarized in Figures A1 to A5.

NEPTUNE was developed from classical concepts of effective stress and pore water flow of modern soil mechanics. The interactions of systems with interacting components such as saturated sediments can also be viewed in terms of developing theories of mixtures. Participants in the SDP (J. Nunziato and S. Passman) have been examining how effective stress concepts and their mixture theories compare. This work has been examined as part of the creep modeling activity, and the equations in NEPTUNE have been supplemented to coincide with the mixture theories within the same set of assumptions as given before.

A number of improvements have recently been incorporated in the NEPTUNE program (Figure 3). These changes are directed at providing a more efficient program which is also easier to use. Documentation of the program was also completed this year. This report is a user's manual that describes the governing equations, numerical techniques, and instructions for using the program.

The confidence in the predictions made using a simulation tool such as NEPTUNE is limited by the accuracy of the constitutive equations that characterize the sediment. NEPTUNE is based on a creeping flow premise that the nonelastic, viscous deformations dominate elastic deformations. The flow equation shown in Figure 4 provides a mathematical relationship between the motion of the sediment and the stress applied to it. The parameters in the model are in general functions of the deformation rate, strain, temperature, and structure. These parameters must be chosen to characterize the general behavior of the sediment as determined in laboratory measurements. To accomplish this, equations involving the invariants of the stress and motion are decomposed into the volumetric and shear components. A functional form of the model and the parameters in the model can then be determined from laboratory data that has been reduced to illustrate the invariant relationships observed in the tests.

Several nonlinear equations have been studied for the first invariant behavior (Figure A6). It was found that forms explicitly involving the porosity of the sediment could be fit to individual consolidation tests quite well (Figures 7 and 8). Howver, the resulting sensitivity of the predicted sediment behavior to small differences in the initial porosity was large. This motivated the examination of a second set of equations which do not explicitly involve the porosity, but rather included an internal variable that is more sensitive to relative changes in the sediment structure. This model could also be fit to the data quite well for individual tests (Figure 9), but showed less sensitivity to initial variations in the sediment state than the previous model. Work continues on this, with correlation of the model to tests of longer duration and use of NEPTUNE to simulate the effects of spatial variations in motion within the test spectrum.

NEPTUNE has also been exercised in simulating SDP applications. Simplified constitutive equations (with parameters estimated from test results reported in the open literature) were assumed for the sediments. Motion around a heat-producing sphere was examined for a range of the sediment system properties of porosity, bulk modulus, and drag coefficient. The rates of motion were smaller than those predicted by corresponding computations made assuming undrained conditions (i.e., a single constituent). This behavior is due to the dissipation of some of the thermal energy as work, which drives the pore fluid motion relative to the skeleton.

The work summarized here has resulted in computational tools that are able to simulate creeping motion of deep ocean sediments. Efforts in the upcoming year will be directed at determining and implementing more accurate representations of the sediment behavior in the computational tools.

ACTIVITIES

Fig. 1

A. IMPROVEMENT OF THE CREEPING POROUS MEDIA CODE (NEPTUNE)

- CAPABILITIES
- DOCUMENTATION

B. CREEP MODEL DEVELOPMENT

- TYPES OF MODELS IN NEPTUNE
- DATA REDUCTION
- VOLUMETRIC AND SHEAR BEHAVIOR

C. SIMULATION OF SUBSEABED DISPOSAL APPLICATIONS

- THERMALLY-DRIVEN CREEP
- PENETRATION HOLE CREEP CLOSURE

NEPTUNE

Fig. 2

CAPABILITIES AND ASSUMPTIONS

NONLINEAR CREEPING FLOW OF SATURATED COHESIVE POROUS MEDIA

PORE FLUID MOVEMENT RELATIVE TO MINERAL SKELETON

THERMAL RESPONSE INCLUDING CONVECTION FROM RELATIVE MOTION

ARBITRARY PLANE OR AXISYMMETRIC TWO-DIMENSIONAL GEOMETRIES

LARGE MOVEMENTS OF BOTH THE SOLID AND FLUID

EFFECTIVE STRESSES DRIVE THE SKELETON DEFORMATIONS

NEGLIGIBLE INERTIA OF THE SOLID AND FLUID

INCOMPRESSIBLE PORE FLUID AND MINERAL PLATELETS

HOMOGENEOUS AND ISOTROPIC MATERIAL PROPERTIES

EQUAL SOLID AND FLUID TEMPERATURES AT COINCIDENT POINTS

NEGLIGIBLE FLUID SHEAR STRESSES ON THE SURFACE

NEPTUNE

RECENT DEVELOPMENTS Fig. 3

GOVERNING EQUATIONS

- COMPARISON TO MIXTURE THEORIES
- CLOSER EXAMINATION OF THE BOUNDARY CONDITIONS
- IMPLEMENTATION OF NONLINEAR CONSTITUTIVE EQUATIONS

GENERAL CAPABILITIES

- STREAMLINED INPUT DATA REQUIREMENTS
- ADDED CONTINOUS PORE PRESSURE APPROXIMATION
- EXPANDED PROBLEM SIZE CAPABILITIES
- IMPROVED POST-PROCESSING PROGRAMS
- PERFORMED ADDITIONAL VERIFICATIONS PROBLEMS

DOCUMENTATION - USERS MANUAL

- GOVERNING EQUATIONS
- NUMERICAL TECHNIQUES (FEM)
- INPUT DATA INSTRUCTIONS, OPERATING INSTRUCTIONS, AND SAMPLE PROBLEMS

SEDIMENT CONSTITUTIVE MODELS Fig. 4

NEPTUNE CREEPING FLOW APPROXIMATION

ASSUME $d_{ij}^{e} \ll d_{ij}^{v}$ VALID FOR SLOWLY CHANGING STRESS FIELDS

$d_{ij} \approx d_{ij}^{v}$

CREEPING FLOW MODEL

$$\bar{\sigma}_{ij} = 2\mu d_{ij} + \left(\chi d_{I} + \Omega d_{II}' + \phi w_k \frac{\partial \alpha}{\partial x_k}\right)\delta_{ij}$$

$$\mu, \chi, \Omega, \phi = f(d_{I}, d_{II}', \theta, \alpha, \beta)$$

FUNCTIONS ARE USED TO DESCRIBE
- NONLINEAR RATE DEPENDENCE
- STRAIN HARDENING AND/OR SOFTENING
- CONSOLIDATION HISTORY
- THERMAL SOFTENING AND/OR HARDENING
- SHEAR-INDUCED DILATANCY

ELASTIC EFFECTS ARE NEGLECTED
- THERMOELASTIC STRAINS
- STRESS RELAXATION AT CONSTANT STRAIN

PRINCIPAL ADVANTAGE LIES IN ABILITY TO SIMULATE CREEPING MOTION OVER LONG TIME SPANS EFFICIENTLY

CANDIDATE MODELS

Fig. 5

PARAMETERS μ, K, Ω & ϕ ARE DETERMINED FROM FUNCTIONS OF THE EFFECTIVE STRESS AND DEFORMATION RATE INVARIANTS

FIRST INVARIANT

$$\bar{\sigma}_I = 3K\, d_I + 3\Omega\, d'_{II} + 3\phi\, w_K \frac{\partial \alpha}{\partial X_K}$$

SECOND INVARIANT

$$\bar{\sigma}'_{II} = 3\mu\, d'_{II}$$

SCALAR EQUATIONS THAT ARE ASSUMED TO BE TRUE FOR ANY STRESS STATE

FIRST INVARIANT → VOLUMETRIC RESPONSE

SECOND INVARIANT → SHEAR RESPONSE

EVALUATION OF MATERIAL PARAMETERS FROM LABORATORY TEST DATA

Fig. 6

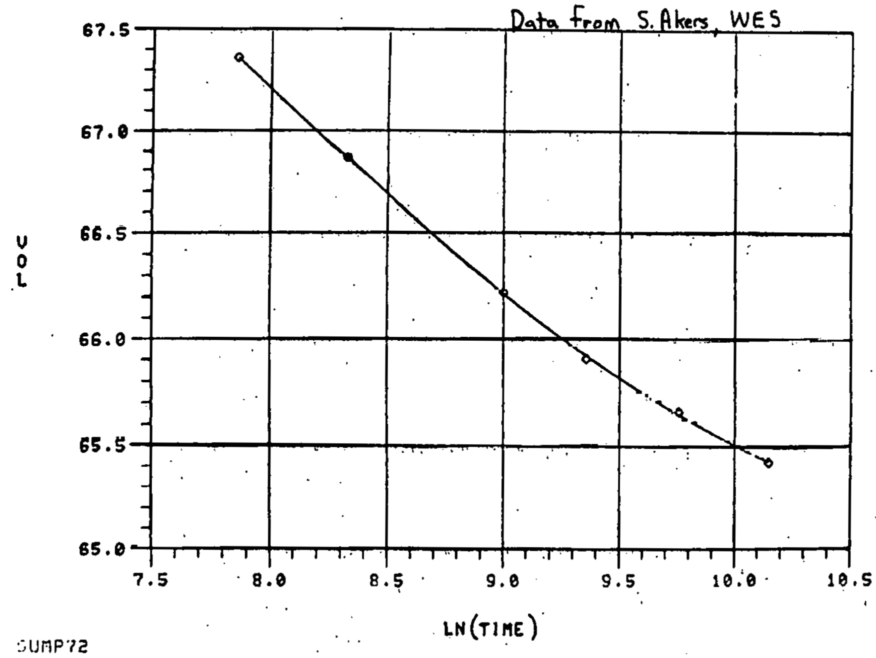
1. CONVERT TEST DATA TO PLOTS OF THE INVARIANTS

2. USE CONSOLIDATION TEST DATA FOR FIRST INVARIANT BEHAVIOR (WITHOUT DILATANCY OR POROSITY GRADIENT TERMS)

3. USE CREEP TEST AND SHEAR TEST DATA TO EVALUATE THE SECOND INVARIANT BEHAVIOR AND DILATANCY BEHAVIOR

Consolidation Test Data Fig. 7

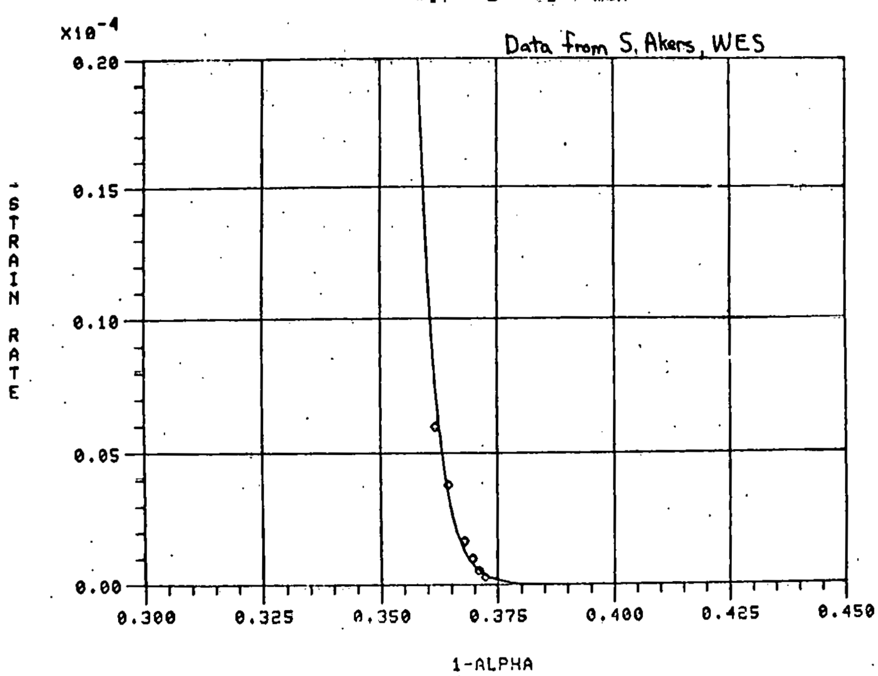
FIT: V = (V1-VA)*(1.+A*t)**(1./m)+VA



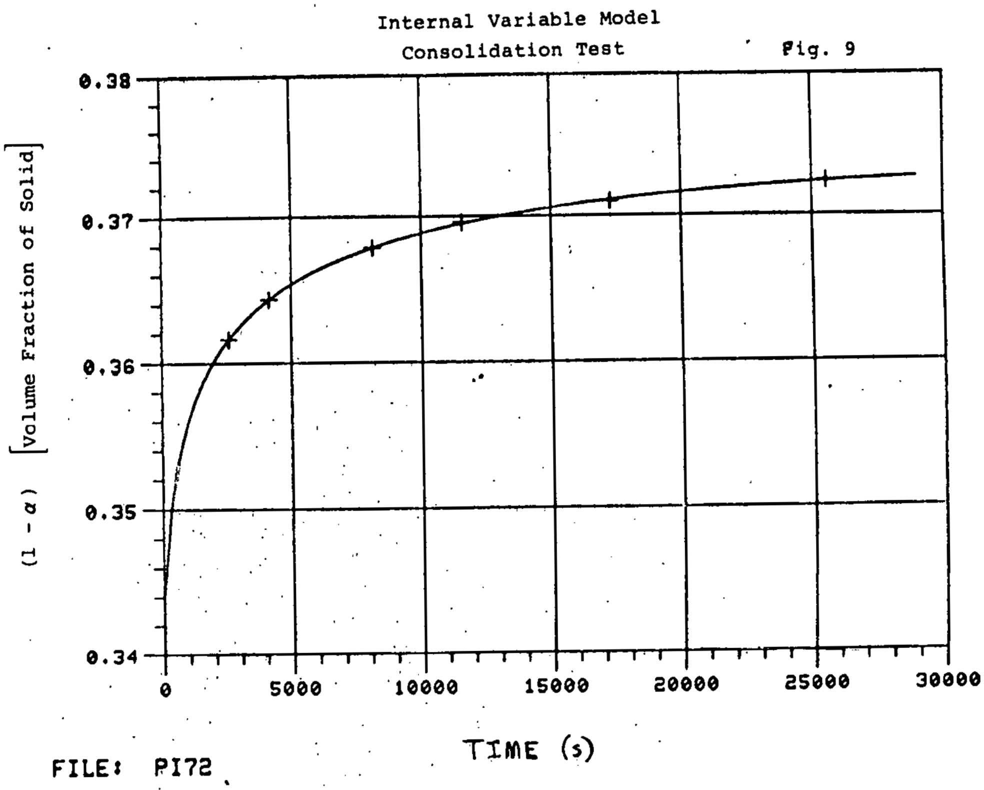
SUMP72

Consolidation Test Data Fig. 8

FIT: Z = Ba + m*X



[Volume Fraction of Solid]



OBSERVATIONS Fig. 10

(NOT CONCLUSIONS)

INITIAL FITS OF CONSOLIDATION DATA TO MODELS INVOLVING THE POROSITY EXPLICITLY IMPLIED THAT THE MODELS MIGHT BE UNSATISFACTORY

INITIAL FITS OF CONSOLIDATION DATA TO MODELS HAVING THE INTERNAL VARIABLE β FOR THE BONDING INTENSITY INDICATED THE MODEL COULD BE FIT TO THE DATA AND RESULT IN REASONABLE PARAMETER VALUES

RESULTS ARE NOT CONCLUSIVE BECAUSE:

1. THE DATA IS NOT OF SUFFICIENT DURATION TO ENSURE THAT THE GRADIENTS OF PORE PRESSURE ARE SMALL
2. THE NUMBER OF DATA POINTS WAS TOO LIMITED TO HAVE CONFIDENCE IN THE FITTED PARAMETERS

THERMALLY-DRIVEN CREEP SIMULATIONS

Fig. 11

SIMULATIONS

CANISTER MODELED AS A SPHERE

RESPONSE DETERMINED FOR VARIATIONS IN:
- POROSITY
- BULK MODULUS OF THE SKELETON
- DRAG COEFFICIENT

OBSERVATIONS

RATES OF MOTION WERE APPRECIABLY SLOWER THAN PREDICTED BY THE SINGLE-CONSTITUENT ANALYSES

NET MOTION WAS QUITE SMALL

GOVERNING EQUATIONS

MECHANICAL BEHAVIOR

Fig. A1

CONSERVATION OF MASS

SOLID: $-\frac{\partial \alpha}{\partial \tau} + \frac{\partial}{\partial x_i}\left[(1-\alpha)u_i\right] = 0$; ρ_s = CONSTANT

FLUID: $\frac{\partial \alpha}{\partial \tau} + \frac{\partial}{\partial x_i}(\alpha v_i) = 0$; ρ_f = CONSTANT

CONSERVATION OF LINEAR MOMENTUM

SYSTEM: $\frac{\partial}{\partial x_i}\left[(1-\alpha)\bar{\sigma}_{ij}\right] - \frac{\partial p}{\partial x_j} + F_j^s + F_j^f = 0$

PORE FLUID: $\alpha \frac{\partial p}{\partial x_i} + b w_i - F_i^f = 0$

GOVERNING EQUATIONS Fig. A2

MECHANICAL BEHAVIOR

KINEMATIC RELATIONSHIP

$$d_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

CONSTITUTIVE EQUATIONS

$$b = f_1(\alpha, \theta)$$

$$\bar{\sigma}_{ij} = f_2(d_{ij}, \epsilon, \theta, \alpha, \beta)$$

POROUS MEDIA CREEPING FLOW VARIATIONAL STATEMENT Fig. A3

$$\delta J = \int_V (1-\alpha)\bar{\sigma}_{ij}\,\delta d_{ij}\,dV + \int_V (-b w_i \delta u_i + b w_i \delta v_i)\,dV - \int_V (F_i^s \delta u_i + F_i^f \delta v_i)\,dV$$

$$- \int_S T_i^s \delta u_i\,dS - \int_S T_i^f \delta v_i\,dS + \delta \int_V \lambda\left(d_{ii} + \frac{\partial}{\partial x_i}(\alpha w_i)\right) dV$$

$$\{u(x_i)\} = [N_u(x_i)]\{U\}$$

$$\{w(x_i)\} = [N_w(x_i)]\{W\}$$

$$\lambda(x_i) = [N_\lambda(x_i)]\{P\}$$

GOVERNING EQUATIONS

THERMAL BEHAVIOR

Fig. A4

CONDUCTIVE-CONVECTIVE HEAT TRANSFER EQUATION

$$\frac{\partial}{\partial X_i}\left(k_e \frac{\partial \theta}{\partial X_i}\right) - \frac{\partial \theta}{\partial X_i}\left(\alpha \rho_f C_{pf} v_i + (1-\alpha)\rho_s C_{ps} u_i\right) + \dot{Q}_e = (\rho C_p)_e \frac{\partial \theta}{\partial T}$$

$$k_e = \alpha k_f + (1-\alpha) k_s$$
$$(\rho C_p)_e = \alpha \rho_f C_{pf} + (1-\alpha)\rho_s C_{ps}$$
$$\dot{Q}_e = \alpha \dot{Q}_f + (1-\alpha)\dot{Q}_s$$

INCREMENTAL SOLUTION PROCEDURE FOR TRANSIENT RESPONSE Fig. A5

1. INITIALIZE VELOCITIES, TEMPERATURES, MATERIAL PROPERTIES AND POROSITY
2. SOLVE THE MOMENTUM EQUATIONS FOR THE SKELETON AND PORE FLUID VELOCITY FIELDS
3. SOLVE THE ENERGY EQUATION FOR THE TEMPERATURE DISTRIBUTION
4. DETERMINE

   A. NODAL POINT COORDINATES BASED ON THE SKELETON VELOCITIES
   B. POROSITY DISTRIBUTION BASED ON THE DEFORMATION RATES
   C. MATERIAL PROPERTIES BASED ON TEMPERATURE AND DEFORMATION RATE

CANDIDATE MODELS

Fig. A6

POWER LAW TYPE*

$$\bar{\sigma}_I = A_1 e^{Q_1/R\theta} (1-\alpha)^{m_1} d_I^{n_1}$$

$$\bar{\sigma}_{II}' = A_2 e^{Q_2/R\theta} \epsilon^{m_2} d_{II}'^{n_2}$$

INTERNAL VARIABLE TYPE*

$$\bar{\sigma}_I = A_1 e^{Q_1/R\theta} \beta^{m_1} d_I^{n_1}$$
$$\bar{\sigma}_{II}' = A_2 e^{Q_2/R\theta} \beta^{m_2} d_{II}'^{n_2}$$
$$\dot{\beta} + A_3 \beta = B_3 \alpha$$

β = INTERNAL VARIABLE (QUANTITATIVE MEASURE OF BONDING INTENSITY)

* DILITATION AND POROSITY GRADIENT TERMS NOT SHOWN

DYNAMIC PROPERTIES AND MODELING OF SEABED SEDIMENT

Summary of Presentation by Behzad Rohani,
U. S. Army Engineer Waterways Experiment Station

The purpose of this presentation is to discuss briefly the U. S. Army Engineer Waterways Experiment Station (WES) efforts in support of the Subseabed Disposal Program (SDP) and to summarize our progress for the period October 1980 - October 1981. The SDP efforts at WES consist of two tasks--Task I is a theoretical investigation and Task II is an experimental program. The purpose of the theoretical investigation is to develop an appropriate elastic-plastic, effective-stress constitutive model and the necessary numerical algorithms for seabed sediments for use in computer code simulations of both early-time dynamic penetration of waste canisters and late-time hole closure. The purpose of the experimental program is to provide high-pressure dynamic stress-strain and strength properties for seabed sediments of interest, which in conjunction with data provided by the University of Rhode Island could be used to guide the development and verification of a constitutive model for such materials.

Under Task I an elastic-plastic, effective-stress model has been developed for describing the mechanical response of seabed sediment. The effective-stress model is based on the assumption that the normal stress components at a point in a saturated material may be divided into two parts: (1) the stress carried by the solid skeleton referred to as the effective stress and (2) the stress carried by the pore fluid, referred to as the pore pressure. This indicates that the total pressure p is the sum of the effective pressure p' and the pore pressure u, while the total- and effective-stress deviation tensors are equal. Therefore, the effective stress is the only part of the total stress that affects the shear strength of the material.

A time-independent, incremental plasticity theory is used in this model, and it is further assumed that the elastic and plastic increments are additive. The model contains 14 material constants that must be determined experimentally.

Under the experimental program a large number of tests have been conducted at WES on both undisturbed and remolded samples of Pacific illite, and the results have been quantified to provide information on the stress-strain and strength properties of seabed sediments under high-pressure static and dynamic loading conditions. The static and dynamic low-pressure shear tests showed that an increase in strain rate from 10^{-6}/second to 1/second produced an increase in shear strength between 67 and 145 percent. More confidence, however, is given to the value of 67 percent due to the better quality specimens tested (Figure 1). Drained static uniaxial strain tests indicated that large volumetric strains (as great as 70 percent) can be expected at stress levels on the order of 67 MPa (Figure 2).

The experimental data were consolidated to a set of representative material properties for fitting the effective-stress constitutive model and obtaining the numerical values of the 14 material constants for Pacific illite. The numerical values of these constants are summarized in Table 1. The subscript s in Table 1 is assigned to material constants associated with the drained behavior of the model and the subscript m is assigned to those constants associated with the undrained behavior. Figures 3 through 6 compare the representative properties with the corresponding model fits. Figure 3 compares the fit to the isotropic consolidation test data up to an effective-stress level of 1 MPa. It is noted that the model is able to qualitatively simulate the hydrostatic response of the material for the entire stress range of interest. In order to have a better quality fit, the bulk modulus of the material would have to be expressed in terms of the plastic volumetric strain which would increase the number of material constants. Effective-stress path fits for consolidated-undrained triaxial shear tests at various confining pressure levels are compared with the data in Figure 4. It should be noted that the representative failure envelope is a curve while the model failure envelope is a straight line. Principal stress difference versus axial strain fits and pore pressure versus axial strain fits associated with the effective-stress paths of Figure 4 are compared with the data in Figure 5. Figure 5 clearly shows that the initial stiffness of the principal stress difference axial strain curves is independent of confining pressure. In order to make this stiffness a function of confining pressure, the shear modulus of the material must be made a function of plastic volumetric strain. Figure 6 compares the undrained hydrostat with the model behavior.

Comparisons of representative laboratory material property test data with corresponding model predictions (Figures 3 through 6) indicate that the present model cannot quantitatively fit all salient features of the mechanical response of the material. There are several features of the model that can be improved in order to more accurately simulate the overall behavior of the material. However, before major modifications of the model are undertaken, it is important to know which aspects of the mechanical behavior of seabed sediments significantly affect the mechanisms of dynamic penetration and hole closure. This can be ascertained through parametric calculations of penetration and hole closure phenomena using the present model with an appropriate wave code. The model has been successfully incorporated into two-dimensional wave codes at Sandia National Laboratories for conducting such analyses.

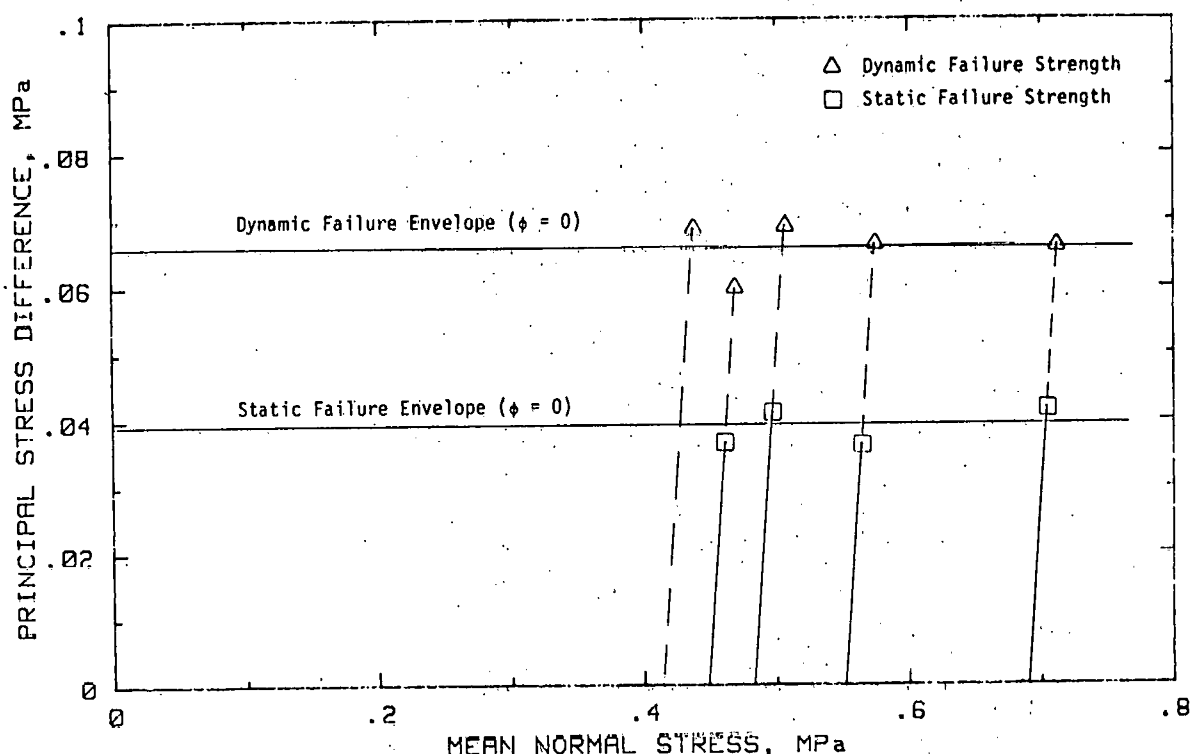


Figure 1. BACK PRESSURE SATURATED CONSOLIDATED UNDRAINED TRIAXIAL SHEAR PI 5-8 SPECIMENS

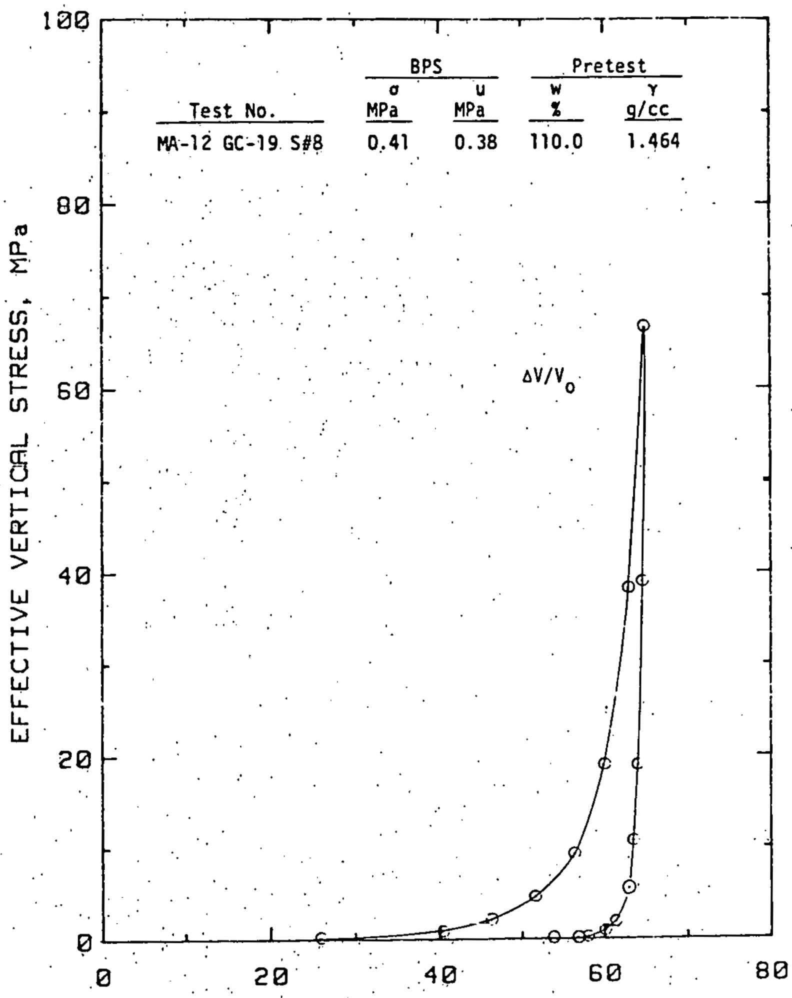


Figure 2. BACK PRESSURE SATURATED DRAINED UNIAXIAL STRAIN SPECIMEN MA-12 GC-19 S#8

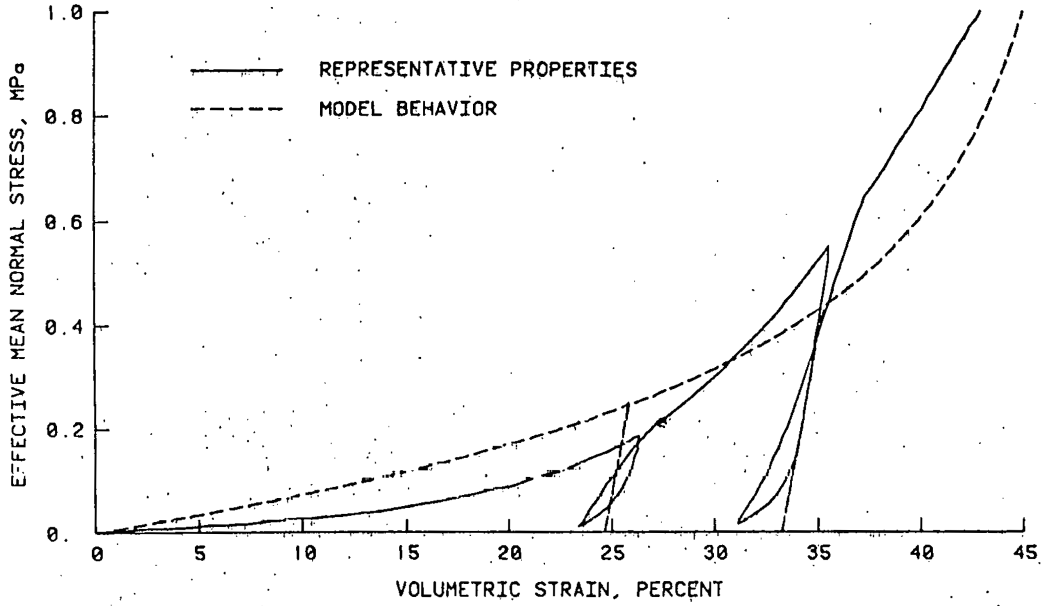


Figure 3. Isotropic consolidation response; representative properties versus model fit.

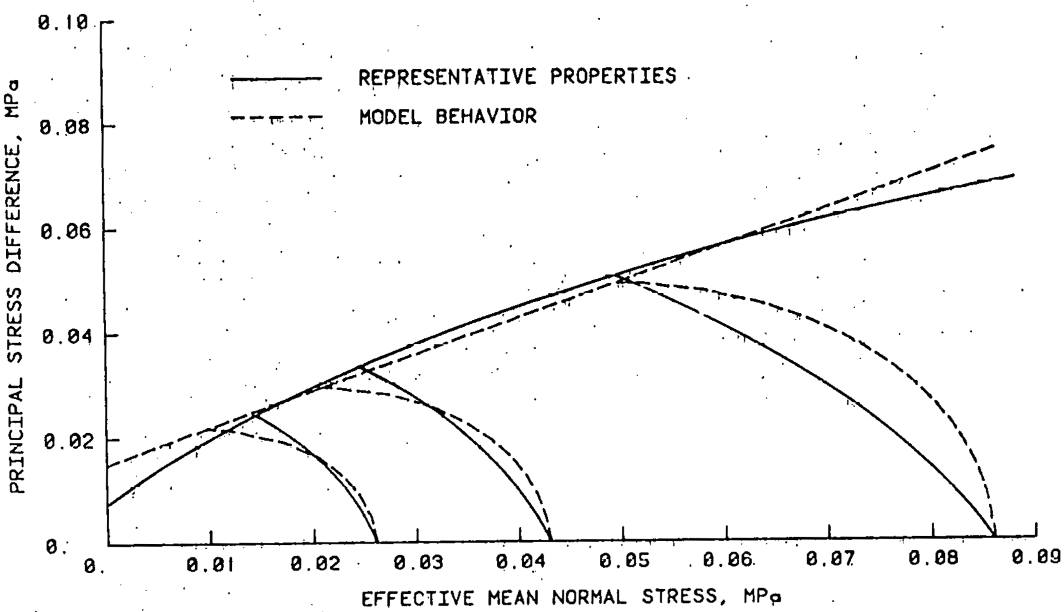


Figure 4. Effective stress paths for consolidated-undrained triaxial test; representative properties versus model fit.

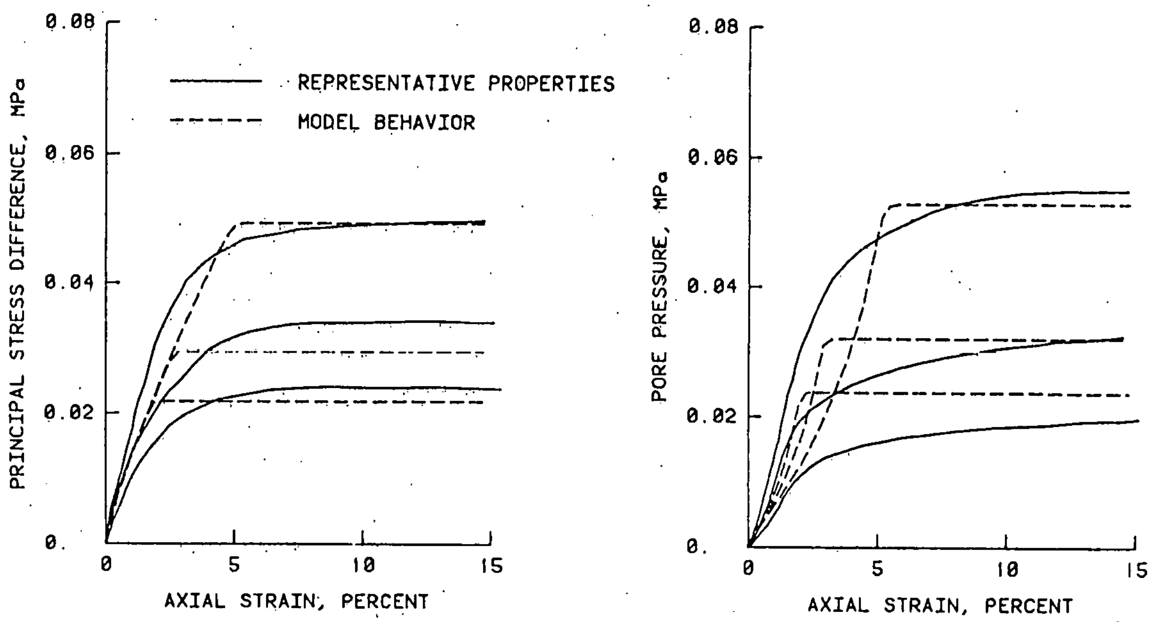


Figure 5. Principal stress difference and pore pressure versus axial strain for consolidated-undrained triaxial test; representative properties versus model fit.

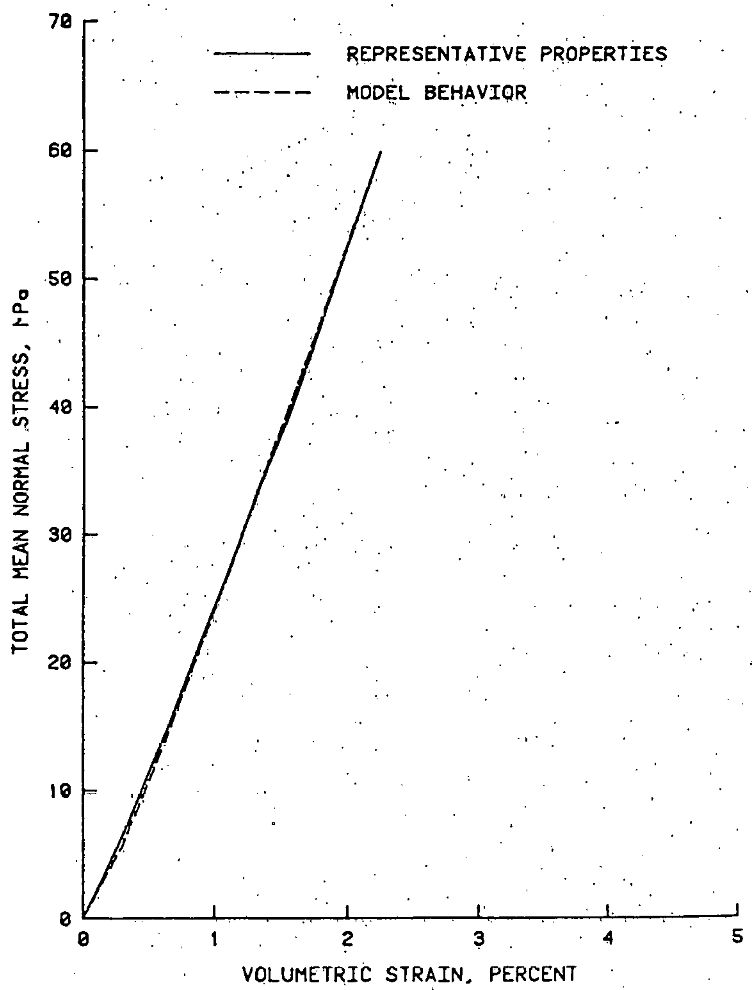


Figure 6. Isotropic compression response; representative properties versus model fit.

Table 1. Numerical values of material constants for drained and undrained behavior of Pacific illite

Material Constants			
Name	Notation	Units	Numerical Values
Density	ρ	g/cc	1.5
Effective Failure Envelope Parameters	C_s	MPa	0.00866
	α_s	---	0.133336
Hardening Surface Parameters	R_s	---	4.00
	W_s	---	0.42
	D_s	$(MPa)^{-1}$	1.20
Effective Bulk Modulus Parameters	K_{is}	MPa	20.00
	K_{1s}	---	0.999
	K_{2s}	$(MPa)^{-1}$	0.0002
Total Bulk Modulus Parameters	K_{im}	MPa	1875.00
	K_{1m}	---	0.35
	K_{2m}	$(MPa)^{-1}$	0.05
Shear Modulus Parameters	G_{is}	MPa	0.60
	G_{1s}	---	-1.00
	G_{2s}	$(MPa)^{-1}$	200.00

VI. EMPLACEMENT STUDIES

Technical Program Coordinator: D. M. Talbert

Introduction - Status of Emplacement Studies
D. M. Talbert, SNLA 173

Preliminary Penetration Studies
S. N. Burchett, SNLA 177

Hole Closure Calculations
T. Canfield, SNLA 186

Boosted Penetrator System Status
L. T. James, SNLA 197

Status of Emplacement Studies

by

D. M. Talbert

During FY 81, the SDP emplacement studies have been limited to five areas of effort. These areas were (1) development of long range emplacement engineering program plans, (2) penetration calculations for shallow dynamic emplacement, (3) hole closure calculations, (4) dynamic sediment response studies, and (5) development of a boosted penetrator system.

The long range plans development activity has essentially been geared to the international Seabed Working Group activities being conducted by the Engineering Studies Task Group (ESTG). A preliminary work-flow diagram was developed at the February, 1981, and September, 1981, meetings of the ESTG. That work-flow diagram is currently being converted into a network analysis diagram and will soon be published by that group.

The development of a penetration calculation capability for shallow dynamic emplacement was a continuing activity from the past several years. The principals involved in this activity have been P. Dzwilewski, T. Canfield, and S. Burchett. A report by Burchett in this section will summarize these activities.

The development of the models necessary for the assessment of the hole closure conditions following emplacement have continued during FY 81. Both dynamic and quasi-static conditions are being investigated as they might pertain to the hole closure situation following emplacement of a waste package. The principals involved in this activity encompass a number of individuals at the Waterways Experiment Station and Sandia. T. Canfield will summarize these activities in this section.

The dynamic sediment response studies involving material model development and dynamics laboratory investigations have been conducted at the Waterways Experiment Station during the past two and one-half years and are discussed in the section on Mechanical Response Studies. These studies are approximately 80% complete and will be essentially concluded in FY 82.

The development of a boosted penetrator system has been ongoing for approximately two years and has drawn heavily on the Sandia expertise in terridynamics and past marine sediment penetrator development. This activity is essentially a two part activity aimed at developing a penetration capability for depths greater than that attainable using free-fall techniques for possible emplacement of a waste container and for deploying in-situ instrumentation packages, T. James will report on these developments in his report on the Instrumented Seabed Penetrator development in this section.

Activities during FY 82, under the current budget constraints, will continue to focus on model development, boosted penetrator proof-of-concept tests, and development of long range engineering plans (without the development of absolute time scales).

In summary, the status of the activities currently underway in the emplacement studies is as follows:

(1) Development of long range plans has been initiated and is being pursued in cooperation with the international Seabed Working Group parallel activity, and a report of this activity will be published during FY82;

(2) The simulation models for penetrator emplacement are operational and are now data limited;

(3) The simulation models for dynamic hole closure studies are essentially operational and are also data limited;

(4) Development of sediment material models for dynamic response studies will be completed during FY82 and a choice of a material model will be made for further simulation model/code development;

(5) A boosted penetrator system will be field tested during FY82 as a first proof-of-concept test.

SUBSEABED DISPOSAL PROGRAM

EMPLACEMENT ENGINEERING

SCOPE

- EMPLACEMENT METHODS
- ON-SITE SUPPORT FACILITIES
- SEA TRANSPORT
- PORT AND DOCK FACILITIES
- POST EMPLACEMENT BEHAVIOR OF CANISTER (SHORT TERM)
- SALVAGE SYSTEMS
- RETRIEVAL SYSTEMS (FOR ENGINEERING TESTS)
- MONITORING (THROUGH PROOF OF CONCEPT)

EMPLACEMENT ENGINEERING

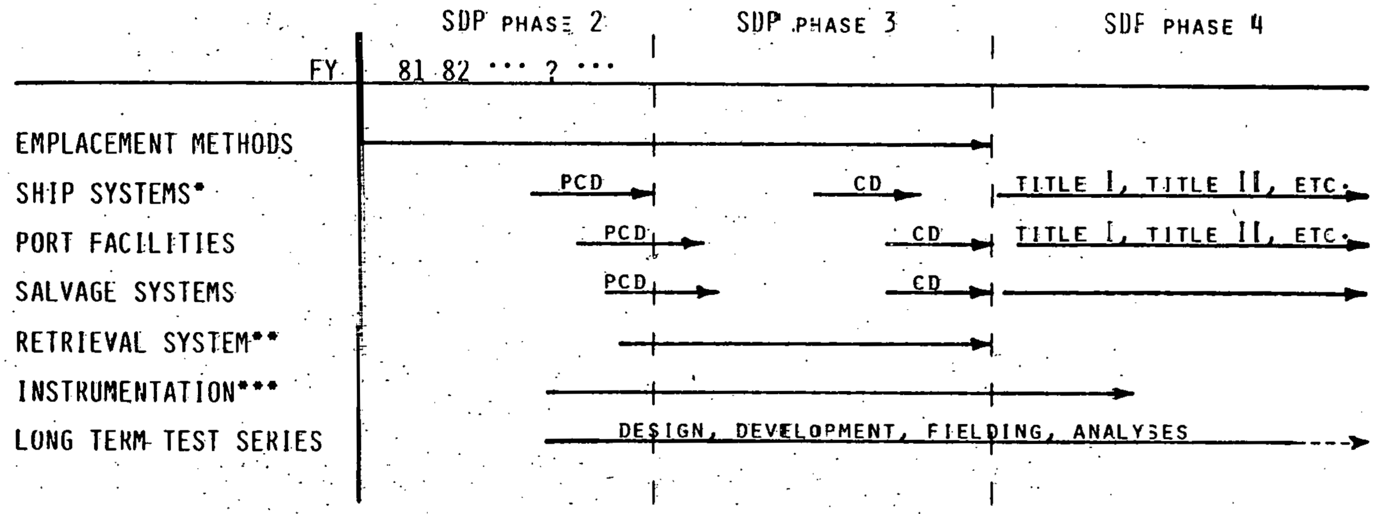
	FY 81	FY 82
• LONG RANGE PLANS	A	A
• PENETRATION MODELING	A	C
• HOLE CLOSURE MODELING	A	A
• DYNAMIC SEDIMENT RESPONSE	A	C
• BOOSTED PENETRATORS	A	A

A = ACTIVE

C = COMPLETE

SUBSEABED DISPOSAL PROGRAM

---- EMPLACEMENT ----



*ON SITE SUPPORT FACILITIES AND SEA TRANSPORT

**FOR ENGINEERING TESTS

***FOR (1) POST EMPLACEMENT BEHAVIOR OF CANISTER (SHORT TERM)
(2) MONITORING (THROUGH PROOF OF CONCEPT)
(3) LONG-TERM TEST SERIES

4/81
TALBERT

PRELIMINARY PENETRATION STUDIES

Steven N. Burchett
Sandia National Laboratories - 5521

One of the methods proposed to emplace nuclear waste into subseabed sediments is the use of penetrator technology. Two preliminary penetration studies were completed this year. First, a parameter study to determine the ball park performance of a generic emplacement vehicle was done. Secondly, a study to estimate the effect of sand layers on penetration was done.

Penetration Parameter Study:

The assumed geometry of the emplacement vehicle is shown in viewgraph 1. The steel (ρ = 7800 kg/m^3) vehicle/canister was assumed to be cylindrical in shape with a hemispherical nose. The waste package was assumed to be cylindrical and have a density of 2500 kg/m^3. Five sets of calculations, corresponding to D_O = 0.3 m to D_O = 0.7 m, were done. It was assumed that the diameter of the waste package, D_{OP}, was 0.05 m less than the vehicle diameter, (vehicle wall thickness = t_W = 0.025 m = 1.0"). The total vehicle length, ZLT, was defined by specifying the length to diameter ratio (ZLT/D_O). The waste package length was assumed to be 80% of the total vehicle length (ZLP = 0.8 * ZLT).

The forces tending to stop the emplacement vehicle are the end bearing load at the nose of the penetrator, the wall shearing force and the hydrodynamic drag. The forces are defined in viewgraph 2.

The sediment properties used in this study were from MPG-1 as obtained from LL44-GPC3. The density is ρ_S = 1400 kg/m^3 and the cohesion is

$$C = 19540 \ln (1 + 0.1189z) \text{ Pascals}$$

where Z = depth below water/sediment interface, m.

The results of this study are shown in viewgraphs 3-5. In viewgraph 3, the calculated emplacement depth is plotted as a function of impact velocity for a vehicle with an outer diameter of D_O = 0.4 m for a variety of vehicle lengths. The calculated terminal velocities for each of the vehicles are also indicated. This plot shows, for a given emplacement vehicle, the impact velocity required to emplace to a certain depth and if boosting is required. The results for an emplacement vehicle with outer diameters of D_O = 0.3 m, 0.5 m, 0.6 m, and 0.7 m are shown in viewgraphs 4a, 4b, 5a, and 5 b respectively.

The results of this study are preliminary ball park estimates. In general, the results indicate that to obtain reasonable emplacement depths with reasonable emplacement vehicle geometries either free fall or boosted systems could be used. Greater flexibility of possible geometry parameters could be obtained, however, by use of a boosted system.

Effect of Sand Layers:

It has been postulated that preliminary suitable sites in the Atlantic may have sand layers through which the emplacement vehicle must pass. Field evidence has suggested that sand layers or clay/sand layers are difficult to penetrate. This presentation presents a preliminary evaluation of the effect of sand layers on the penetration capability of an emplacement vehicle.

The forces tending to stop an emplacement vehicle are the end bearing load at the nose of the vehicle, the wall shearing force, and the hydrodynamic drag. In this study, it was assumed that the end bearing load and the wall shearing force was equal to the so-called point resistance and shaft resistance used in deep foundation pile capacity equations. The total capacity of a pile in sand and in clay are given in viewgraph 6. Using these equations with typical values and neglecting hydrodynamic drag, the resisting forces on a specific emplacement vehicle can be plotted as a function of penetration depth (viewgraph 7). The area under these curves is the energy required to penetrate to a certain depth. The effect of sand layers can be estimated by combining the curves and evaluating the energy loss due to sand layer as was done in viewgraphs 8a and 8b.

The penetration capability of an emplacement vehicle obviously depends upon site specific stratigraphy and material properties. This study indicates that sand layers have a significant effect and must be evaluated further .

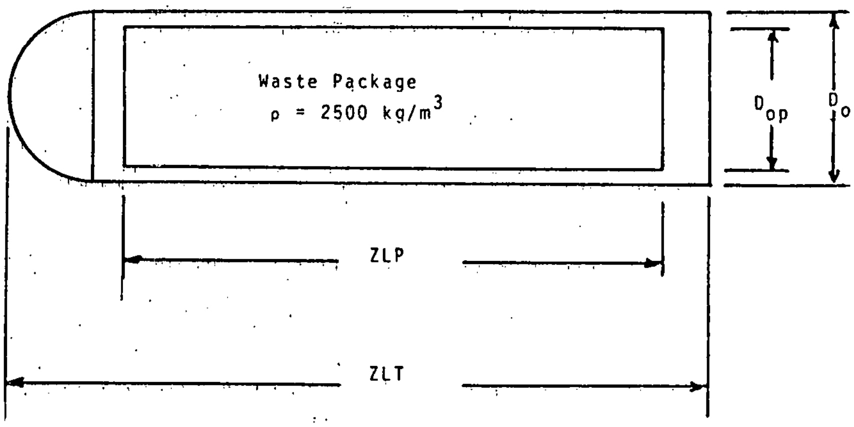


Figure 1: Assumed Geometry of Emplacement Vehicle

END BEARING FORCE:

$$F_{END} = (N_C C + N_Q \sigma')A$$

WHERE C = COHESION OF SEDIMENT

σ' = EFFECTIVE STRESS

N_C, N_Q = BEARING CAPACITY FACTORS,
$N_C = 9$, $N_Q = 1$

AND A = FRONTAL AREA,

WALL SHEARING:

$$F_S = \pi D_o \int_{z_1}^{z_2} \alpha C dz$$

WHERE D_o = OUTSIDE DIAMETER OF PENETRATOR

C = COHESION OF SEDIMENT

α = EMPERICALLY DETERMINED FACTOR = 0.26

HYDRODYNAMIC DRAG:

$$F_D = 1/2 \, \rho_{SW} \, C_D \, AV^2$$

WHERE ρ_{SW} = DENSITY OF SEAWATER = 1030 KG/M^3

C_D = DRAG COEFFICIENT = $C_{BP} + C_{SF}$

C_{BP} = BASE PRESSURE DRAG COEFFICIENT

C_{SF} = SKIN FRICTION DRAG COEFFICIENT

A = FRONTAL AREA

AND V = VELOCITY

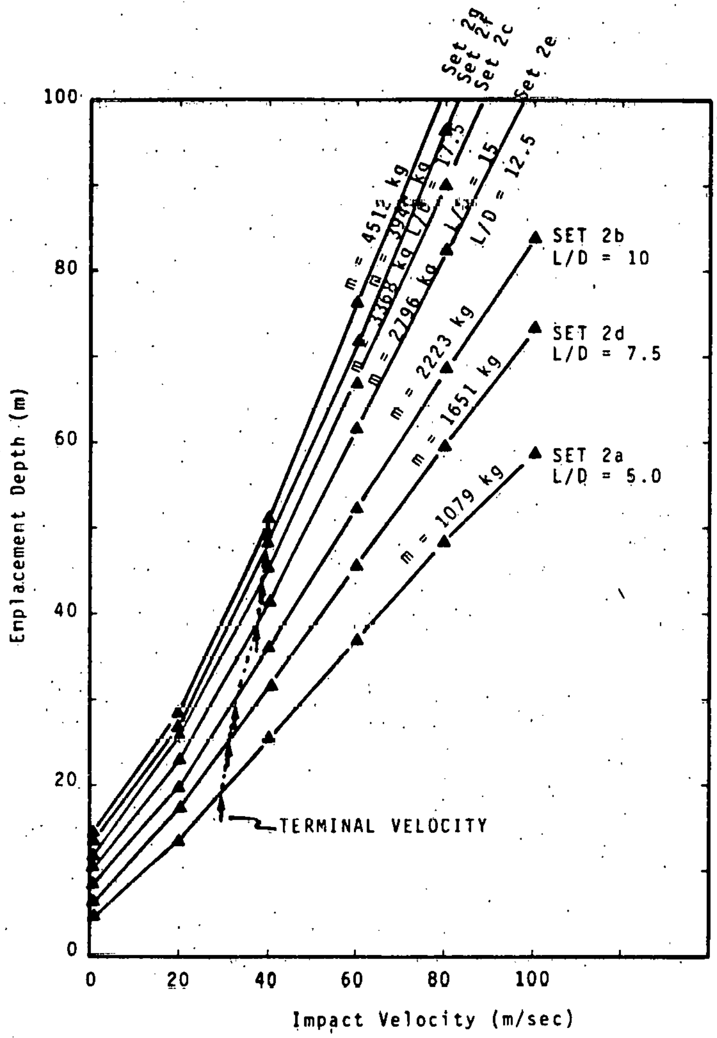


Figure 3: Results - Emplacement Depth vs Impact Velocity D_0 = 0.4 m

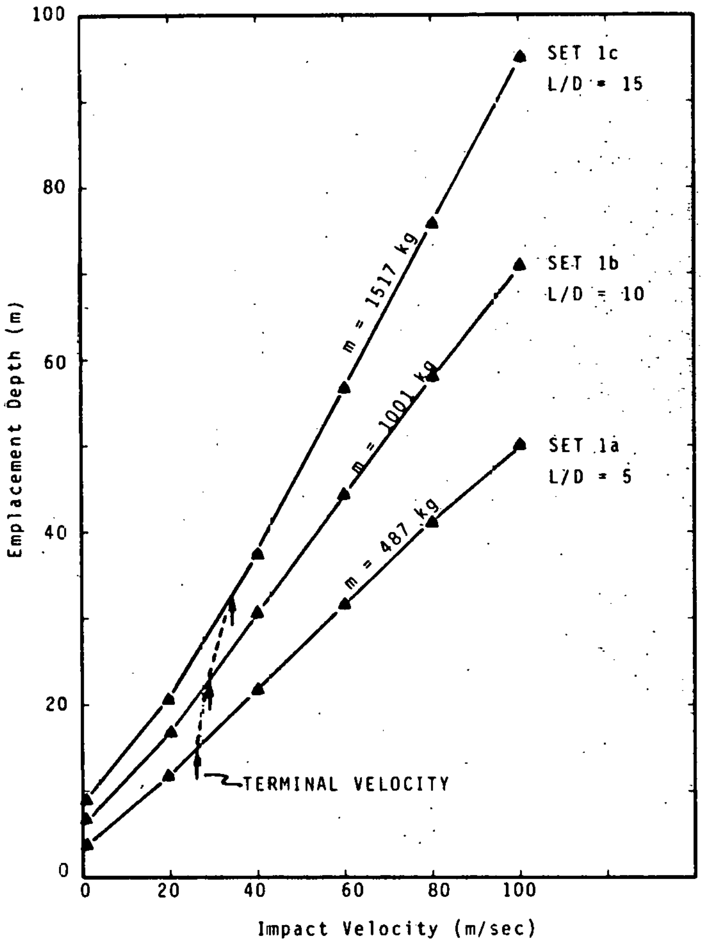


Figure 4a: Results - Emplacement Depth vs Impact Velocity D_o = 0.3 m

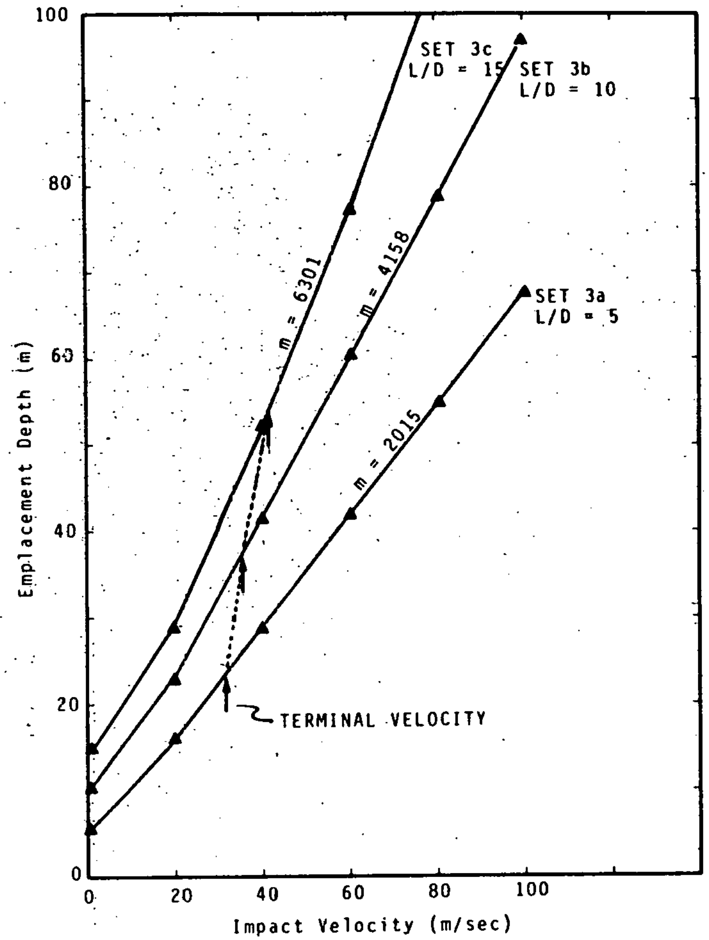


Figure 4b: Results - Emplacement Depth vs Impact Velocity D_o = 0.5

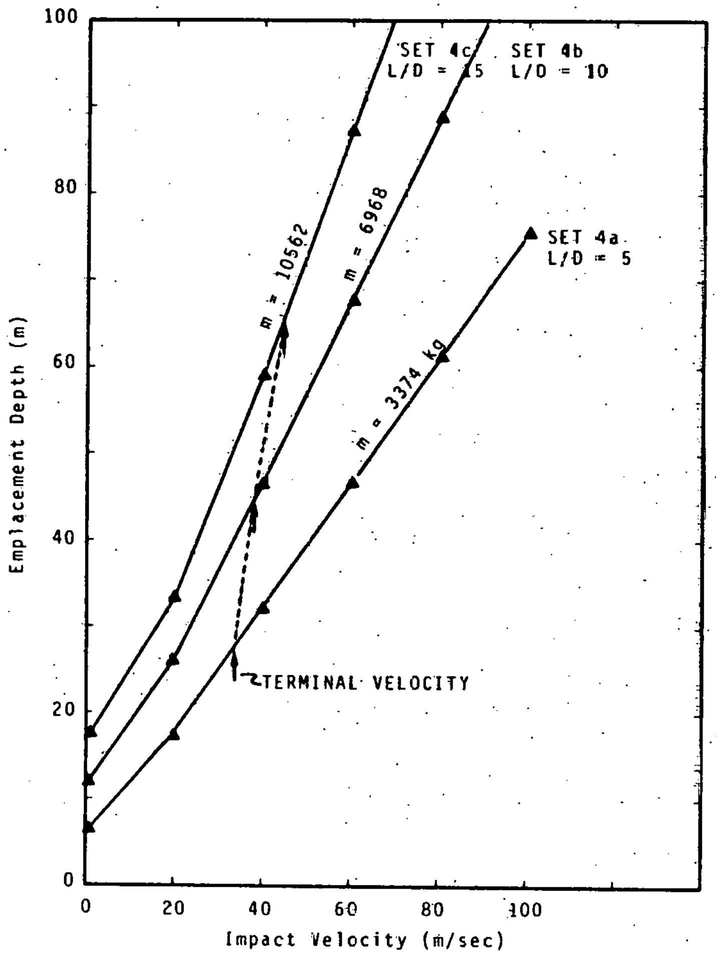


Figure 5a Results - Emplacement Depth vs Impact Velocity D_o = 0.6

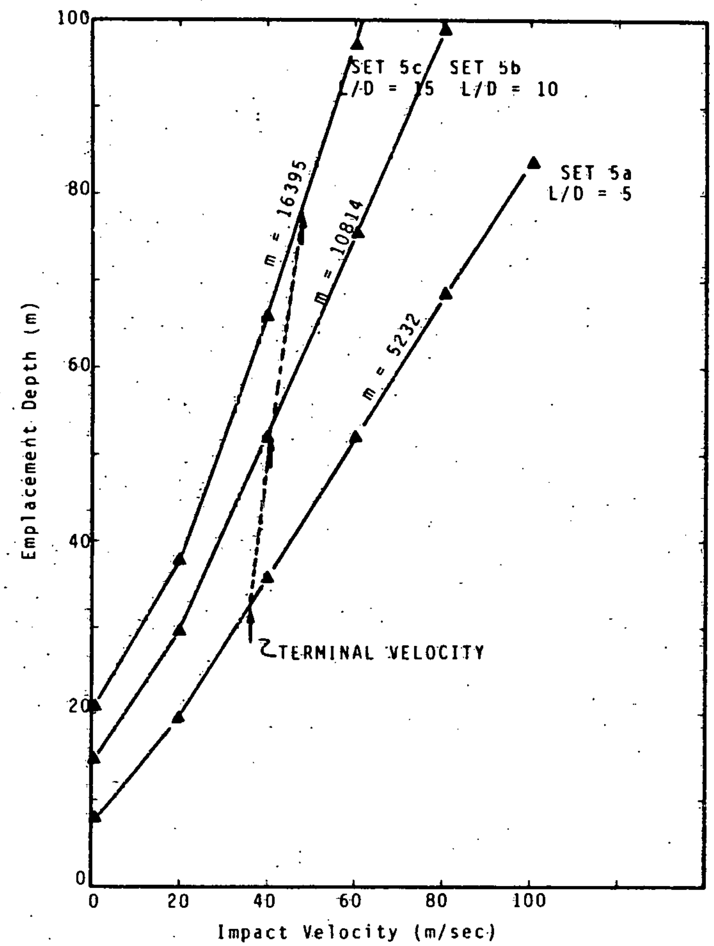


Figure 5b Results - Emplacement Depth vs Impact Velocity D_o = 0.7 m

SAND:

$$Q = A_P(\rho_S - \rho_{SW}) G Z\, N_Q + \sum (\Delta L A_S)\, K\, (\rho_S - \rho_{SW}) G Z \tan \phi_\mu$$

N_Q = BEARING CAPACITY FACTOR = $F(\phi)$ = 15→400

ϕ = FRICTION ANGLE AT ULTIMATE STRENGTH = 25°→35°

K = DENSIFICATION FACTOR 1→3

ϕ_μ = PARTICLE TO PARTICLE FRICTION ANGLE 20°→30°

CLAY:

$$Q = A_P[C N_C + (\rho_S - \rho_{SW}) G Z] + \sum \Delta L A_S\, \mu C$$

N_C = BEARING CAPACITY FACTOR = 9.0

C = COHESION = 19540 ℓn (1.0+0.1189Z) PASCALS

μ = EMPERICALLY DETERMINED FACTOR = 0.26

ASSUMPTIONS:

$\rho_{SAND} = \rho_{CLAY} = 1400\ KG/M^3$

$\rho_{SW} = 1020\ KG/M^3$

$D_O = 0.4$ M

L = 3.35 M

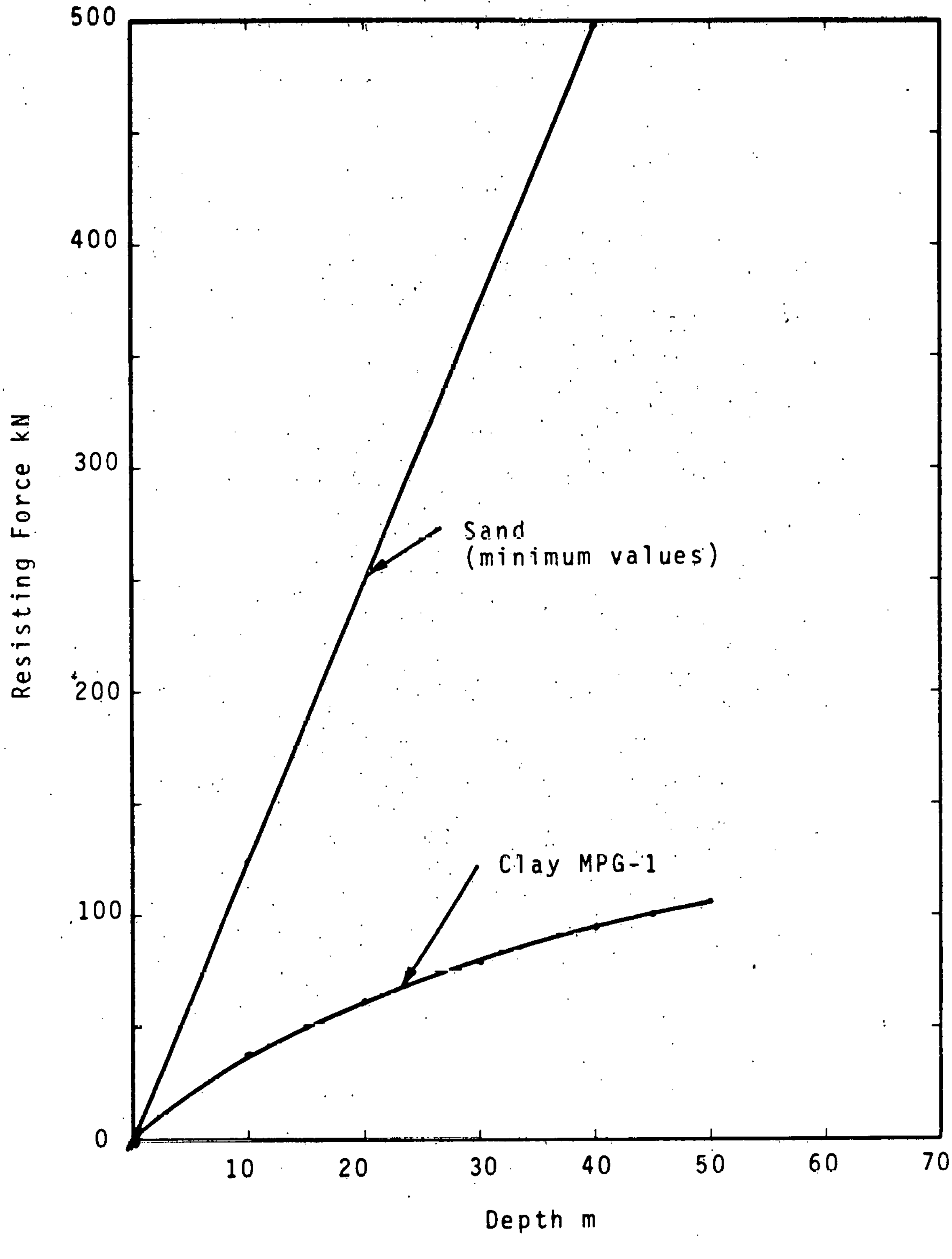


Figure 7: Comparison of Resisting Forces

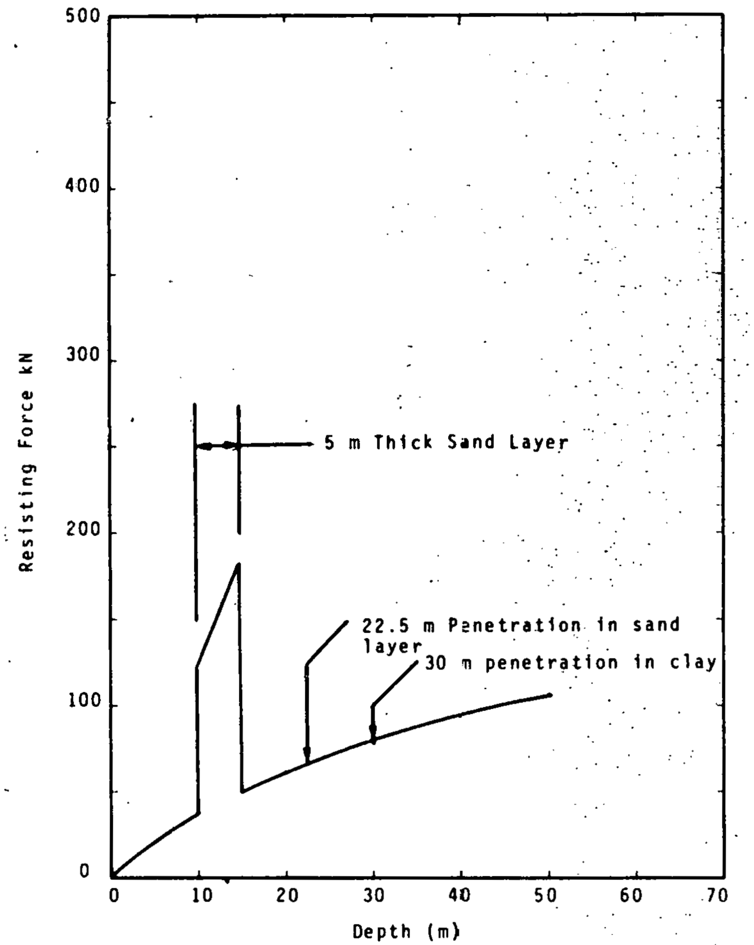


Figure 8a: Resisting Forces in Idealized Stratigraphy
5 m Thick Sand Layer in Clay

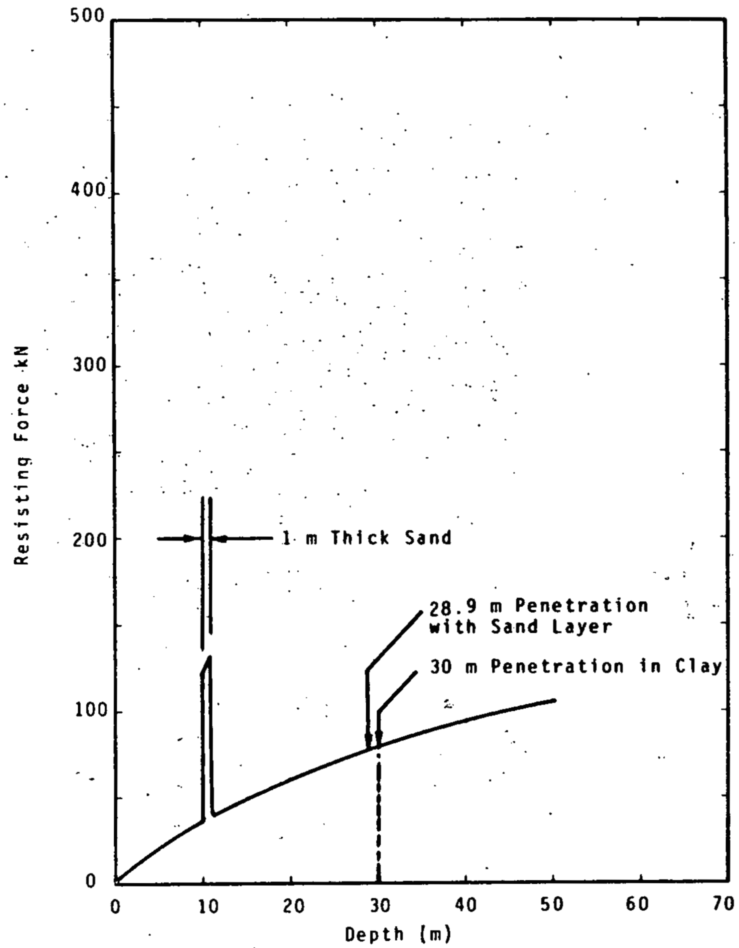


Figure 8b: Resisting Forces in Idealized Stratigraphy
1 m Thick Sand Layer in Clay

DYNAMIC HOLE CLOSURE CALCULATIONS *

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ABSTRACT

A primary goal in disposal of nuclear waste in remote subseabed repositories is successful burial of the waste cannister. This is important because the almost impervious sediment will serve as a barrier to migration of radioactive nuclei. The current approach to emplacement employs earth penetrator concepts. A vehicle carrying a waste cannister is dropped or boosted to its final resting place some 30 to 50 meters beneath the ocean floor at 4 to 6 km sea depth. Hole closure should follow shortly after penetration to circumvent deep sea burial operations. The assurance of short term hole closure requires either experimental observation of subseabed penetrations or, alternatively, careful computer simulations. The latter approach is attractive for feasibility study because of cost and it allows for parameter variations which should lead to better understanding of processes involved.

Numerical simulations have been performed to investigate hole closure. These have included both 1-D and 2-D axi -symmetric geometries with an elastic-plastic material model and the WES [1] effective stress model, developed specifically for subseabed sediments. Calculations were performed with the Lagrangian finite difference code, STEALTH, the Lagrangian finite element code, HONDO, and an arbitrary Lagrangian-Eulerian (ALE) code that is currently under development at Sandia. The 1-D calculations have been performed with thin sections centered about a 3 m depth below the ocean floor while the 2-D STEALTH calculations employed sections modeling the first 10 m of sediment. In all cases the attempt has been made to model semi-infinite regimes with models of finite size. This has been accomplished by the incorporation of Lysmer's [2] absorbing boundary condition into the codes.

Penetration has been simulated by applying a displacement time history at R = 0.0 to approximate the profile of a vehicle with an ogival nose and a cylindrical body. After passage the displacement boundary condition is replaced with a pressure boundary condition inside the hole. It has the form

$$p = \rho_w(gz - \tfrac{1}{2}v^2) \qquad (1)$$

This expression is derived from potential flow with g the acceleration due to gravity (9.81 m/s^2), the density of water (1030.0 kg/m^3), z the depth below the ocean surface (6000.0 m + depth below ocean floor) and v the velocity of water in the hole. The velocity, v, is constant in the case where the penetrator velocity and the tube diameter are constant. This is not true in fact but can be regarded as a conservative estimate of the pressure loss due to flow of water into the hole following penetration.

Hole closure occured quickly (20–30 ms in 1-D and 10–20 ms in 2-D at $v = 30$ m/s) in all calculations employing the above pressure boundary condition. In fact the 2-D HONDO calculations were performed with the hole initially open. When the fluid-dynamic pressure component was neglected, hole closure did not occur. Only slight variations were noted when the effective stress and elastic-plastic models were compared in 1-D while almost none were noted in 2-D. This is probably due to the presence of overburden pressures that may speed up hole closure and are neglected in the 1-D calculations. Calculations in both STEALTH and HONDO demonstrated that hole closure times could be increased by higher yield stress when the elastic-plastic material was employed. Other factors influencing hole closure times are penetration speed and geometry but these have not been thoroughly investigated.

* This work was supported by the U.S. Department of Energy under contract DE–AC04–76DP00789.

† A U.S. Department of Energy facility.

It is clear that fluid-dynamic pressure is a primary factor in hole closure. Current investigations are underway to model the fluid-dynamics more accurately. The ALE code will allow fluid to be drawn into the hole following penetration. Also, it appears that more refined modelling of sediment material is not warranted on the basis of these preliminary hole closure calculations but a full scale parameter study of the WES model is necessary to resolve the issue.

References

1. Baladi, George Y., and Akers, Stephen A., "Constitutive properties and material development for marine sediments in support of the Subseabed Disposal Program." Subseabed Disposal Annual Report, January to December 1979, Vol. II, SAND80-2577/II pp 621-634, 1981.

2. Lysmer, John, and Kuhlemeyer, Roger M., "Finite dynamic model for infinite media." J. of Eng. Mech. Div., Proc. ASCE, pp 859-877, 1969.

HOLE CLOSURE CALCULATIONS

I. MODELING CONSIDERATIONS
   A. INITIAL CONDITIONS
   B. BOUNDARY CONDITIONS
   C. MATERIAL MODELS
      1. ELASTIC-PLASTIC
      2. WES CAP MODEL

II. CALCULATIONS
   A. 1-D
   B. 2-D

III. CONCLUSIONS

IV. DIRECTIONS

A. INITIAL CONDITIONS

1. FULL PENETRATION CALCULATION

a) MATERIAL INITIALLY UNDISTURBED

$$\sigma_{ij}\Big|_{t_o} = (\rho g z - p_o)\,\delta_{ij}$$

b) NO MOTION

$$v_i = 0$$

2. HOLE CLOSURE ONLY

a) MATERIAL PRESTRESSED

$$\sigma_{ij}\Big|_{t_o} = \sigma_{oij}$$

b) MATERIAL IN MOTION

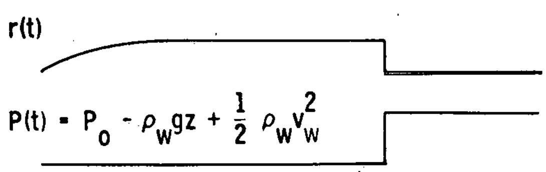
$$v_i \neq 0$$

B. BOUNDARY CONDITIONS

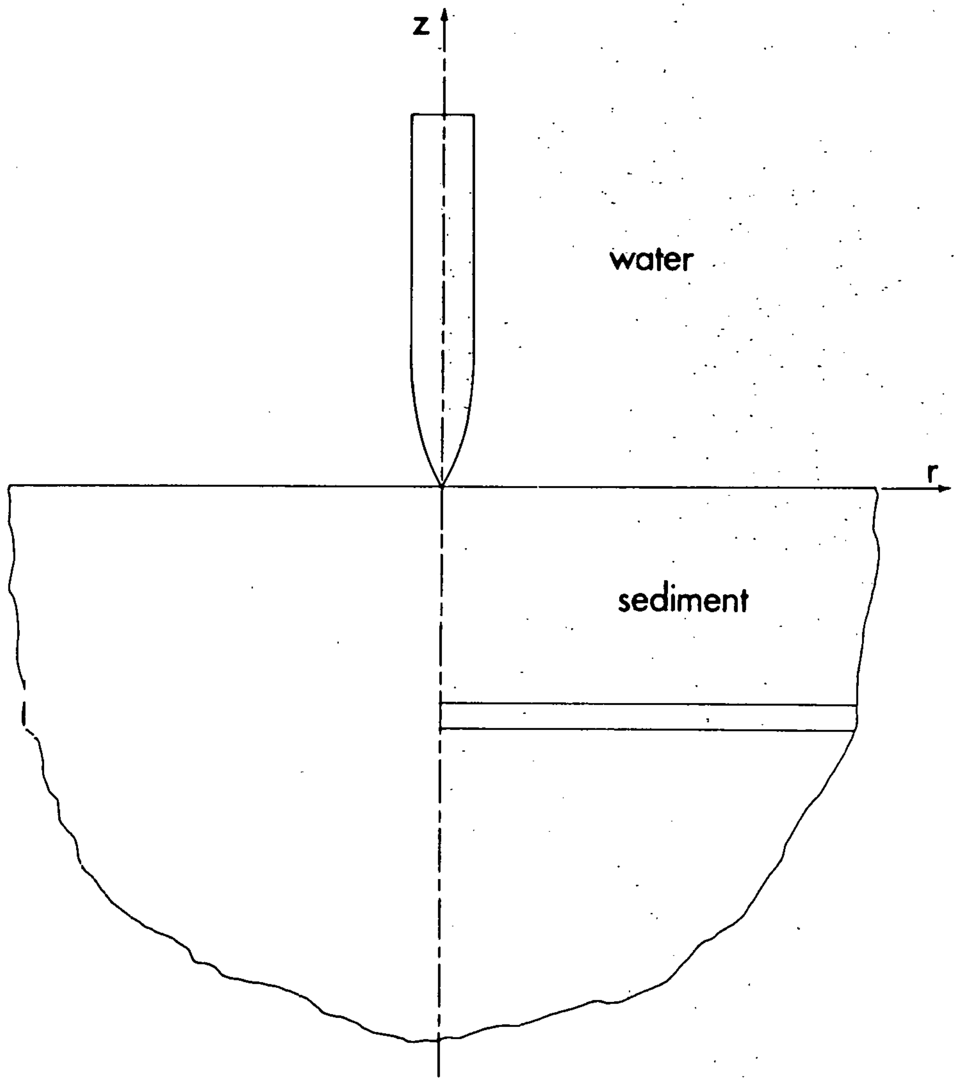
1. 1-D

a) Only radial motion considered

b) First apply radial displacement to make hole then apply pressure traction after passage of the penetrator.



c) Fix outer boundary if it is far enough away or apply an absorbing boundary.

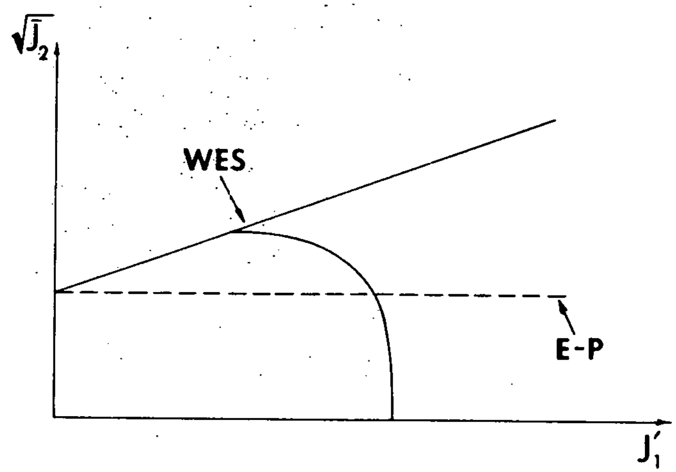


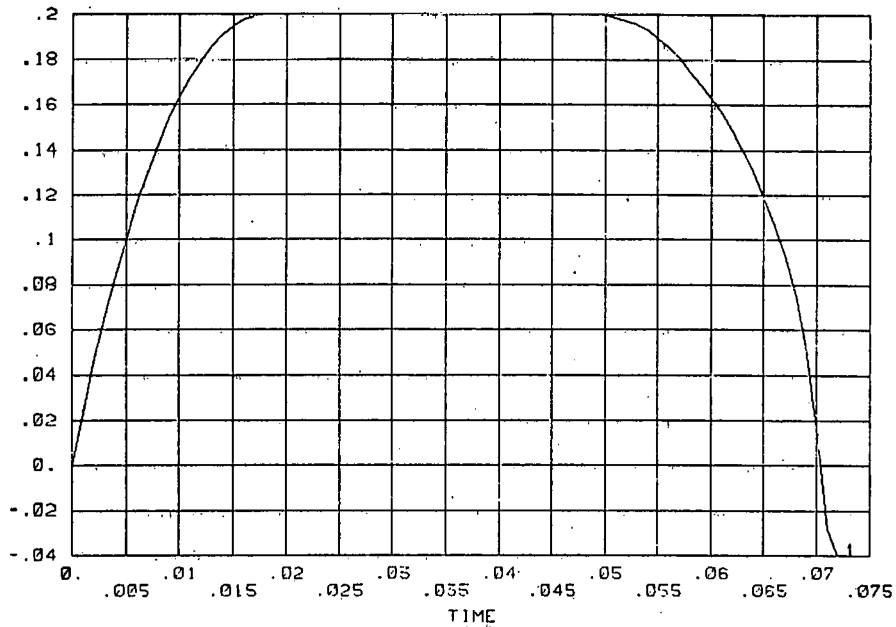
C. MATERIAL MODELS

1. ELASTIC-PLASTIC

2. WES CAP MODEL

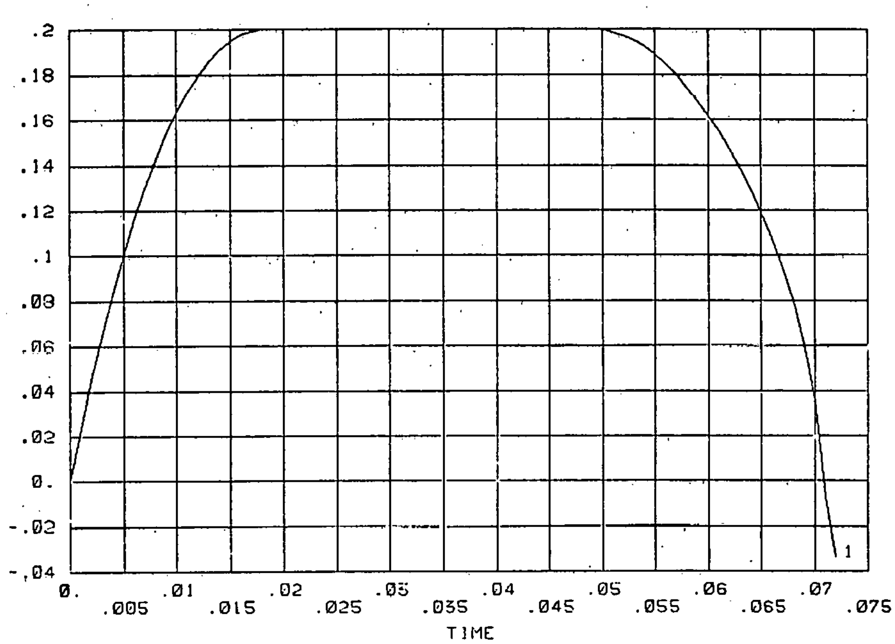
$$\sigma_{ij} = \sigma_{ij}^{e} - u\,\delta_{ij}$$





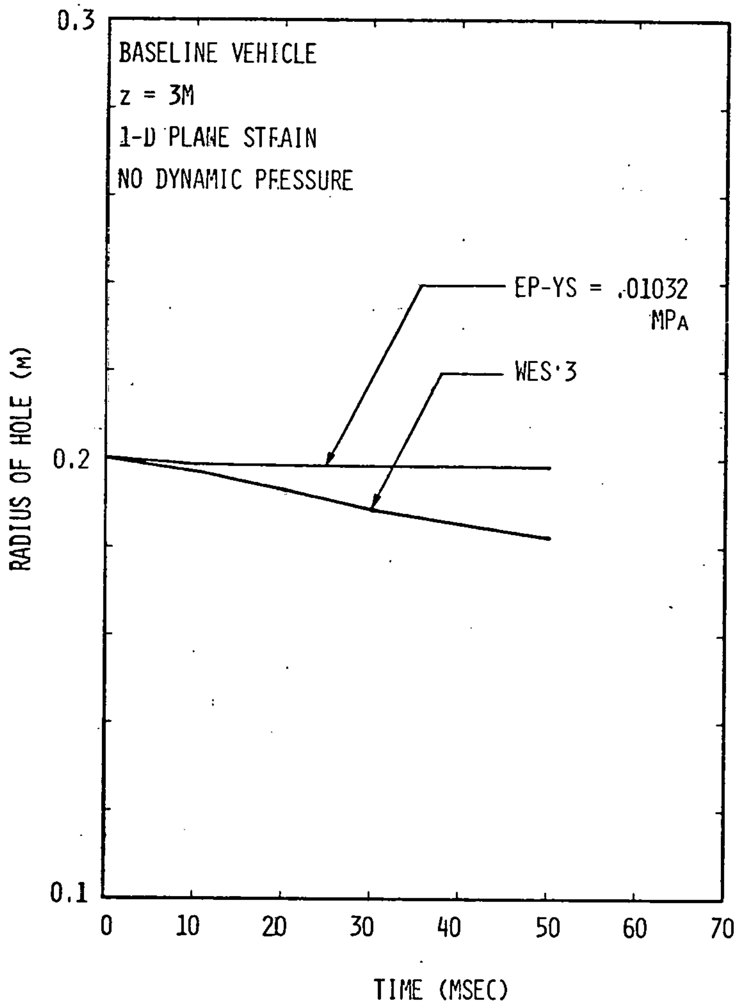
1D HOLE CLOSURE: 60 ELE., 125M RADIUS (WES)

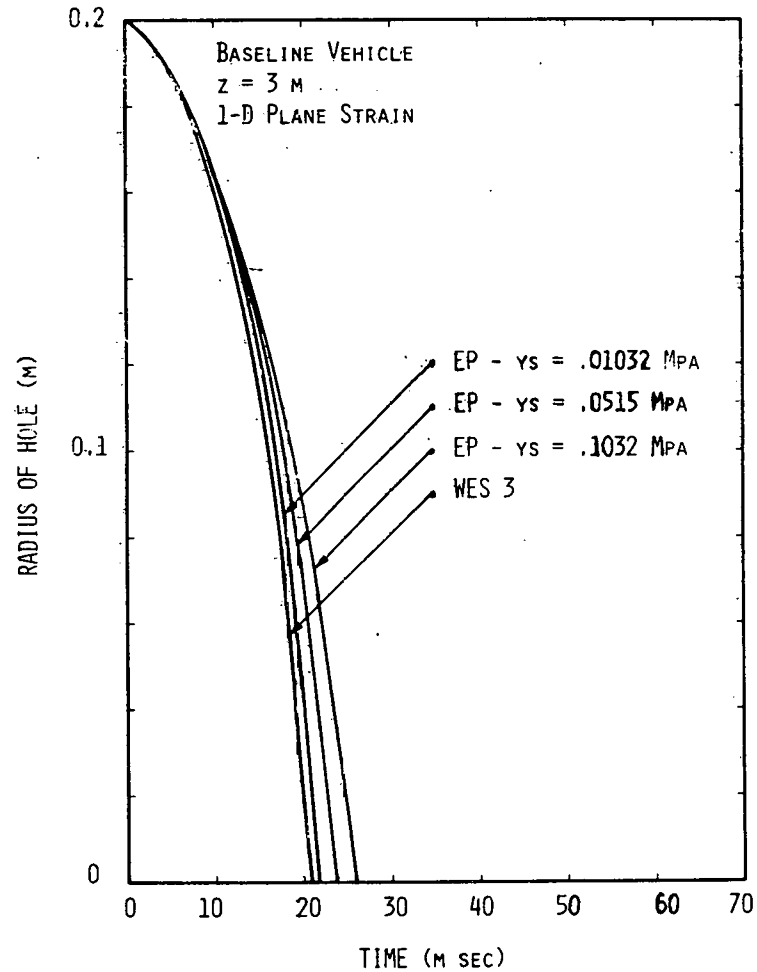
1 DISPLR AT NODAL POINT NO. 1



1D HOLE CLOSURE: 21 ELE., 5M RADIUS (WES)

1 DISPLR AT NODAL POINT NO. 1


BASELINE VEHICLE
z = 3M
1-D PLANE STRAIN
NO DYNAMIC PRESSURE
EP-YS = .01032 MPA
WES 3
RADIUS OF HOLE (M)
TIME (MSEC)
0.3
0.2
0.1
0
10
20
30
40
50
60
70


BASELINE VEHICLE
z = 3 M
1-D PLANE STRAIN
EP - YS = .01032 MPA
EP - YS = .0515 MPA
EP - YS = .1032 MPA
WES 3
RADIUS OF HOLE (M)
TIME (M SEC)
0.2
0.1
0
0
10
20
30
40
50
60
70

HOLE CLOSURE BEHIND AN ADVANCING PENETRATOR

TWO-DIMENSIONAL CALCULATIONS USING THE STEALTH CODE.

PENETRATOR: LENGTH = 3.4 M
DIAMETER = 0.4 M
VELOCITY = 15, 30, 60 M/S

SEDIMENT: ELASTIC - PLASTIC
ρ = 1400 KG/M^3
K = 3.2 x 10^9 PA
G = 2.0 x 10^8 PA
YIELD STRENGTH IS A FUNCTION OF DEPTH:
$Y_{BASELINE}$ = 39,000 LN(1 + 0.1189 Z), PA

HOLE CLOSURE IS MAINLY A FUNCTION OF:

1. SEDIMENT YIELD STRENGTH. FOUR YIELD STRENGTHS USED: A) BASELINE YIELD, B) 5 X BASELINE YIELD, C) 20 X BASELINE YIELD, AND D) THE 5 M YIELD STRENGTH, 0 - 5 M DEPTH, AND THE BASELINE YIELD STRENGTH BELOW 5 M.

2. PRESSURE DROP BEHIND THE PENETRATOR. BY ANALOGY TO FLOW IN PIPES, THE PRESSURE IN THE HOLE AT DEPTH Z IS:

$$P(Z) = \rho_{SW} GZ + 1/2\ \rho_{SW} V_W^2$$

WHERE: ρ_{SW} = SEAWATER DENSITY

G = GRAVITATIONAL CONSTANT

Z = DEPTH

V_W = WATER VELOCITY AT DEPTH, Z

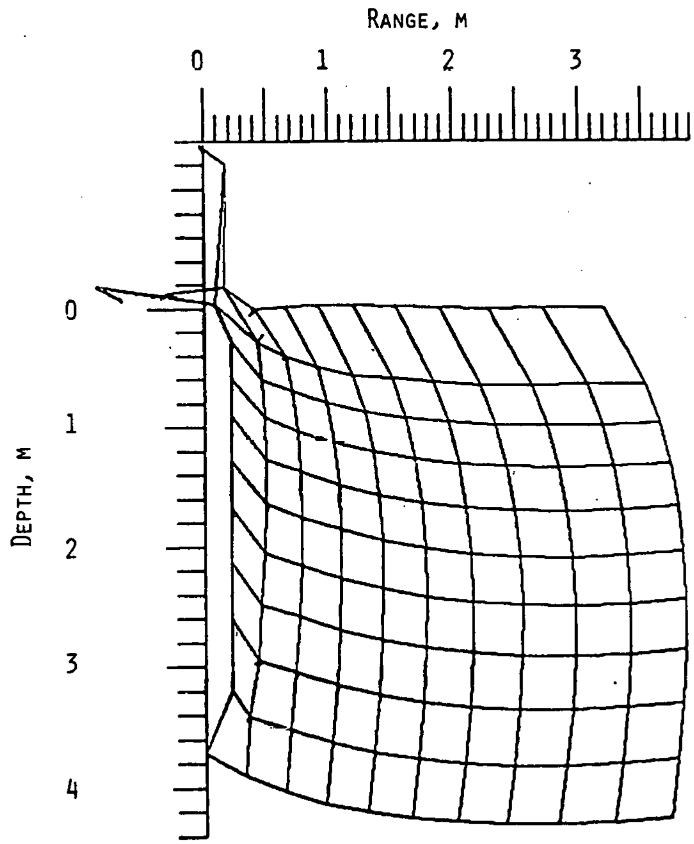
ASSUMING THE WATER VELOCITY, V_W, IS EQUAL TO THE PENETRATOR VELOCITY (I.E., THE FLOW OF THE SEDIMENT INTO THE HOLE WAS NEGLECTED), SEVEN CALCULATIONS WERE PERFORMED:

HOLE CLOSURE TIME AT 2 M DEPTH

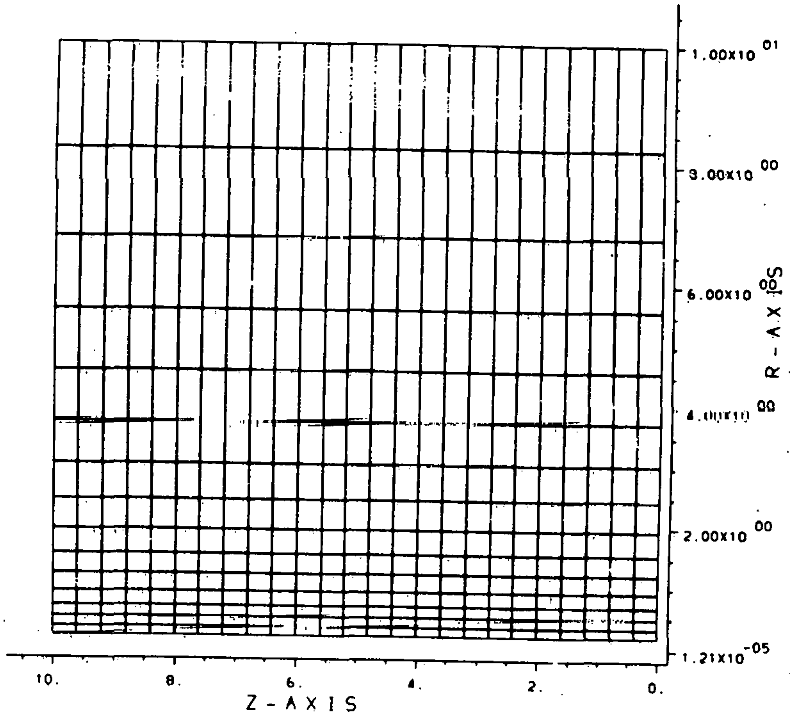
YIELD STRENGTH	PENETRATOR VELOCITY		
	15 M/S	30 M/S	60 M/S
BASELINE	26 MS*	21 MS	10 MS
5 X		22 MS	
20 X	53 MS*	31 MS	
5 M		21 MS	

* AT 0.5 M DEPTH

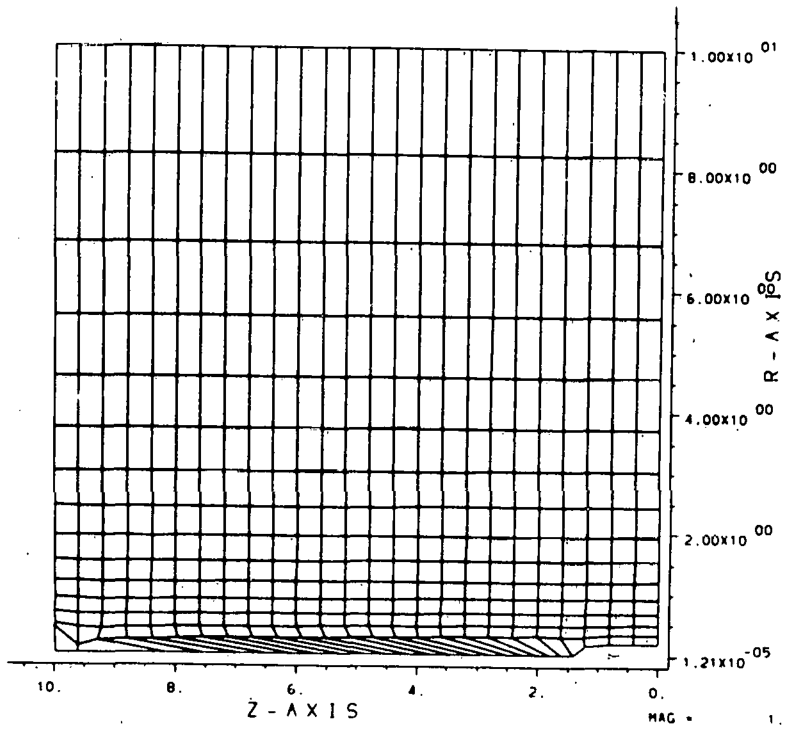
BASELINE YIELD, 30 M/S



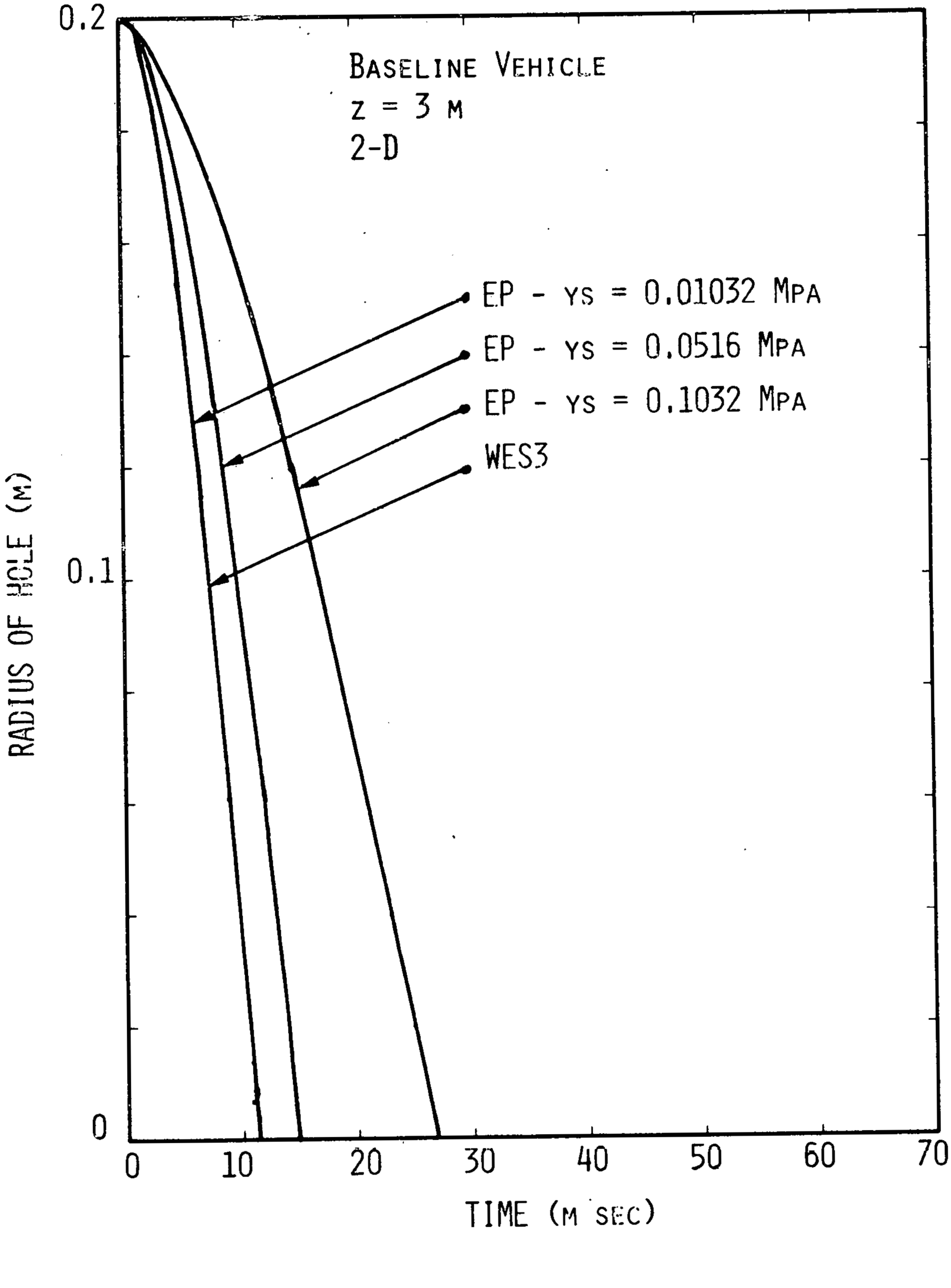
UNDEFORMED MESH



TIME = .300031



* 2D HOLE CLOSURE-SET1-RUN1 *



Baseline Vehicle
z = 3 m
2-D
EP - ys = 0.01032 MPa
EP - ys = 0.0516 MPa
EP - ys = 0.1032 MPa
WES3
Radius of Hole (m)
0.2
0.1
0
0
10
20
30
40
50
60
70
Time (m sec)

III. CONCLUSIONS

A. Hole closure is driven predominantly by the fluid dynamic pressures that follow behind a penetrator.

B. Little effect was observed with different material models or change in the parameters of these models.

C. 2-D may be faster than 1-D because of overburden.

IV. DIRECTIONS

A. More accurate estimates of dynamic pressure losses will be considered.

B. Addition of frictional effects between penetrator and sediment.

C. Deceleration.

D. More systematic parameter study.

BOOSTED PENETRATOR SYSTEM STATUS

The goal of the Instrumented Seabed Penetrator (ISP) project at Sandia National Laboratories (SNL) is to extend seabed penetration technology both by increasing penetration depth and by developing a greater variety of instruments for in situ measurements of marine-sediment properties. A first-generation, gun-launched, instrumented seabed penetrator (ISP-1) has been fabricated. The ISP-1 is designed to produce penetration depths on the order of 50 m into soft sediments while operating in water depths ranging from 30 m to 6 km.

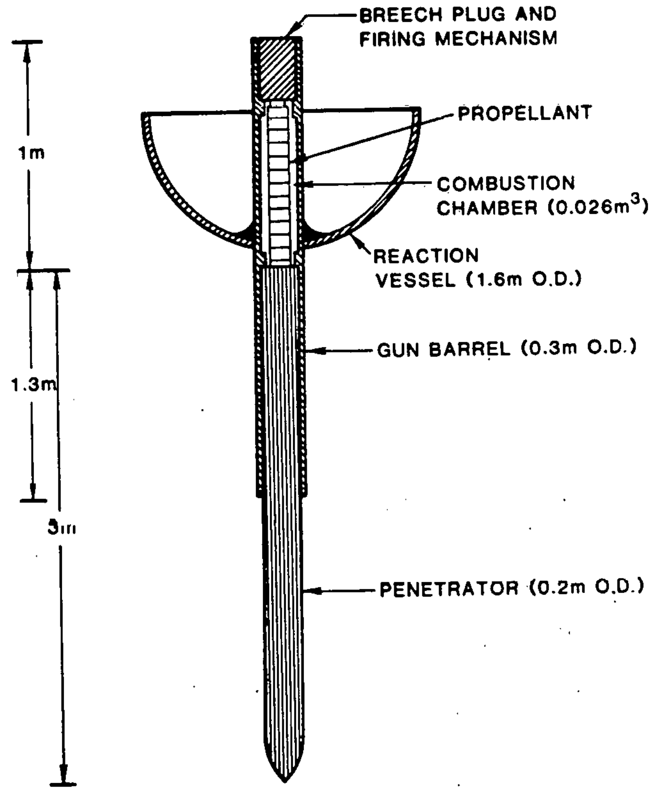
The instrumentation package consists of an axial accelerometer followed by an analog-to-digital converter and a microprocessor. The microprocessor acquires samples of the deceleration record and integrates these data twice to produce an estimate of penetration depth, which is telemetered after the penetrator has come to rest by an explosive acoustic telemetry (EATM) system.

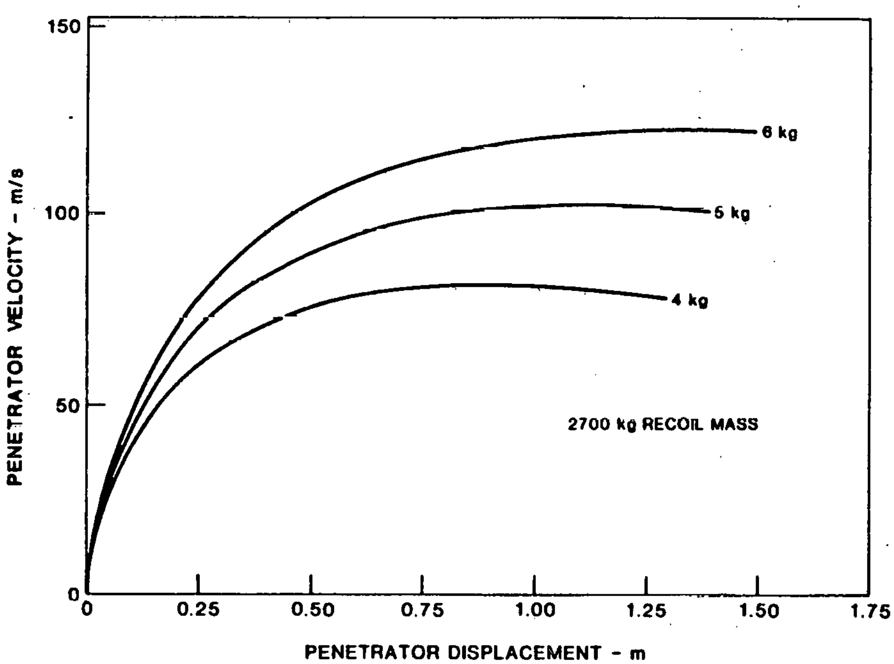
The EATM is a pulse-position modulation system in which the signal pulses are generated by small (sub-gram) explosive charges (eight in the case of ISP-1). Data are conveyed by modulating the time intervals between successive detonations. The receiver uses one or more hydrophones followed by time-of-arrival processing.

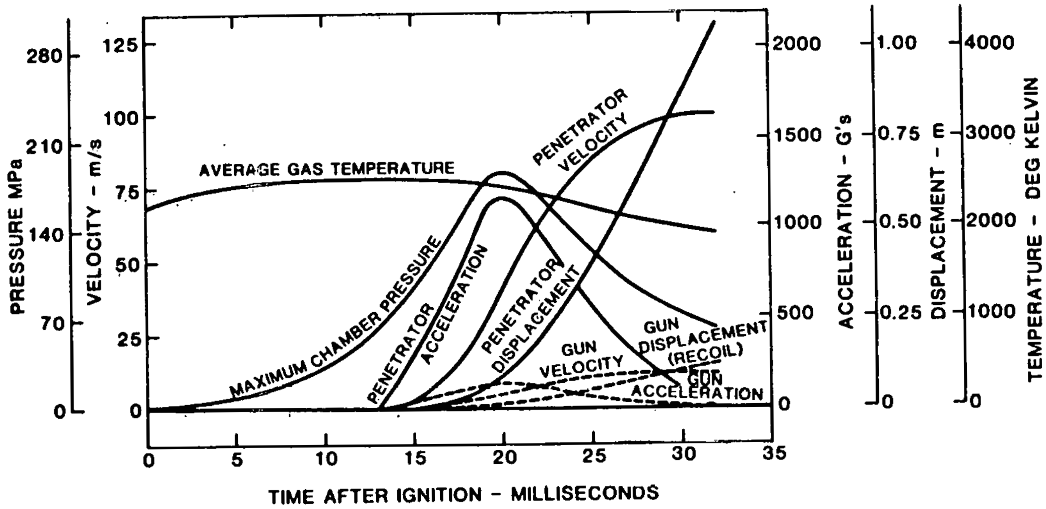
The instrumentation package also contains a clock which enables the firing of the first charge at a predetermined time, thereby permitting measurement of the sound speed in the sediment path between the penetrator and a hydrophone by computing the ratio of the penetration depth and the time delay between detonation and reception of the report from the first charge.

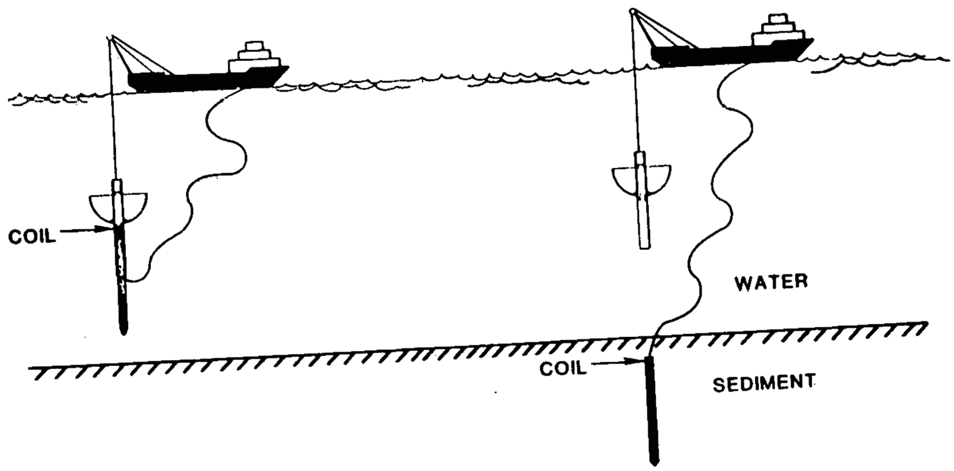
The ISP-1 is currently undergoing preliminary tests on the sled track at SNL in Albuquerque. These tests will be followed by shallow water tests in the Gulf of Mexico south of Morgan City, LA (Eugene Island Block 258) in January 1982.

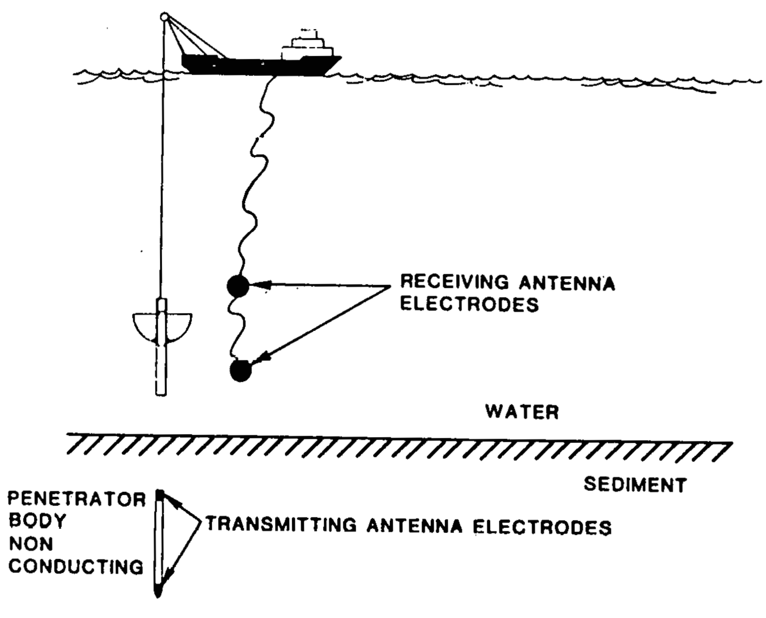
Subsequent generations of gun-launched penetrator systems that will employ improved telemetry and a greater variety of instruments are being designed.

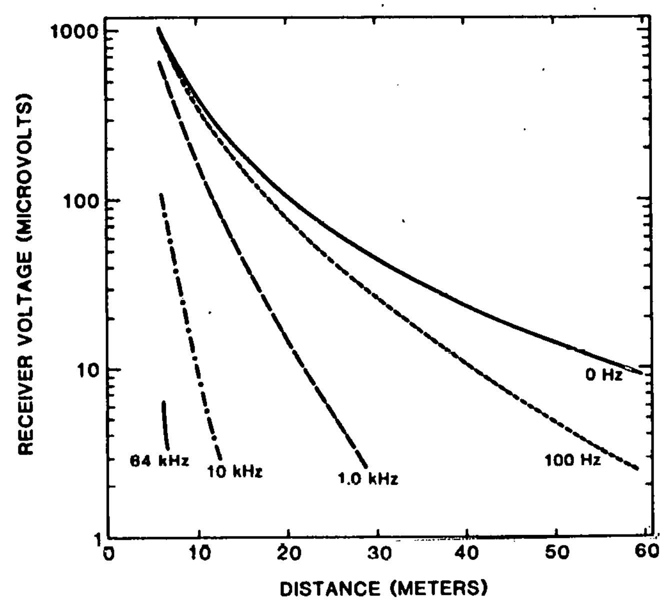

BREECH PLUG AND
FIRING MECHANISM
PROPELLANT
COMBUSTION
CHAMBER (0.026m³)
REACTION
VESSEL (1.6m O.D.)
GUN BARREL (0.3m O.D.)
PENETRATOR (0.2m O.D.)
1m
1.3m
3m

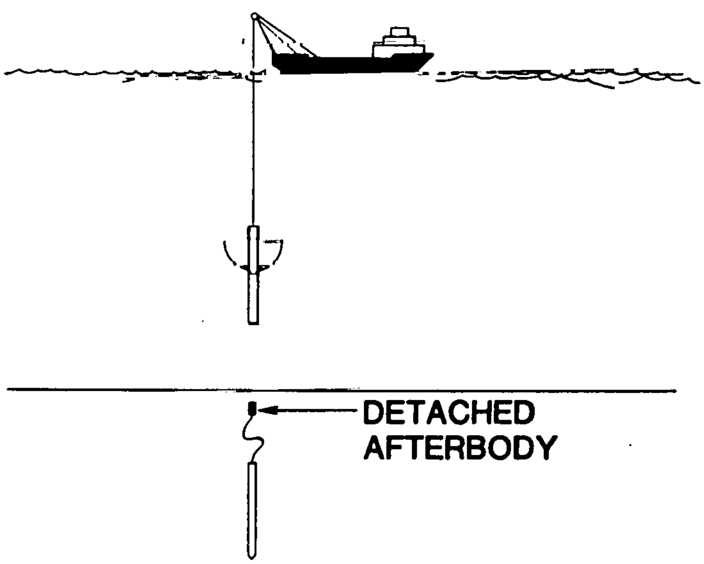

PENETRATOR VELOCITY - m/s
150
100
50
0
0
0.25
0.50
0.75
1.00
1.25
1.50
1.75
PENETRATOR DISPLACEMENT - m
6 kg
5 kg
4 kg
2700 kg RECOIL MASS

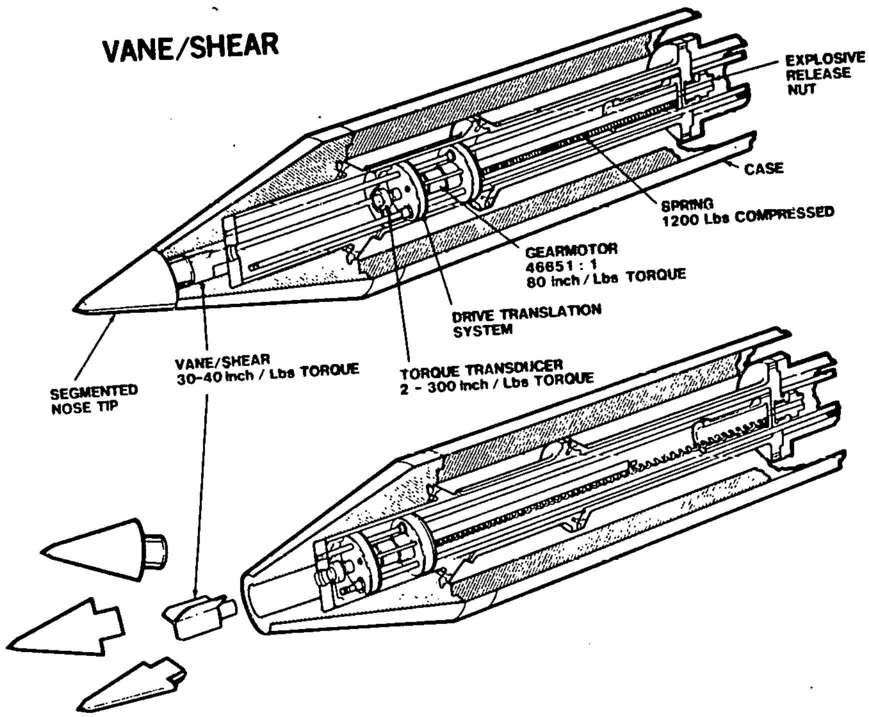

PRESSURE MPa
VELOCITY - m/s
280
210
140
70
0
125
100
75
50
25
0
AVERAGE GAS TEMPERATURE
PENETRATOR VELOCITY
MAXIMUM CHAMBER PRESSURE
PENETRATOR ACCELERATION
PENETRATOR DISPLACEMENT
GUN VELOCITY
GUN DISPLACEMENT (RECOIL)
GUN ACCELERATION
2000
1500
1000
500
0
ACCELERATION - G's
1.00
0.75
0.50
0.25
0
DISPLACEMENT - m
4000
3000
2000
1000
0
TEMPERATURE - DEG KELVIN
0
5
10
15
20
25
30
35
TIME AFTER IGNITION - MILLISECONDS


COIL
WATER
COIL
SEDIMENT


RECEIVING ANTENNA
ELECTRODES
WATER
SEDIMENT
PENETRATOR
BODY
NON
CONDUCTING
TRANSMITTING ANTENNA ELECTRODES


1000
100
10
1
RECEIVER VOLTAGE (MICROVOLTS)
0
10
20
30
40
50
60
DISTANCE (METERS)
0 Hz
100 Hz
1.0 kHz
10 kHz
64 kHz


DETACHED
AFTERBODY


VANE/SHEAR
EXPLOSIVE
RELEASE
NUT
CASE
SPRING
1200 Lbs COMPRESSED
GEARMOTOR
46651 : 1
80 inch / Lbs TORQUE
DRIVE TRANSLATION
SYSTEM
TORQUE TRANSDUCER
2 - 300 inch / Lbs TORQUE
VANE/SHEAR
30-40 inch / Lbs TORQUE
SEGMENTED
NOSE TIP

VII. SYSTEMS ANALYSIS

Technical Program Coordinator: R. D. Klett

Introduction - Primary Barrier Sensitivity
R. D. Klett, SNLA 205

Subseabed Disposal Safety Analysis
C. M. Koplik, The Analytic Sciences Corporation 208

Systems SDP Abstract

R. D. Klett

Introduction

Of the four systems functions in the SDP, only sensitivity and safety studies were active the past year. Cost/benefit analyses are scheduled to start late in FY'82, and optimization studies will begin during the engineering feasibility phase of the program. The initial primary barrier sensitivity studies including heat transfer and ion transport in the sediment are nearly complete. Ocean ion transport sensitivity studies began late in FY'81. Safety studies concentrated on ocean transportation and modeling pathways to man. Other safety work included analyses of handling and storage facilities and the prediction of potential accident probabilities and consequences.

Primary Barrier Sensitivity

Heat transfer and ion migration studies using computer programs MARIAH and IONMIG showed that convection effects were negligible even with twice the allowable heat generation. This permits the use of the systems programs ARRAYF and TRION to be used for the sediment sensitivity studies. The initial thermal analyses established limits and system response for each of the independent variables. The ion transport studies are not complete but the effects of canister life, leaching rates, bedrock proximity and permeability have been defined. The effects of K_D and burial depth are currently being investigated. The use of the sediments to serve as a passive, slow-release valve to disperse I-129 in the ocean was studied. The release rates generated by TRION will be used as inputs to MARINRAD to predict dose to man.

PRELIMINARY ION TRANSPORT RESULTS

1. CANISTER DRIVEN THERMAL CONVECTION IS NEGLIGIBLE EVEN WITH TWICE THE REFERENCE HEAT LOAD.

2. THICKNESS OF SEDIMENT BELOW THE CANISTER AND PERMEABILITY OF THE BED ROCK HAVE NEGLIGIBLE EFFECTS ON TOTAL ION RELEASE.

3. PLACING THE WASTE NEXT TO THE BED ROCK MINIMIZES ION RELEASE FROM THE SEDIMENT.

4. WITH THE EXCEPTION OF ANIONS IN OXIDIZING SEDIMENTS, RELEASE RATES FOR ALL ISOTOPES ANALYZED HAVE LARGE SAFETY FACTORS EVEN WITH PROPOSED EPA REGULATIONS FOR MINED REPOSITORIES

5. REDUCING SEDIMENTS WITH K_D's > 0.2 m^3/kg COULD RETAIN TC-99 WITH 30 m BURIAL DEPTH.

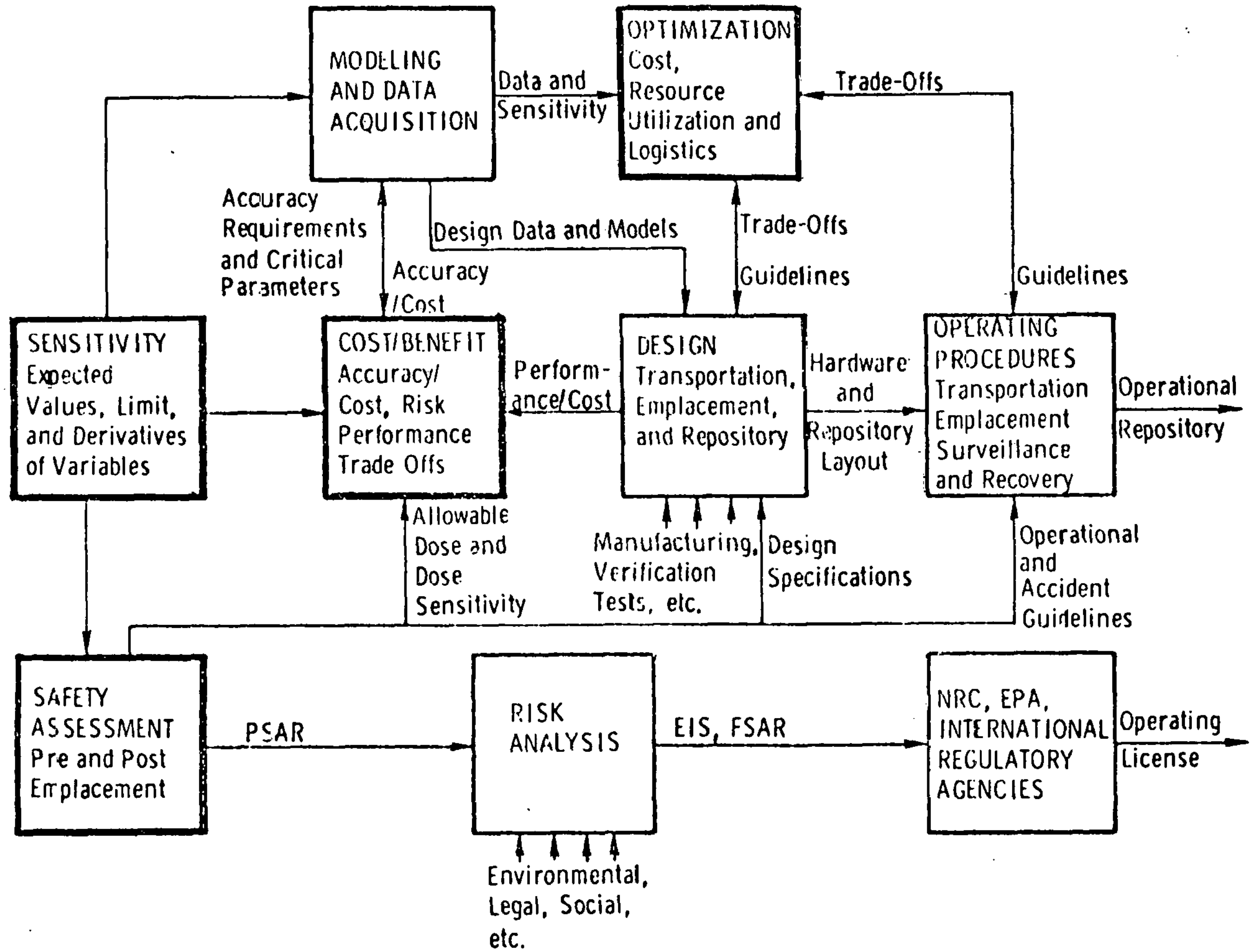
6. BURIAL IN THE SEDIMENTS WOULD ACT AS A PASSIVE LOW RATE VALVE FOR RELEASE TO THE OCEAN AND SUBSEQUENT DILUTION OF I-129.

7. K_D's ARE UNIMPORTANT FOR SHORT HALF-LIFE ISOTOPES BECAUSE OF THE LARGE SAFETY FACTOR AND FOR VERY LONG HALF-LIFE ISOTOPES BECAUSE THE ISOTOPES WILL REACH THE OCEAN WITH ANY REASONABLE K_D.

8. BURIAL DEPTH IS THE DOMINANT PARAMETER FOR LIMITING THE TOTAL RELEASE OF SHORT HALF-LIFE ISOTOPES WITH HIGH K_D's.

9. BURIAL DEPTH HAS LITTLE EFFECT ON <u>TOTAL</u> ION RELEASE OF ISOTOPES WITH HALF LIVES AND LOW K_D's BUT THE MINIMUM EFFECT ON RELEASE <u>RATE</u> IS PROPORTIONAL TO THE DEPTH OF BURIAL SQUARED.

10. FOR WASTE PROPERLY EMPLACED IN THE SEDIMENTS, PROTECTION OFFERED BY CANISTERS IS NOT NEEDED FOR SHORT HALF LIFE ISOTOPES AND IS INSIGNIFICANT FOR LONG HALF LIFE ISOTOPES. CANISTERS COULD HAVE AN IMPORTANT FUNCTION IN THE EVENT OF AN ACCIDENT OR RETRIEVAL.


MODELING AND DATA ACQUISITION
Data and Sensitivity
OPTIMIZATION Cost, Resource Utilization and Logistics
Trade-Offs
Accuracy Requirements and Critical Parameters
Accuracy /Cost
Design Data and Models
Trade-Offs
Guidelines
Guidelines
SENSITIVITY Expected Values, Limit, and Derivatives of Variables
COST/BENEFIT Accuracy/ Cost, Risk Performance Trade Offs
Perform-ance/Cost
DESIGN Transportation, Emplacement, and Repository
Hardware and Repository Layout
OPERATING PROCEDURES Transportation Emplacement Surveillance and Recovery
Operational Repository
Allowable Dose and Dose Sensitivity
Manufacturing, Verification Tests, etc.
Design Specifications
Operational and Accident Guidelines
SAFETY ASSESSMENT Pre and Post Emplacement
PSAR
RISK ANALYSIS
EIS, FSAR
NRC, EPA, INTERNATIONAL REGULATORY AGENCIES
Operating License
Environmental, Legal, Social, etc.

SUBSEABED DISPOSAL SAFETY ANALYSIS

Annual Workshop, October 27-29, 1981

Prepared under:
Contract No. 74-1012
for
SANDIA NATIONAL LABORATORIES
Seabed Programs Division 4516
Albuquerque, New Mexico 87185

Prepared by:
Charles M. Koplik
Daniel A. Ensminger
THE ANALYTIC SCIENCES CORPORATION
Reading, Massachusetts 01867

1. INTRODUCTION

This report summarizes the status of work performed by TASC in FY'81 on subseabed disposal safety analysis. Safety analysis for subseabed disposal is divided into two phases: pre-emplacement which includes all transportation, handling, and emplacement activities; and long-term (post-emplacement), which is concerned with the potential hazard after waste is safely emplaced. Details of TASC work in these two areas are provided in two technical reports (Refs. 1 and 2). The work to date, while preliminary, supports the technical and environmental feasibility of subseabed disposal of HLW.

2. PRE-EMPLACEMENT SAFETY STUDIES

In order to assess system safety, a prototype transportation system involving the handling, storage, shipping and emplacement of high-level waste (HLW) was developed. The system was particularized to the penetrometer emplacement concept and to the borosilicate HLW form.

Casks containing canisters of HLW are transported by truck or train from reprocessing plants or other originating sites to dedicated port facilities. Then the canisters are removed from their transportation casks, inspected for damage, and transferred to an interim storage pool. When a disposal ship is available, the canisters are fitted with penetrometer nose cones, inserted into a transfer cask, and loaded into the disposal ship's storage area via an overhead crane. Instrumented tail sections are added to the canisters aboard the ship. When it is fully loaded, the ship transports the HLW to the final disposal site, where the canisters are emplaced into the seabed sediment. Each ship carries 144 canisters and 360 shipments are required to transport a quantity of waste equivalent to that contained in a land-based repository.

A preliminary set of scenarios that lead to release of waste were developed for pre-emplacement operations. The following accidents were found <u>not</u> to be relevant threats to the integrity of the HLW canisters.

- Accidents during port loading operations
- Ship accidents involving short-term immersion of undamaged canisters, impact, and fire
- Accidents during emplacement operations.

Ship accidents that can result in potential radionuclide releases to the sea include collision accidents, groundings, ramming accidents, and structural failure accidents. Event trees were developed for each accident type. Outcomes ranged from a floating ship from which all canisters could be recovered to a sunken ship from which recovery of the canisters was considered nearly impossible.

Accident probabilities for each scenario were calculated using ship accident statistics from Ref. 3. The likelihood of some degree of accidental release over 360 shipments is conservatively estimated to be 10^{-2}.

Subsequent efforts will complete the safety analysis by evaluating radionuclide release rates, transport in the water column, uptake by marine plants and animals, and dose to man for each accident scenario.

3. POST-EMPLACEMENT SAFETY STUDIES

Work focused primarily on developing systems models for assessing the consequences of release of radioactive materials into the ocean. These models are simple, flexible, and designed for conducting sensitivity analyses.

The models are implemented via the computer code MARINRAD (Marine Radionuclide Transport and Dose). The code can calculate radionuclide concentrations in ocean water and sediment, doses to aquatic biota, doses to man, population doses, integrated population doses, and health effects.

MARINRAD will be used in conjunction with the Sandia computer model TRION for post-emplacement safety analyses. TRION models the release of radionuclides from buried waste canisters through the sediment and to the ocean. MARINRAD will also be used to compute the consequences of pre-emplacement accident scenarios that result in release of waste into the ocean.

Ocean transport in MARINRAD is simulated by a compartment model. The ocean is divided into sediment and water compartments as determined by mixing processes within the ocean. Transport processes that are considered include advection, dispersion, sorption, diffusion, and sedimentation.

Concentrations of radionuclides within compartment biota are calculated using concentration factors. Transport of radionuclides via aquatic food chains is assessed using a simple steady-state model.

A wide variety of pathways of exposure to man are considered. These include ingestion of aquatic biota, external exposure to contaminated water or sediments, and inhalation of spray or shore sediments. Doses to aquatic biota are also computed.

Preliminary analyses were conducted for a representative ocean disposal scenario. Fifty-thousand canisters of HLW were assumed to be disposed of in an area of 10^4 km^2. Radionuclide inventories were computed using the ORIGEN computer code (Ref. 4). A hypothetical disposal site off Cape Hatteras in the Atlantic Ocean was chosen because of the availability of good data for predicting contaminant transport in that region. Information was also collected on concentration factors, food chain transfer parameters, aquatic resources, dosimetry and health effects factors, and individual usage rates (a maximum individual aquatic diet was derived based on the diet of Japanese fishermen).

Preliminary model runs suggest both very low radionuclide concentration levels in seawater and small doses to individuals. Future work will involve refining the models and improving the data base. Ocean models will be particularized to potential HLW disposal sites in the Atlantic and

Pacific. Sensitivity analyses will be conducted to identify important parameters.

REFERENCES

1. Ensminger, D.A., "Release Scenarios and Accident Probabilities for the Subseabed High-Level Waste Disposal Transportation System," The Analytic Sciences Corporation, TIM-3539-1, September 1981.

2. Koplik, C.M., "A Systems Model for Assessing the Consequences of Release of Radioactive Material into the Ocean," The Analytic Sciences Corporation, TIM-3539-2, September 1981.

3. "Hazardous Environments Experienced by Radioactive Material Packages Transported by Water," (DRAFT), prepared by Operations Research, Inc., for the Transportation Technology Center, Sandia Laboratories, TTC-0081, October 1981.

4. Croft, A.G., "ORIGEN2 - A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code," Oak Ridge National Laboratory, ORNL-5621, July 1980.

SUBSEABED DISPOSAL SAFETY ANALYSIS

OCEAN RELEASE CONSEQUENCE MODELING

TASC

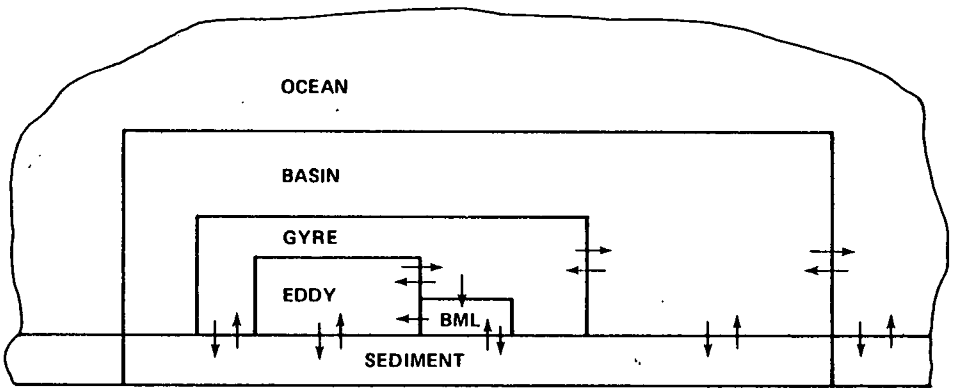
MARINRAD: A MARINE RADIONUCLIDE TRANSPORT AND DOSE MODEL

R-78455

- COMPARTMENT MODEL - CALCULATES WATER AND SEDIMENT NUCLIDE CONCENTRATIONS
- STEADY STATE FOOD CHAIN MODEL - COMPUTES BIOTA CONCENTRATION FACTORS
- PATHWAYS-TO-MAN MODEL - COMPUTES DOSES AND HEALTH EFFECTS

OCEAN COMPARTMENT MODEL

R-76676a



COMPARTMENT MODEL EQUATIONS

R-78457

$$\frac{d\underset{\sim}{C}^{(N)}(t)}{dt} = \underset{\sim}{A}^{(N)} \quad \underset{\sim}{C}^{(N)}(t) \quad + \quad \underset{\sim}{R}^{(N)}(t)$$

CHANGE IN CONCENTRATION WITH TIME	TRANSFER COEFFICIENTS	CONCENTRATION	NORMALIZED SOURCE TERM

$$\underset{\sim}{R}^{(N)}(t) = \underset{\sim}{S}^{(N)}(t) \quad \underset{\sim}{V}^{-1} \quad + \quad \lambda^{(N)} \quad \sum_i \underset{\sim}{C}^{(i)}(t)$$

NORMALIZED SOURCE TERM	RELEASE RATE	INVERSE VOLUMES	DECAY RATE	CONCENTRATIONS OF PARENT NUCLIDES

SOURCE TERM ($\underset{\sim}{S}^{N}$)

R-78458

- OPTION 1: INPUT VALUES FROM TRION
- OPTION 2:

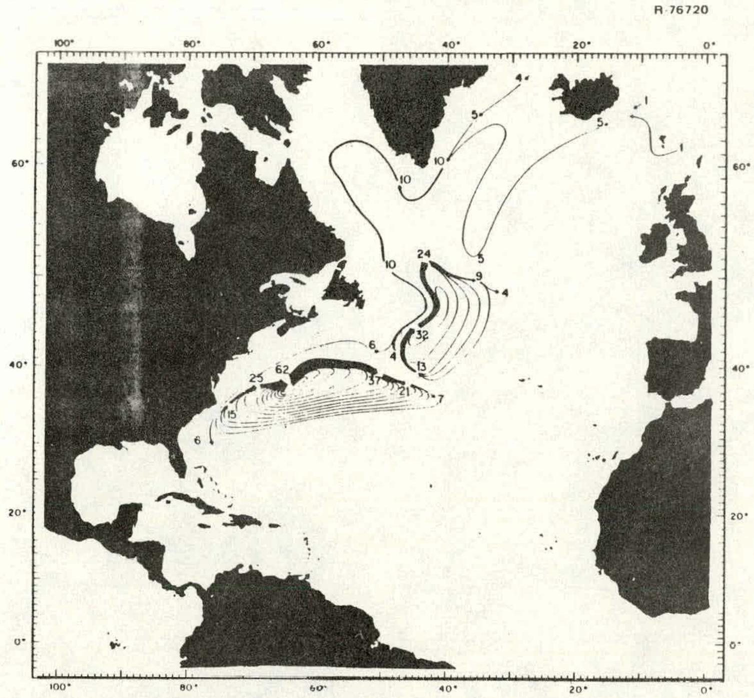
$S^{(N)}(t)$ =	N	× LOAD	× $I^{(N)}(t)$	× Le^{-Lt}
RELEASE RATE	NUMBER OF CANISTERS	CANISTER LOADING	INVENTORY	LEACH RATE

ATLANTIC OCEAN MODEL

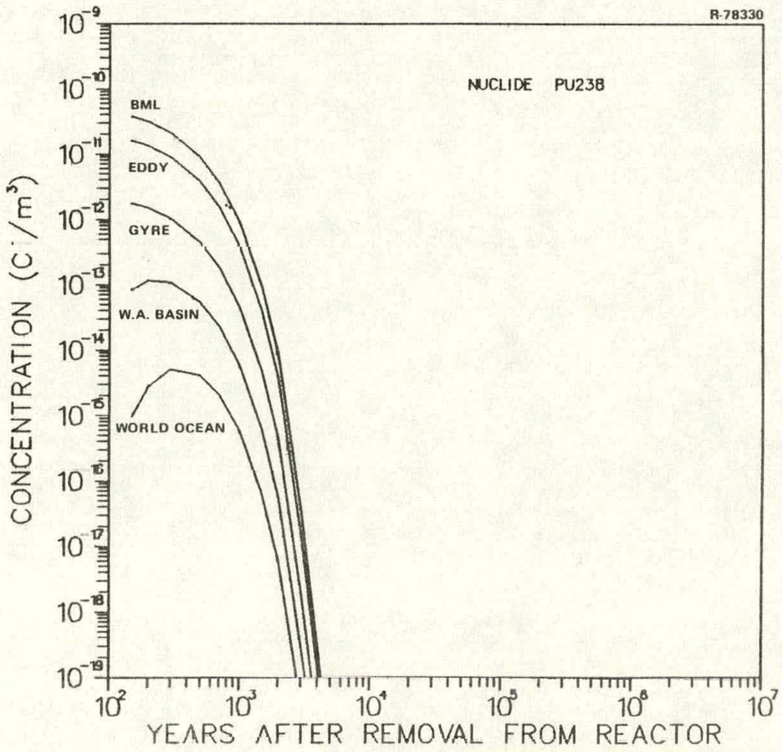
R-78459

- FIVE WATER COMPARTMENTS AND FIVE ASSOCIATED SEDIMENT COMPARTMENTS
- SOURCE TERMS (BASE CASE)
  - ORIGEN INVENTORY FOR MIXED OXIDE FUEL
  - $4 \times 10^{+4}$ CANISTERS
  - 50 MWc-YR/CANISTER
  - 10^{-4}/YR LEACH RATE

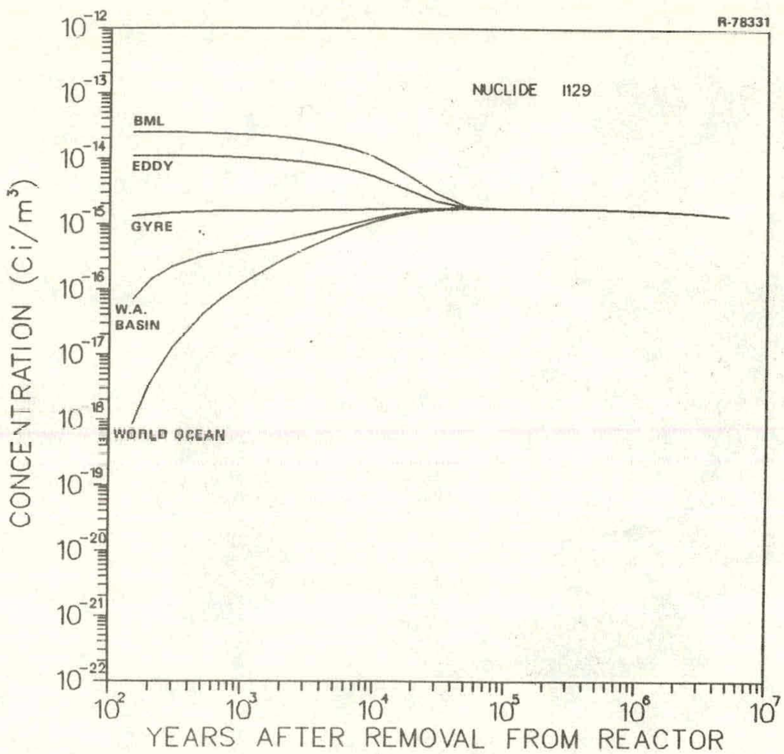
DEEP CIRCULATION IN THE WESTERN NORTH ATLANTIC



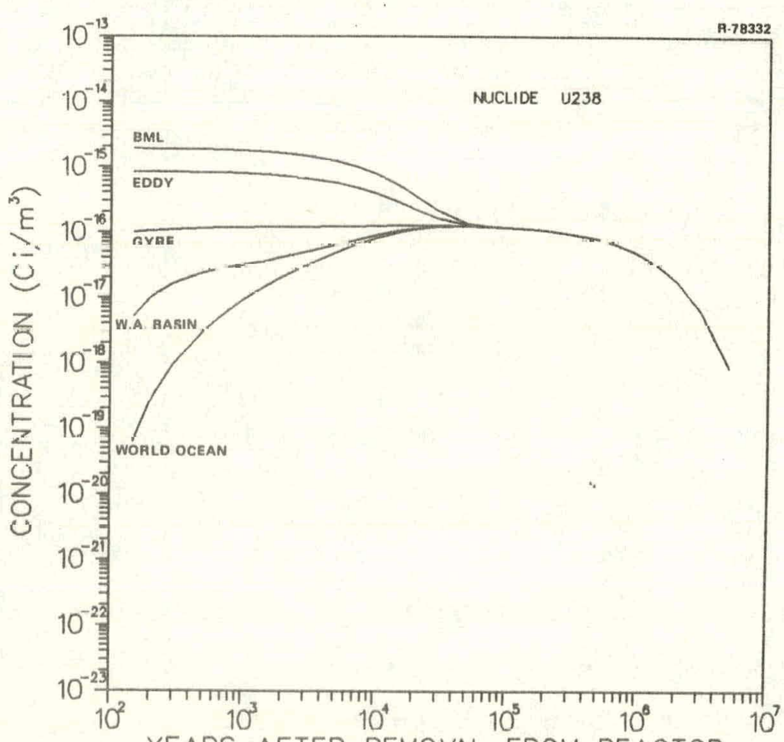
CONCENTRATION VS TIME



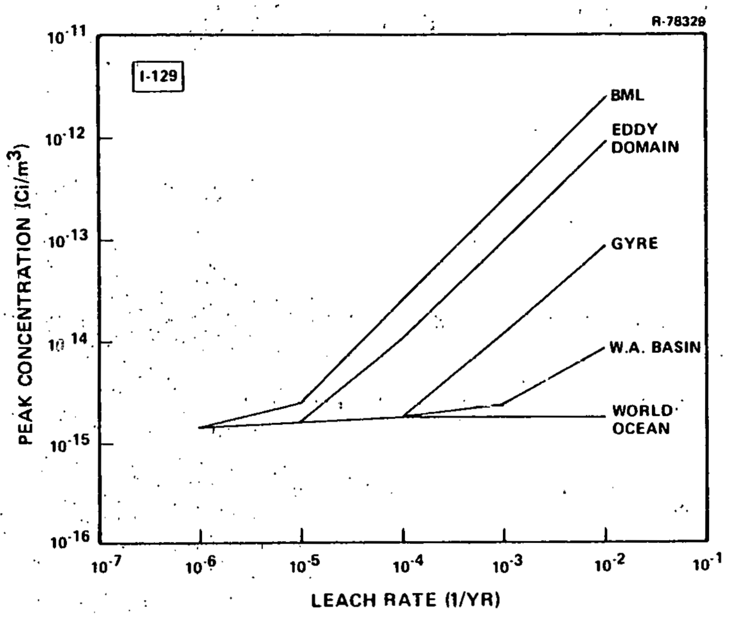
CONCENTRATION VS TIME



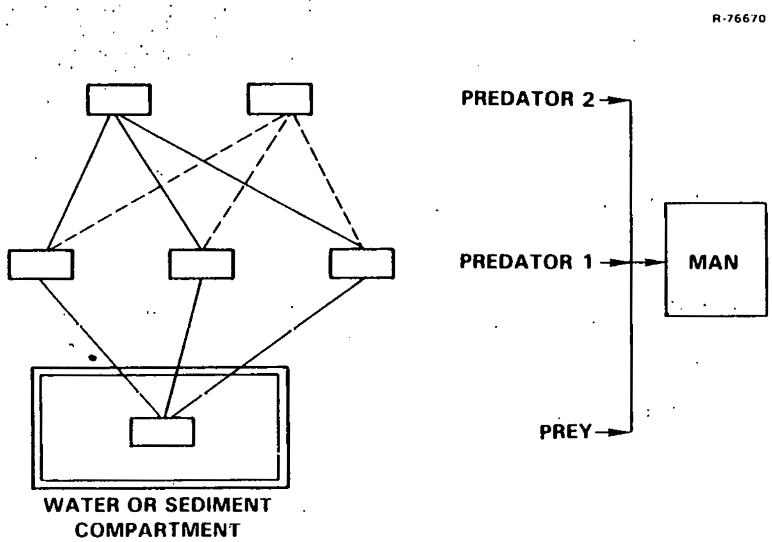
CONCENTRATION VS TIME



SENSITIVITY OF PEAK CONCENTRATION TO RELEASE RATE



SIMPLIFIED FOOD CHAIN MODEL



PATHWAYS TO MAN MODEL

R-78461

- INGESTION OF AQUATIC BIOTA
- EXTERNAL EXPOSURE TO CONTAMINATED WATER OR SEDIMENTS
- INHALATION OF AIRBORNE SPRAY OR SHORE SEDIMENTS
- MISCELLANEOUS PATHWAYS (DESALINIZATION, SALT PRODUCTION, ETC.)

UPTAKE RATES

R-78462

- MAXIMUM INDIVIDUAL: DATA ON JAPANESE FISHERMAN
- POPULATION: DATA FROM FOOD AND AGRICULTURAL ORGANIZATION OF THE UN ON FISH RESOURCES OF THE OCEAN
  - CURRENT RESOURCES
  - MAXIMUM PROJECTED RESOURCES

DOSE AND HEALTH EFFECTS FACTORS

R-78463

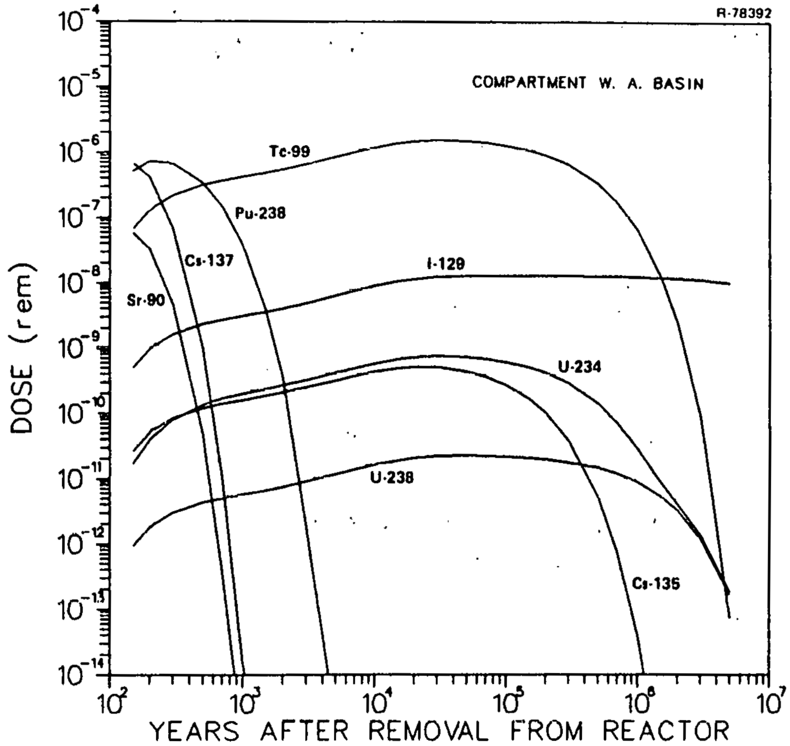
- INGESTION AND INHALATION
  - INREM II COMPUTER CODE
- EXTERNAL EXPOSURE
  - NRC REGULATORY GUIDE 1.109
- CANCER INCIDENCE AND GENETIC EFFECTS
  - ICRP RECOMMENDATIONS

BIOTA DOSE MODEL

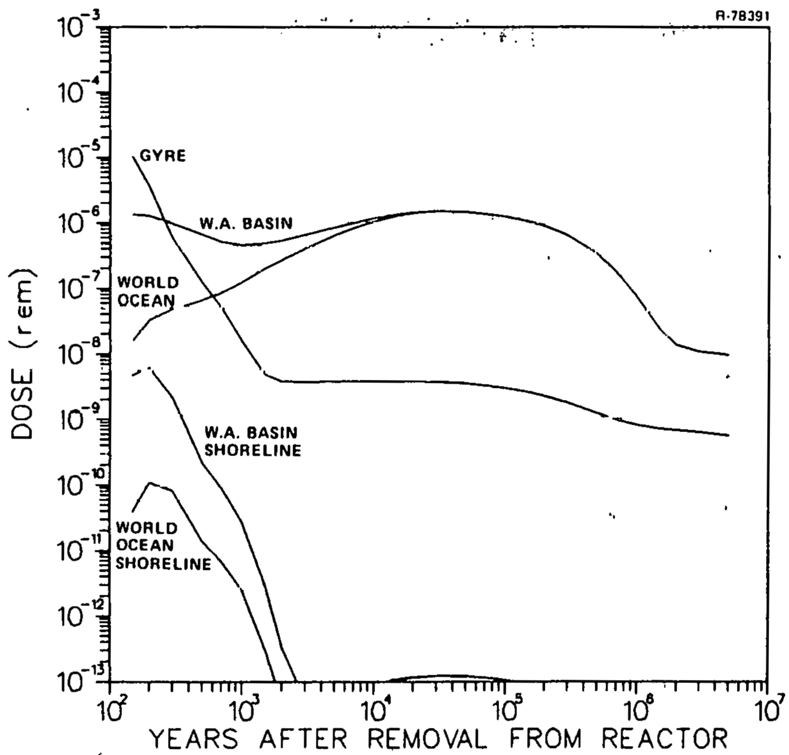
R-78464

- EXTERNAL EXPOSURE TO WATER
- SEDIMENT EXPOSURE (ASSUMES BIOTA LOCATED AT SEDIMENT INTERFACE)
- INTERNAL EXPOSURE (TWO SETS OF DOSE FACTORS AVAILABLE DEPENDING ON SIZE OF ORGANISM)

INDIVIDUAL DOSE BY RADIONUCLIDE



INDIVIDUAL DOSE BY COMPARTMENT



FUTURE WORK

R-78465

- ASSESS CONSEQUENCES OF SHIP ACCIDENTS
- CONTINUE SENSITIVITY STUDIES: IDENTIFY KEY PARAMETERS, RADIONUCLIDES, AND PATHWAYS
- DETERMINE ALLOWABLE RELEASE RATES INTO THE OCEAN

SUBSEABED DISPOSAL SAFETY ANALYSIS

TRANSPORTATION SYSTEM: RELEASE SCENARIOS AND ACCIDENT PROBABILITIES

TASC

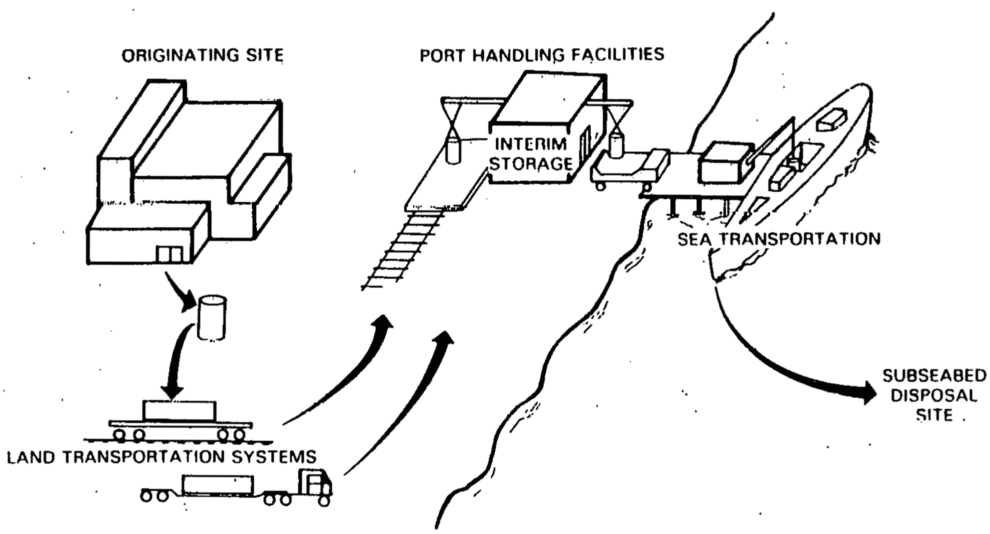
SCOPE OF STUDY

R-78467

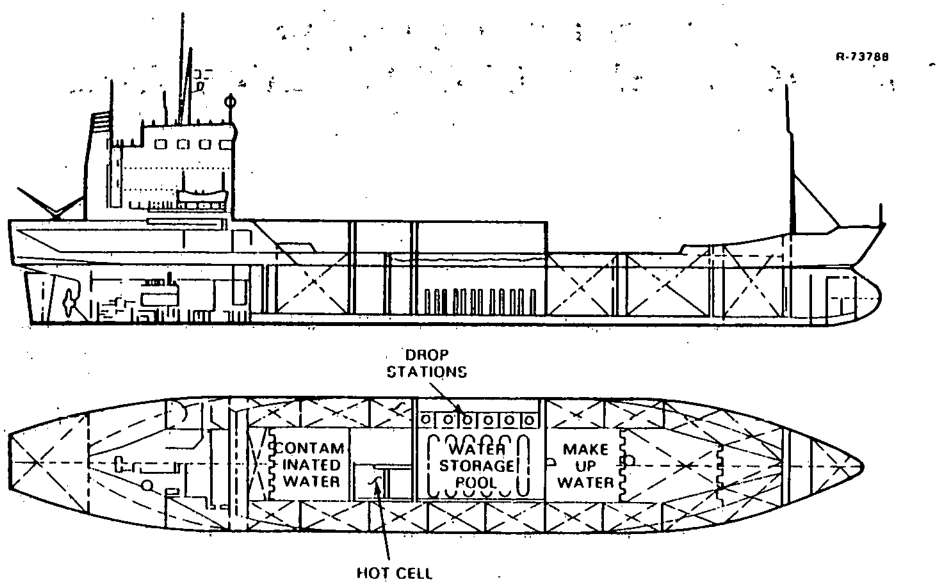
- PRESENT PROTOTYPE WASTE DISPOSAL TRANSPORTATION SYSTEM
- EVALUATE POTENTIAL ACCIDENT SCENARIOS AND PROBABILITIES
- PERFORM SAFETY ANALYSIS AND EVALUATE SIGNIFICANCE OF RISKS

SUBSEABED DISPOSAL TRANSPORTATION SYSTEM

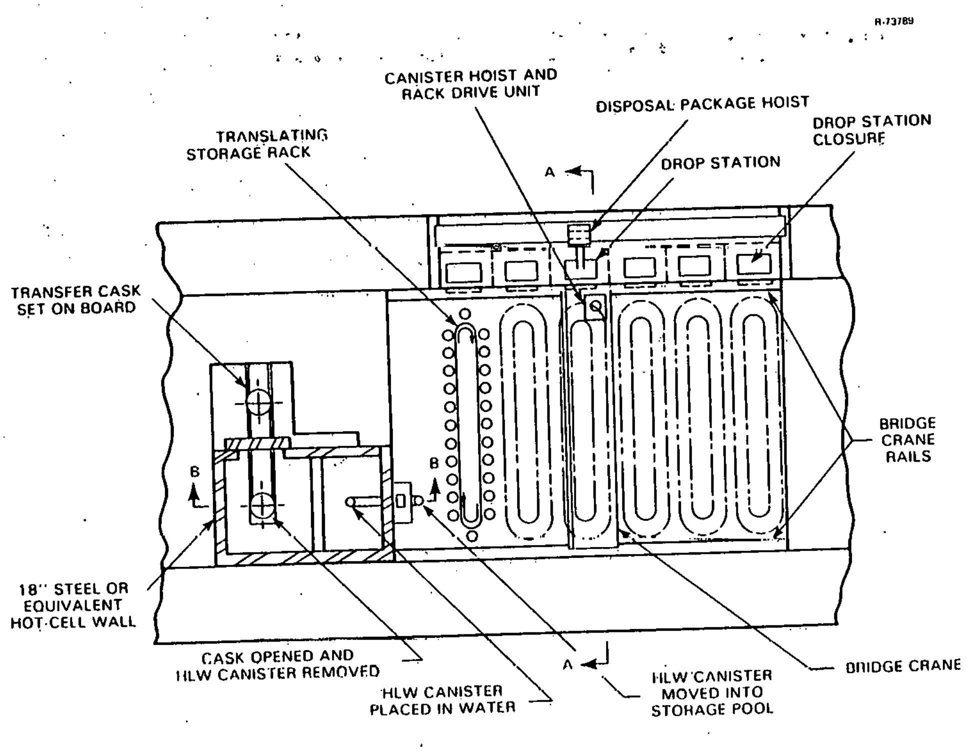
R-73786



HLW DISPOSAL SHIP



DETAIL OF HLW SHIP'S HOT CELL AND STORAGE POOL



ACCIDENT SCENARIOS: THE FIVE KEY ENVIRONMENTS EVALUATED

R-78468

- IMPACT
- FIRE
- CRUSH
- PUNCTURE
- SHORT- AND LONG-TERM IMMERSION

INCONSEQUENTIAL ACCIDENTS

R-78469

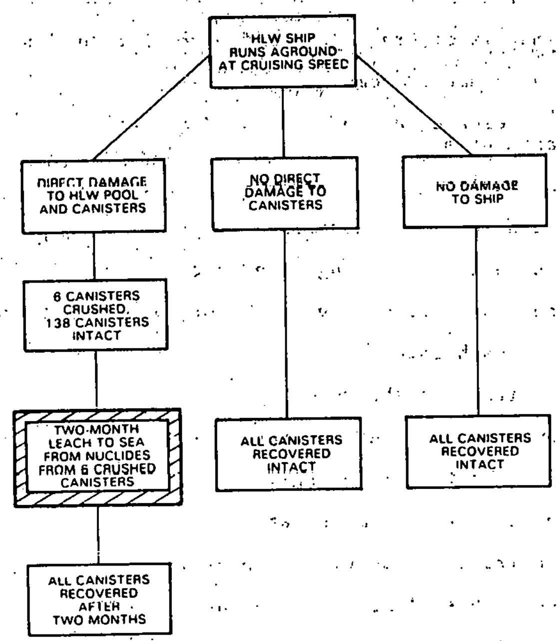
- ACCIDENTS DURING PORT LOADING OPERATIONS
- SHIP ACCIDENTS INVOLVING
  - IMPACT
  - FIRE
  - SHORT-TERM IMMERSION OF UNDAMAGED CANISTERS
- ACCIDENTS DURING EMPLACEMENT OPERATIONS

ACCIDENTS RESULTING IN POTENTIAL RADIONUCLIDE RELEASES TO THE SEA

R-78470

- COLLISION ACCIDENTS, WHERE HLW SHIP STRIKES OR IS STRUCK BY ANOTHER SHIP
- GROUNDING ACCIDENTS
- RAMMING ACCIDENTS
- STRUCTURAL FAILURE ACCIDENTS

EVENT TREE FOR HLW SHIP GROUNDING ACCIDENTS



SUBSEABED DISPOSAL TRANSPORTATION SYSTEM: SUMMARY

R-78472

- HANDLING, STORAGE, SHIPPING, AND EMPLACEMENT OPERATION WERE REVIEWED

- POTENTIAL SHIP ACCIDENT SCENARIOS OF CONSEQUENCE WERE DESCRIBED AND STRATIFIED BY
  - LOCATION
  - FATE OF SHIP FOLLOWING ACCIDENT
  - DEGREE OF PRE-LOSS CANISTER DAMAGE

- ACCIDENT PROBABILITIES WERE DERIVED:
  - PROBABILITY OF SOME DEGREE OF ACCIDENTAL RELEASE IN 360 SHIPMENTS IS OF ORDER 10^{-2}
  - PROBABILITY OF THE MOST SERIOUS RELEASE (COLLISION ACCIDENT OVER CONTINENTAL SHELF WITH SINKING AND NO RECOVERY) IS OF ORDER 10^{-5}
  - PROBABILITY OF THE MOST LIKELY RELEASE (COLLISION ACCIDENT OVER CONTINENTAL SHELF WITH TWO-WEEK LEACH FROM FLOATING SHIP) IS OF ORDER 10^{-3}

- THESE PROBABILITIES ARE CONSIDERED TO BE CONSERVATIVELY HIGH

NOMENCLATURE

$C_m^{(N)}(t)$	is the concentration of nuclide n at time t in compartment m
$A_{ij}^{(N)}$	is a matrix of transfer coefficient for nuclide N
V_m	is the volume of compartment m
$S_m^{(N)}(t)$	is the release rate of nuclide N at time t into compartment m
$\lambda^{(N)}$	is the radioactive decay rate of nuclide N
N	is the number of canisters
LOAD	is the canister loading (MWe-yr/canister)
$I^{(N)}(t)$	is the radionuclide inventory for nuclide N (Ci/MWe-yr)
L	is the leach rate
ε	is the fraction absorbed in gut
μ	is the radionuclide loss rate (1/yr)
ϕ	is the ingestion rate (kg/yr)
b	is the predator biomass (kg)
f_i	is the fraction consumed of prey i
CF	is the stable element concentration factor $\left(\frac{Ci/kg}{Ci/m^3}\right)$

SENSITIVITY STUDIES

OBJECTIVE : Reduce the number of variables, eliminate unnecessary research and development, and provide input for design, safety analysis, cost/benefit studies, and design optimization.

GOALS	MILESTONES					
	Completed Previously	FY81	FY82	FY83	FY84	FY85
Thermal models (ARRAYF, TMAX) –	X					
Thermal sensitivity –		X				
Ion transport model (TRION) –			X			
Primary barrier sensitivity –			X			
Physical and biological oceanographic compartmental model (MARINRAD) –		X				
Coupled primary and secondary barrier sensitivity –			X			

SENSITIVITY COMPUTER PROGRAMS

HEAT TRANSFER (SAND80-0440)

TMAXC - COMPUTES PEAK CANISTER TEMPERATURES AS A FUNCTION OF WASTE PROPERTIES, THERMOPHYSICAL PROPERTIES AND DIMENSIONS.

ARRAYF - COMPUTES TEMPERATURES OF CANISTERS AND DISPOSAL MEDIA AS A FUNCTION OF TIME FOR GIVEN WASTE FORM, CANISTER DIMENSIONS, REPOSITORY LAYOUT, AND DISPOSAL MEDIA PROPERTIES.

ION TRANSPORT IN SEDIMENTS

TRION - MATRIX OF OPTIONS INCLUDING:

- POINT SOURCE OR VERTICAL LINE SOURCE IN A HORIZONTAL ARRAY
- INSTANTANEOUS RELEASE FROM CANISTER OR CONSTANT RELEASE FOR A GIVEN PERIOD OF TIME
- EQUILIBRIUM AND IRREVERSIBLE SORPTION
- OUTPUT OPTIONS
  1. PEAK RATE TO THE OCEAN, TIME OF PEAK RELEASE RATE AND TOTAL RELEASE AS A FUNCTION OF ISOTOPE/SEDIMENT PROPERTIES, REPOSITORY DIMENSIONS, LEACH RATE AND CANISTER LIFE.
  2. RELEASE RATE TO THE OCEAN, INTEGRATED RELEASE AND OCEAN BURDEN AS A FUNCTION OF TIME FOR GIVEN REPOSITORY SPECIFICATIONS.
  3. RELEASE RATE PER UNIT AREA AS A FUNCTION OF TIME AND RADIUS
  4. CONCENTRATION IN THE SEDIMENTS AS A FUNCTION OF TIME, RADIUS AND DEPTH

ION TRANSPORT IN OCEAN

MARINRAD - COMPARTMENTAL MODEL WHICH INCLUDES ADVECTION, DISPERSION, MIXING, TRANSFER TO SEDIMENTS AND THE FOOD CHAIN

- NEAR SHORE AND OCEAN OPTIONS
- COMPUTES DOSES TO BIOTA, MAN AND POPULATIONS PARAMETRICALLY

SAFETY ASSESSMENT

OBJECTIVE: Provide input for design; predict potential problems early in design; increase cost effectiveness; meet requirements for licensing.

GOALS	MILESTONES					
	Completed Previously	FY81	FY82	FY83	FY84	FY85
Pre-emplacement						
Release scenarios and accident probabilities for transportation –		X				
Model land accidents and dose –				X		
Model sea transportation accidents and dose –		X				
Preliminary safety assessment –				X		
Post-emplacement						
Model radionuclide transport and dose –		X				
Data acquisition and sensitivity –			X			
Preliminary safety assessment –				X		

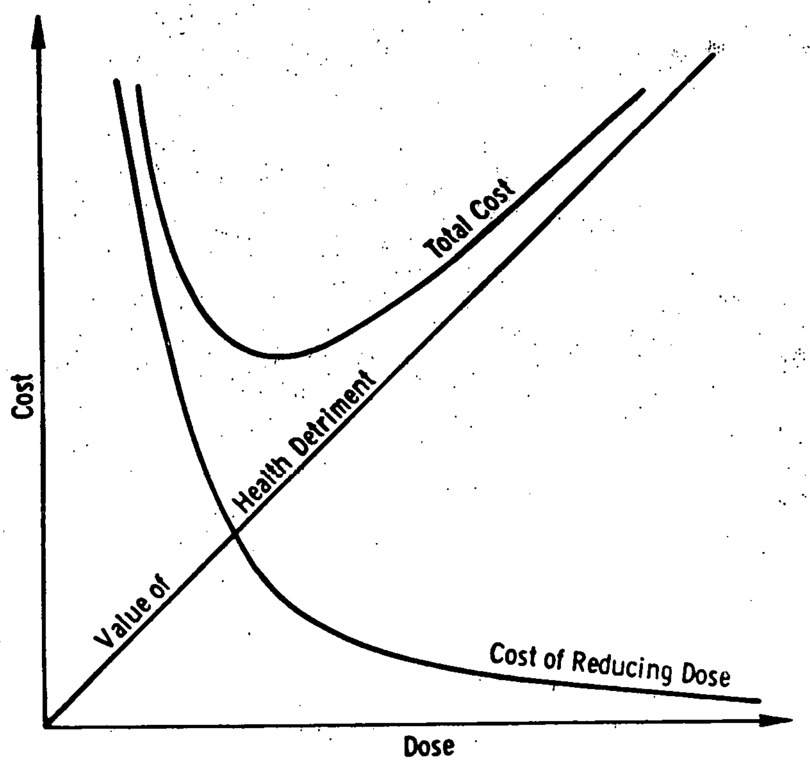
RISK ASSESSMENT AND RELATED COMPUTER CODES AT TASC

CODE	COMMENTS
ORIGEN2	Oak Ridge Isotope Generation and Depletion Code. Most recent version, supersedes ORIGEN. Computes isotope inventory versus time following reactor irradiation.
WASTE	Advection and dispersion contaminant transport code. Models waste transport from a mined repository through a network of one-dimensional pipes. Includes canister corrosion, waste leaching and groundwater hydrology submodels.
BIODOSE	Environmental transport, uptake, and dose code. Computes doses following release of radionuclides via surface or groundwater systems. Dosimetry models based on BNWL work for NRC.
MONC	Performs monte carlo simulations with random sampling. Handles correlated random variables. Four distributions.
SAS	Statistical analysis package used in conjunction with MONC.
NUTRAN (consists of ORIGEN2, WASTE, BIODOSE and input/output routines)	Systems code for risk analysis of waste disposal in mined repositories. Interfaces with MONC and SAS for sensitivity and uncertainty analysis.
PREDOSE	Generic risk analysis of handling, storage and transportation of solidified high-level waste. Systems code using event tree techniques.
AIRSIM	Radionuclide air dispersion and dose code. Handles puff or plume releases.

COST/BENEFIT

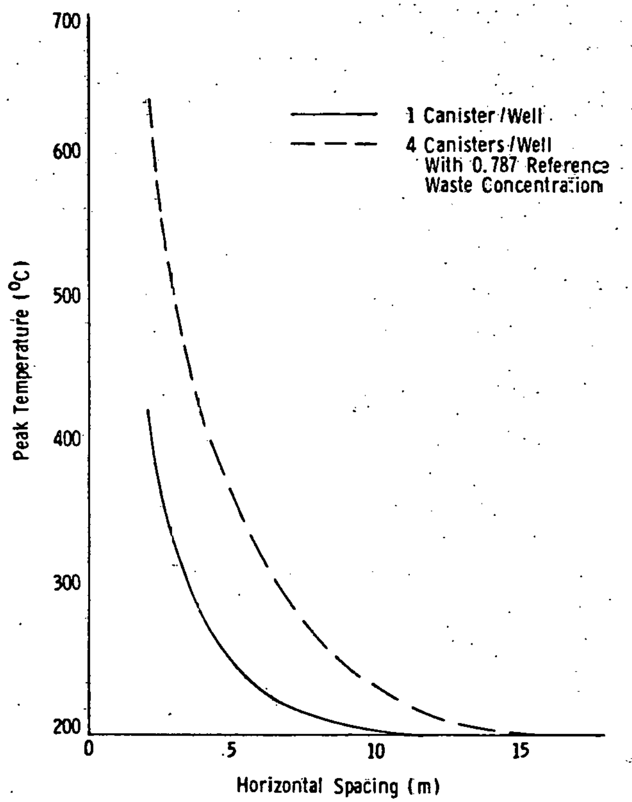
OBJECTIVE: Establish accuracy requirements for data acquisition and models; define the required number of large scale computer runs; improve confidence.

GOALS	MILESTONES					
	Completed Previously	FY81	FY82	FY83	FY84	FY85
Relate data and modeling costs to safety –				X		
Define accuracy requiremen's based on economics –					X	

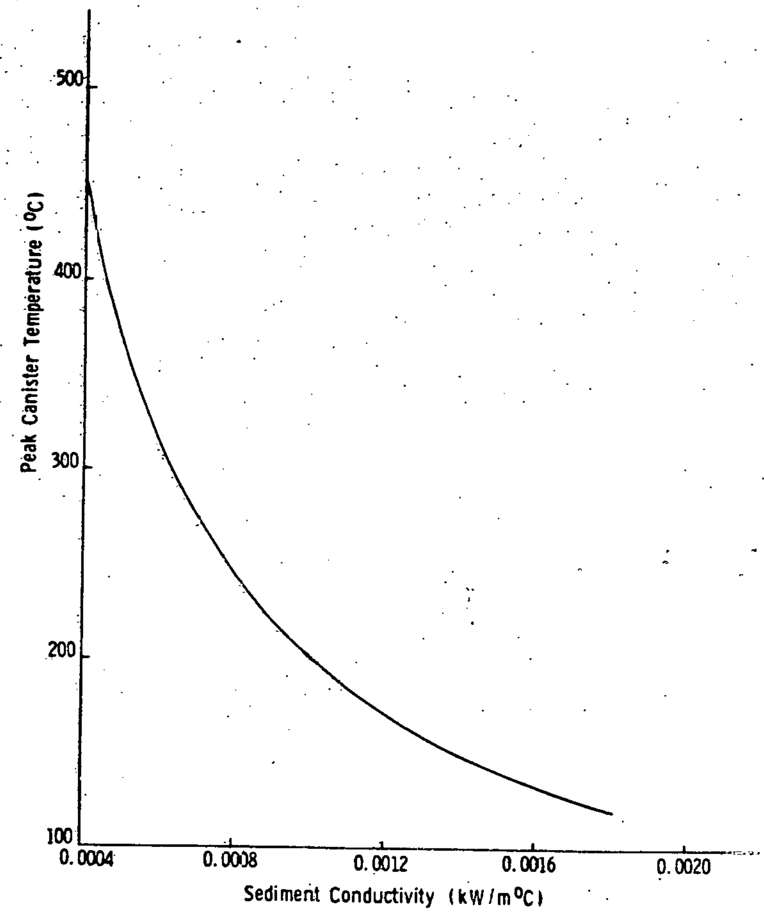


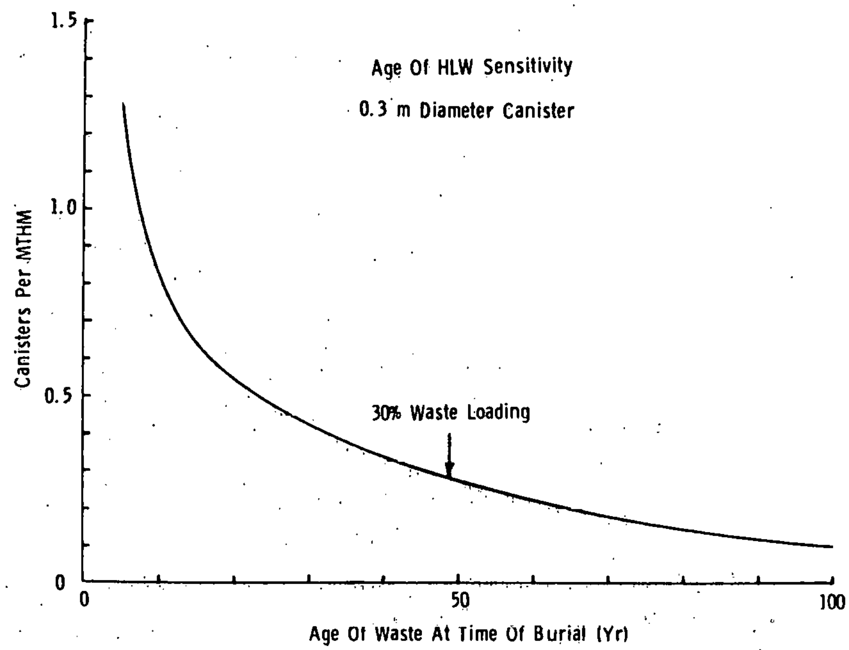
Variations of Costs and Value of Health Detriment Resulting from Emissions as a Function of Residual Collective Dose

Horizontal Spacing Sensitivity — Square Array

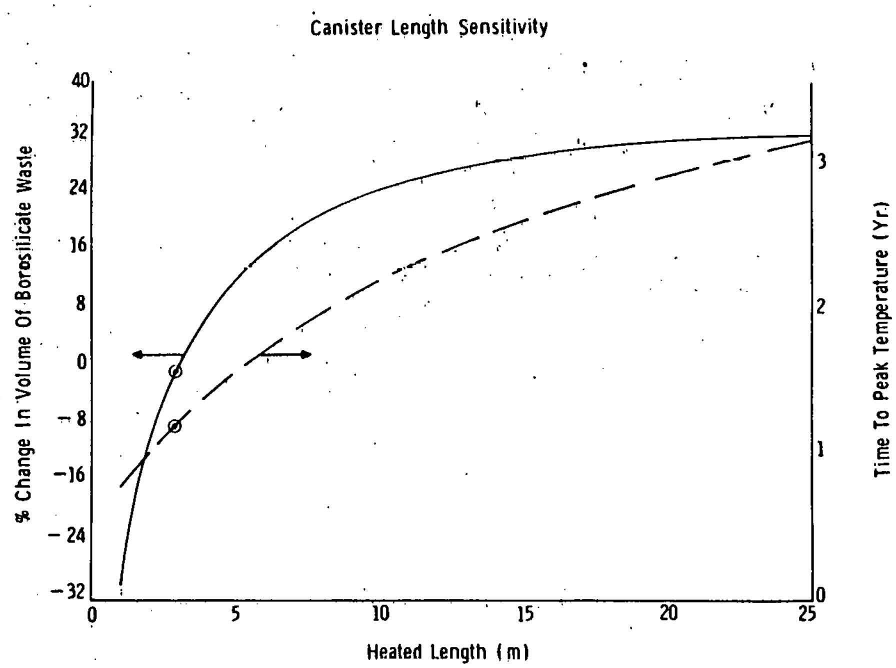


SEDIMENT CONDUCTIVITY SENSITIVITY





Age Of HLW Sensitivity
0.3 m Diameter Canister
Canisters Per MTHM
1.5
1.0
0.5
0
30% Waste Loading
0
50
100
Age Of Waste At Time Of Burial (Yr)



Canister Length Sensitivity
% Change In Volume Of Borosilicate Waste
40
32
24
16
8
0
-8
-16
-24
-32
Time To Peak Temperature (Yr.)
3
2
1
0
0
5
10
15
20
25
Heated Length (m)

THERMAL SENSITIVITY SUMMARY

Limiting Variables

Depth of burial is insensitive greater than 4 m.
Horizontal spacing is insensitive greater than 11 m.

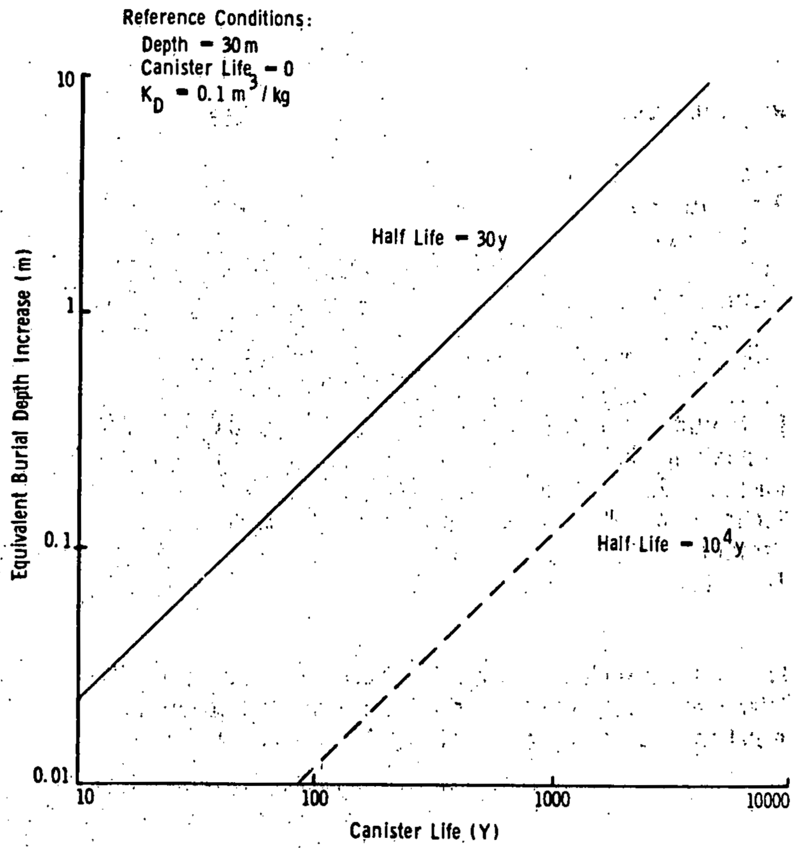
Operational Variables

10% decrease in sediment conductivity decreases loading 9%.
10% decrease in sediment heat capacity decreases loading 1%.
10% increase in sediment porosity decreases conductivity 6%.
Insensitive to permeability.

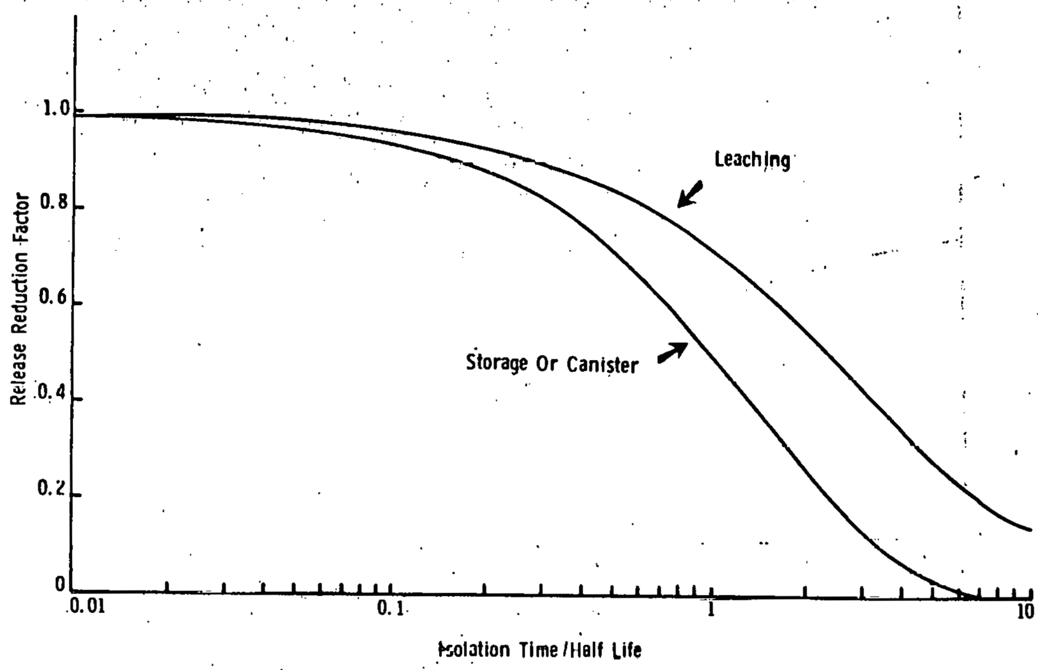
Design Variables

Temperature rise is linear function of waste concentration.
5 year change in waste age changes loading approximately 30%.
Temperature rise is proportional to $(\text{radius})^{1.7}$.
Canister length is insensitive greater than 18 m.
Canisters per well is insensitive greater than 6 per well.
Vertical spacing of canisters is insensitive greater than 7 m.

Release Rate Equivalents of Canister Life and Burial Depth



Reductions In Total Release To The Ocean Caused By Storage And/Or Canister Delay And By A Constant Waste Leach Rate

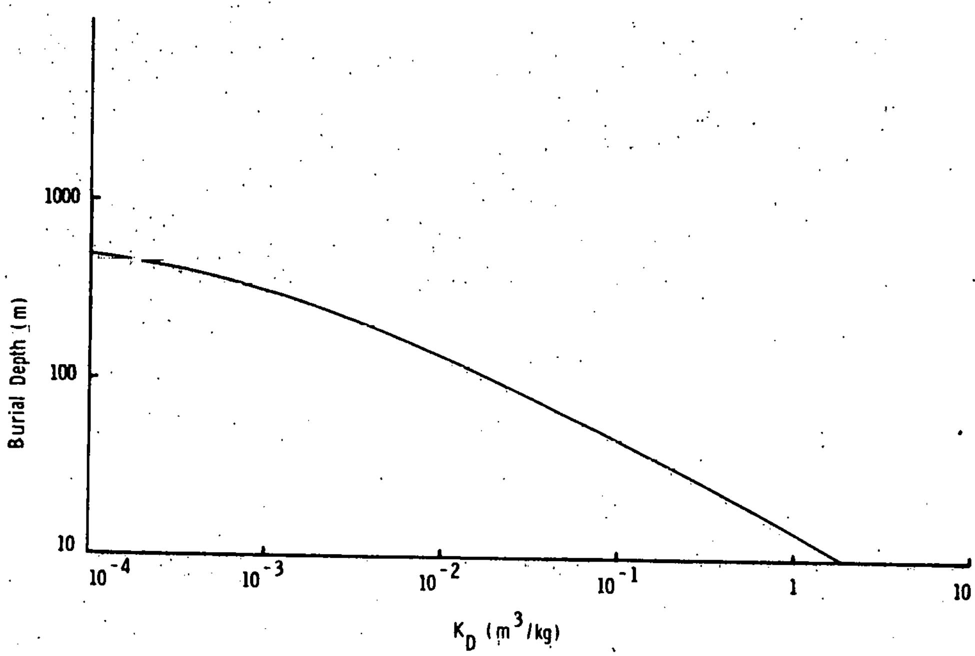


Preliminary EPA Release Limits For Mined Geologic Repositories

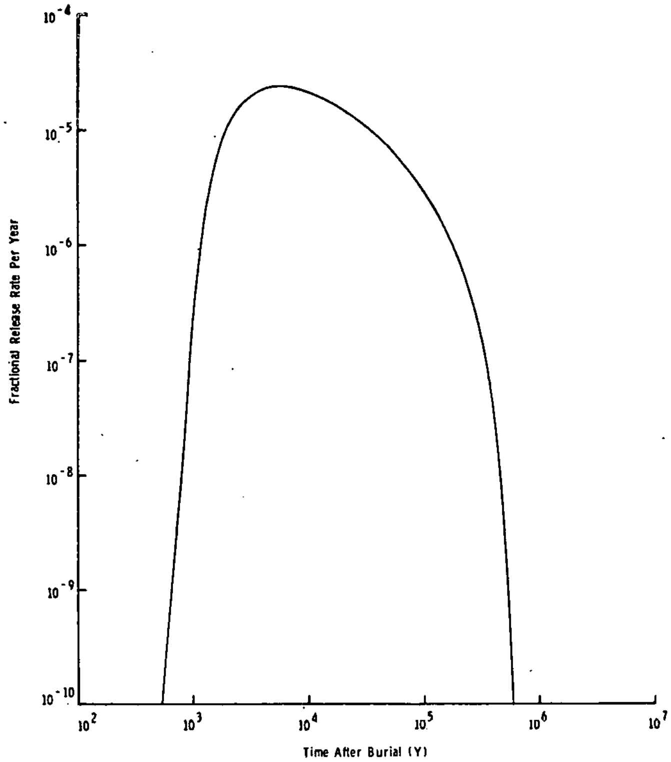
Radionuclides	Curies
Americium – 241	10
Americium – 243	4
Carbon – 14	200
Cesium – 135	2,000
Iodine – 129	900
Neptunium – 237	20
Plutonium – 238	400
Plutonium – 239	100
Plutonium – 240	100
Plutonium – 242	100
Radium – 226	3
Technetium – 99	2,000
Strontium – 90	80
Tin – 126	80

Each release limit represents the maximum cumulative total radionuclide release per 1,000 metric tons of heavy metal that can occur over any 10,000 year period.

Subseabed Burial Depth Vs. Distribution Coefficient Required To Keep Tc-99 Release Below Preliminary EPA Limits (1.43 Ci/MTHM)



IODINE – 129 RELEASE RATE FROM SEDIMENTS WITH NO CANISTER AND A BURIAL DEPTH OF 30m. TOTAL RELEASE FRACTION = 0.903



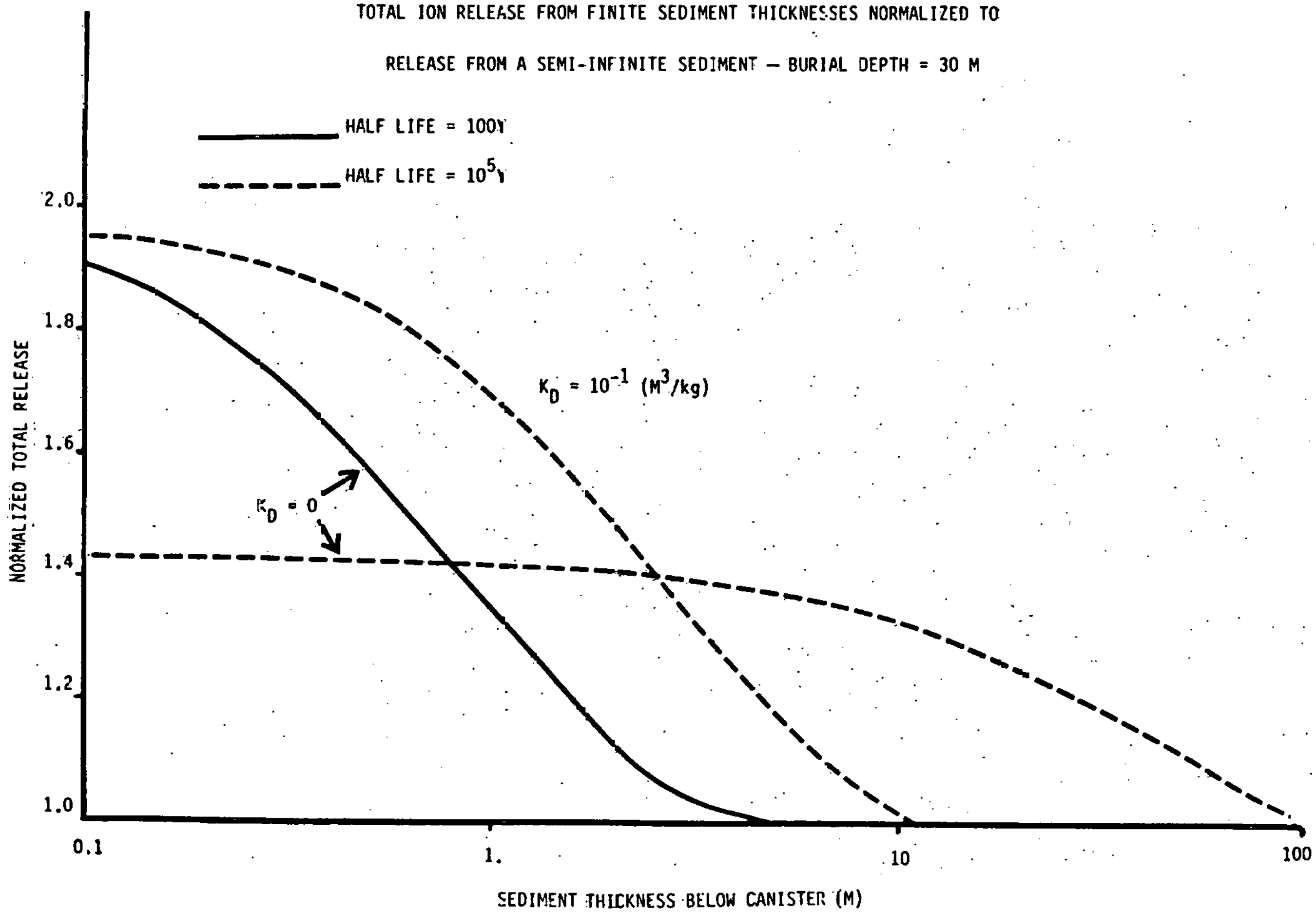
I – 129 Burial Depth Sensitivity

$K_D = 10^{-4}$ (m^3/kg)

Burial Depth (m)	Peak Fractional Release Rate (yr^{-1})	Release Duration (yr) (10^{-4} Peak)
10	2.2×10^{-4}	5.5×10^4
30	2.5×10^{-5}	5.0×10^5
60	6.4×10^{-6}	1.9×10^6
100	2.2×10^{-6}	5.5×10^6

TOTAL ION RELEASE FROM FINITE SEDIMENT THICKNESSES NORMALIZED TO

RELEASE FROM A SEMI-INFINITE SEDIMENT — BURIAL DEPTH = 30 M



Preliminary Ion Transport Results

1. For waste emplaced in the sediments, protection offered by canisters is not needed for short half life isotopes and is insignificant for long half life isotopes. Canisters could have an important function in the event of an accident or retrieval.

2. With the exception of anions, release rates for all isotopes analyzed have large safety factors even with proposed EPA regulations for mined repositories.

3. Deep burial or sediments with $K_D > 0.2\ m^3/kg$ could retain Tc-99.

4. Burial in the sediments would act as a passive low rate valve for release to the ocean and subsequent dilution of I-129.

5. K_D's are unimportant for short half-life isotopes because of the large safety factor and for long half-life isotopes because the isotopes will reach the ocean for any reasonable K_D.

6. Canister driven thermal convection is negligable even with twice the reference heat load.

7. Thickness of sediment below canister and permeability of the bed rock have negligable effects on total ion release.

8. Burial depth has little effect on <u>total</u> ion release with long half lives and low K_D's but the minimum effect on release <u>rate</u> is proportional to the depth of burial squared.

VIII. CHEMICAL RESPONSE STUDIES

Technical Program Coordinator: L. H. Brush

Introduction
L. H. Brush, SNLA 241

Canister Studies
N. J. Magnani, SNLA 242

Near Field Studies
W. E. Seyfried, Jr. and E. C. Thornton - University of Minnesota 248

Synopsis of FY81 Activities - Near Field Studies
J. L. Krumhansl, SNLA 256

Far Field Radionuclide Transport Investigations
K. L. Erickson, SNLA 263

Diffusion of Neptunyl(V)- and Pertechnetate Ions in Marine Sediments
F. Schreiner, S. Fried, A. M. Friedman, Argonne National Laboratory 265

Radiolytic Oxidation of Technetium Dioxide
K. L. Nash, S. Fried, A. M. Friedman, Argonne National Laboratories 270

Chemical Experiments on ISHTE
F. L. Sayles, Woods Hole Oceanographic Institution 274

Introduction

L. H. Brush, SNLA

The presentations for the Chemical Response Group will proceed in the following order: Canister (Nick Magnani), Near-Field Studies (Bill Seyfried, Jim Krumhansl); Far-Field Studies (Ken Erickson, Felix Schreiner, Sherm Fried), and Field Verification (Fred Sayles). We are thus proceeding from the waste package outward to the far-field sediments. We are omitting the waste form because the Subseabed Disposal Program, at the request of DOE Headquarters, does not fund any waste-form research.

Present today but not scheduled to speak is Bruce Bunker of Sandia. Bruce is starting a speciation study to determine if radionuclides leached from the waste package would behave in the far field as predicted by laboratory studies using simple ionic species. We're looking forward to hearing from Bruce next year.

CANISTER STUDIES*

N. J. Magnani
Sandia National Laboratories**
Albuquerque, New Mexico 87185

This presentation summarizes the activities aimed at developing a nuclear waste canister for the U.S. Subseabed Disposal Program. This work is coordinated with work supporting disposal of nuclear wastes in salt environments. In this presentation canister primarily refers to a corrosion resistant overpack but could refer to the container into which the waste is poured if this component were not to be encased in an overpack.

The goal of our program is to qualify a material for, and to develop a canister which will survive in the subseabed environment for hundreds to 1000 years. The canister is not considered to be a viable barrier beyond this time frame even though it may well survive for significantly longer periods of time. There are two different approaches being considered to meet this objective. The first and most heavily pursued approach is to show that a very corrosion resistant material is not susceptible, with a high degree of confidence, to environmental degradation in the repository environment. We have selected TiCode 12 (Ti-0.8% Ni-0.3% Mo) as our primary candidate material. Ti is also being studied and would be proposed if the maximum temperature in the repository is < 150°C. The second approach is to accurately determine the rate of degradation of a material that corrodes but does so in a predictable manner in the repository environment and to design the system so there is a corrosion allowance with a sufficient margin of safety. The latter approach has an advantage that it might be more easily defended in an adversary environment. However, the use of a massive canister and the subsequent generation of large quantities of corrosion products might create a new class of problems.

One of the important areas of our program deals with the effect of radiation on the disposal environment and on corrosion processes. A report, "Effects of Radiation on the Chemical Environment Surrounding Waste Canisters in Proposed Repository Sites and Possible Effects on the Corrosion Process", SAND-81-1677, by R. S. Glass has been prepared. The report concludes in a subseabed environment the products of radiolysis of pure water will be dominant with H_2 and H_2O_2 the stable molecular species. A number of unstable species which could affect corrosion processes will also form. Experimental studies and radiation fields have shown the pH is not affected and H_2 was the only stable species generated which was identified. (The

*This work supported by the U. S. Department of Energy under Contract DE-AC04-76-DPOO789.

**A U. S. Department of Energy facility.

measurements were not made in situ.) Auger analysis of oxide films showed no measurable differences in film composition or thickness due to irradiation.

Another research activity is directed toward the integration of electrochemical and surface study techniques to study the formation of the protective films which form on titanium alloys. If we could accurately determine the conditions required to destroy passivity of Ti and the conditions where Ti will not repassivate if the film is disrupted, and then show these conditions cannot realistically be obtained in the repository environment, we will have almost solved the problem. Kinetics of transport of species such as hydrogen through the film would remain to be determined. Some of the techniques being used to study the kinetics of film formation and the composition of the films are Raman spectroscopy coupled with an in situ electrochemical cell and Auger analysis of films after selected treatments including irradiation. An effort is also directed at the study of H_2 embrittlement/stress corrosion cracking. We have previously shown that if the passive film is disrupted in a cathodic environment TiCode 12 can be embrittled. Our present program is focusing on assessing the tolerance of the material to hydrogen at temperature and the kinetics of transport into the metal. Both gaseous and electrochemical H_2 charging techniques are being used and studies utilizing tritium and tritiated water coupled with autoradiographic techniques are planned.

The effects of welding TiCode 12 on its corrosion properties are also being studied. To date welding has not affected the corrosion response in our test environments. A program studying the sensitization of TiCode 12 has shown that some corrosion enhancement occurs in boiling HCl environments following specific heat treatments; for example, 680°C for 15 minutes. Enhanced corrosion has not been observed in realistic environments. These studies will be used to define the most appropriate weld schedules for TiCode.

Our program to study the corrosion behavior of cast iron in subseabed environments is focusing on defining the corrosion rate of cast iron in deaerated seawater and brine as a function of temperature. These data coupled with the temperature profile of the canister will lead to a required canister thickness. The canister will probably have to be approximately 20 cm thick and therefore the generation of oxidizing species in the environment by radiation would be greatly reduced, i.e., the canister will act as a radiation shield. The rate of generation and availability of these oxidizing species will be expected to control the corrosion rate.

The areas of greatest uncertainty and with the greatest potential for problems are radiation effects and H_2 embrittlement/stress corrosion cracking. Major efforts will continue in these areas over the coming year.

Program Objectives:

(1) Demonstrate a material can survive in a subseabed environment for several hundred to 1000 years.

(2) Design and fabricate a canister (overpack) out of the selected material.

Corrosion Resistant Canister

TiCode 12 leading candidate

Measure the general corrosion rate and demonstrate a mechanism change will not occur.

Show that material will not be susceptible to localized attack in any reasonable environment.

How do we defend the extremely long extrapolations of data which are necessary?

"Corroding" Canister

Cast iron or cast steel

Measure the corrosion rate accurately and design with a corrosion allowance and margin of safety.

Must show mechanism will not change with time.

Definition of the environment becomes more critical since the corrosion process will be controlled by the availability of oxidizing species.

Must consider emplacement of larger and heavier package.

Must consider effect of corrosion products on transport of radionuclides.

Radiation Effects

"Effects of Radiation on the Chemical Environment Surrounding Waste Canisters in Proposed Repository Sites and Possible Effects on the Corrosion Process," SAND-81-1677 in press.

- Radiolysis products of pure water will be important

  Ex. H; OH, e^-_{cg}, H_3O^+, H_2, H_2O_2, OH^-

- Cl_2^- a likely transient species

- "In general metals...which possess fully protective adherent surface oxide films--should be least affected by the oxidizing radiolysis products in aqueous solution."

Experimental Program

- TiCode 12 corrosion rates in seawater not greatly affected by a radiation field (2 μm/year at 10^7 rads).

- pH not affected by radiation field.

- H_2 is the only species generated which has been identified thus far.

H_2 Embrittlement/Stress Corrosion Cracking

- Studies to determine the kinetics of H_2 charging, both gaseous and electrochemical are under way.

- Mechanical property tests under way on charged material.

  TiCode 12 specimen from PNL/SNL test contained 700 ppm H_2 with no effect on mechanical properties or fracture mode at 175°C, fracture mode change at room temperature.

- Tests under way to determine solubility limit of H_2 as a function of temperature.

- Crack propagation tests under way at elevated temperature (200°C).

Physical Metallurgy

- Sensitization study

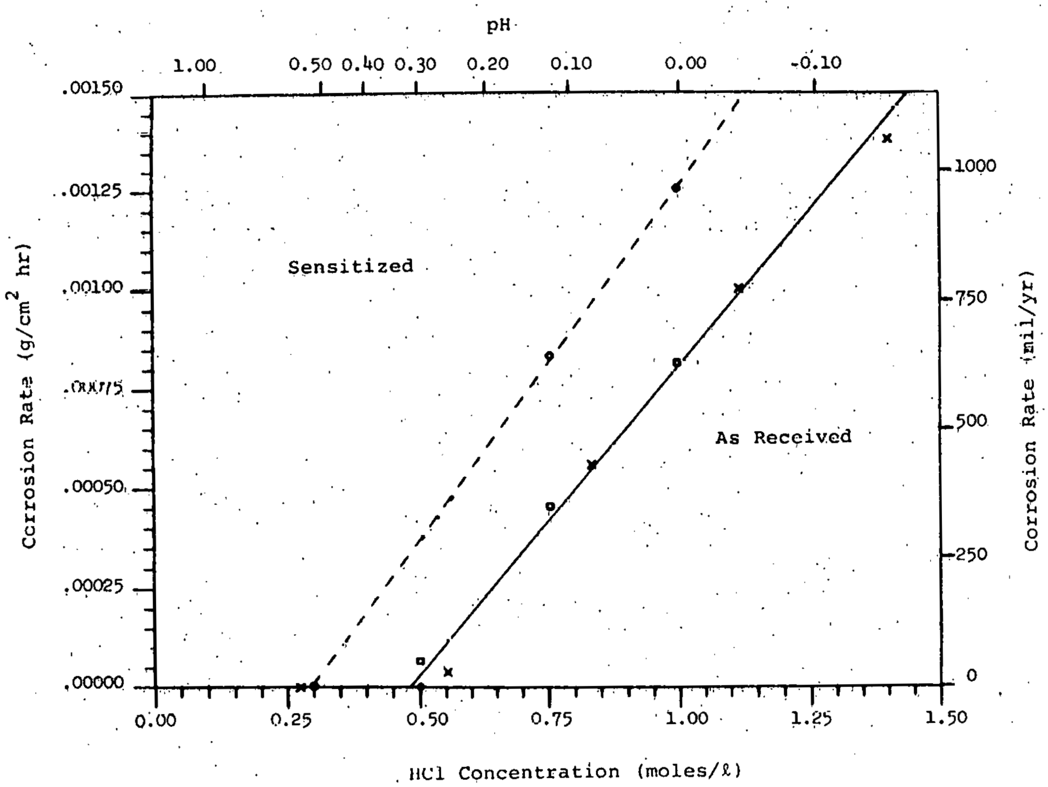
  Region identified but effect not very significant.

- Optimization of thermomechanical treatment schedule

- Effect of alloy chemistry on properties

  Alloy additives

  Impurities



Corroding Canister

  Corrosion rates in deaerated brine and seawater being measured as a function of temperature.

U.K. Program

- Corrosion Resistant Material

  Ti or Ti-0.2% Pd

- Cast Steel & Cast Iron

  Pitting

  S.C.C.

  Joining

- Developing a hot cell stress corrosion cracking capability.

French Program

- Emphasizing electrochemical studies

- In screening stage of their program

- Alloy systems still being studied

  Ti - Ti and Ti-0.2% Pd

  Zr - Zircaloy 4

  Ni - Hasteloy C-276, Inconel 625, Incoloy 825

Future Activities, Emphasis on

- Stress corrosion cracking studies in radiation fields

- Effects of H_2 on properties

- H_2 transport kinetic studies

NEAR FIELD STUDIES

by

W.E. Seyfried, Jr. and E.C. Thornton

Feasibility assessment of subseabed disposal of high level radioactive waste requires information pertinent to chemical reactivity of the sediment-seawater system, both for near field and far field environments. Although the far field is recognized as the primary barrier to radionuclide migration, the near field is also important in that it will act as the initial barrier controlling the flux of chemical species to the far field and will influence significantly the rate of waste-canister corrosion.

Experiments performed at the University of Minnesota using Dickson hydrothermal apparatus have identified and documented processes controlling solution pH and f_{O_2} of the sediment-seawater system at 200°-300°C, 500 bars. These processes include:

(1) Dissolution and reduction of MnO_2 and Fe_2O_3-containing phases;
(2) Oxidation of FeO-containing phases and organic matter;
(3) Precipitation of magnesium hydroxysulfate and Mg-silicate phases (saponite); and
(4) Dissolution of detrital illite, chlorite, quartz, feldspar, volcanic debris and zeolites.

Calculations indicate that the near field environment will be characterized by mildly acidic pore solutions (pH $\simeq$ 4.0) and $f_{O_2} \simeq 10^{-15}$ at 300°C. These parameters should be used to assess the relative corrosion resistence of various alloys for canister construction.

Although 300°C, 500 bars approximates conditions in the immediate vicinity of a canister containing high-level radioactive waste emplaced in seabed sediment, the near field is actually characterized by an extremely pronounced temperature gradient. Thus we have conducted additional experiments designed to obtain a better understanding of processes intrinsic to sediment-seawater interactions in response to a distinct temperature gradient. Our first experiment of this kind provided a temperature gradient of 200°C. The "hot" zone of the pressure vessel was maintained $\simeq$ 300°C, while the "cool" zone was maintained $\simeq$ 100°C. The distance from the "hot" zone to the "cool" zone was approximately 20 cm. Sediment used for this experiment was metalliferous and smectite-rich (poorly crystalline)and was from the Giant Piston Core (GPC-3) retrieved from the MPG-I region. A sediment/seawater mass ratio of 5 was employed. In addition, a portion of waste glass simulant (PNL 76-68) was positioned in the 300°C zone to provide information on waste simulant alteration in a sediment-seawater system and its affect on sediment and solution composition as a function of temperature. The experimental system permitted sampling of solution from the "cool" zone, and thus, a means was available to obtain information pertinent to alteration processes occurring within the sediment "core."

In general changes in solution chemistry in the "cool" zone were similar to those documented during constant temperature experiments at 200-300°C; that is, concentrations of K, SiO_2, Mn, and C_T (total inorganic carbon) in solution increased whereas Mg, Ca, and SO_4 decreased. These changes in solution chemistry can best be interpreted as resulting from mineralogic modifications of the sediment in the "hot" zone. These include smectite formation, dissolution of illite and volcanic glass as well as oxidation of organic matter by MnO_2-containing phases. Other changes in solution chemistry, however, appear to be related to alteration of the waste glass. These include: the marked increase in B and Cl concentrations in solution; and, the relatively high ($\sim$6.0) pH.

Upon removal of the sediment and waste simulant from the pressure vessel at the termination of the experiment it was obvious that significant changes had occurred in the physical properties of the glass and also of the sediment exposed to temperatures $\gtrsim$ 200°C. Although we have not as yet quantified these findings there can be no doubt that smectite formation effectively decreased the porosity and permeability of the sediment as evidence by partial lithification of the sediment and through SEM observations. The glass was thoroughly altered to a mixture of smectite, zeolite (?), iron oxides, and anhydrite. These interesting results, however, need to be further evaluated before an accurate and unequivocal model of sediment and glass waste simulant alteration in a thermal gradient can be formalized.

LIST OF FIGURES

Figure 1. f_{O_2}-pH diagram at 300°C, 500 bars illustrating stability field of metalliferous and smectite-rich (solid squares) and illite-quartz-rich (solid circles) sediment.

Figure 2. Mineral-solution activity diagram for the $MgO-K_2O-SiO_2-Al_2O_3-H_2O$ and $MgO-CaO-SiO_2-Al_2O_3-H_2O$ systems at 300°C, 500 bars. Reaction path depicted by "arrows" is typical of sediment(MPG)-seawater interaction at 300°C.

Figure 3. Mineralogic changes typically observed as a result of sediment(MPG)-seawater interaction at 200-300°C, 500 bars.

Figure 4. Schematic illustration of pressure vessel used for temperature gradient experiments.

Figure 5. Change in concentration of K, Ca, SiO_2, and Mg in solutions sampled from the "cool" zone ($\simeq$ 100°C) of the temperature gradient experiment.

Figure 6. Concentrations of Mn, B, C_T (total inorganic carbon), and pH in solutions sampled from the "cool" zone ($\simeq$ 100°C) of the temperature gradient experiment.

Figure 7. Photograph of entire sediment core subsequent to termination of the temperature gradient experiment.

Figure 8. Photograph of the top ("cool" zone) portion of the sediment core from temperature gradient experiment.

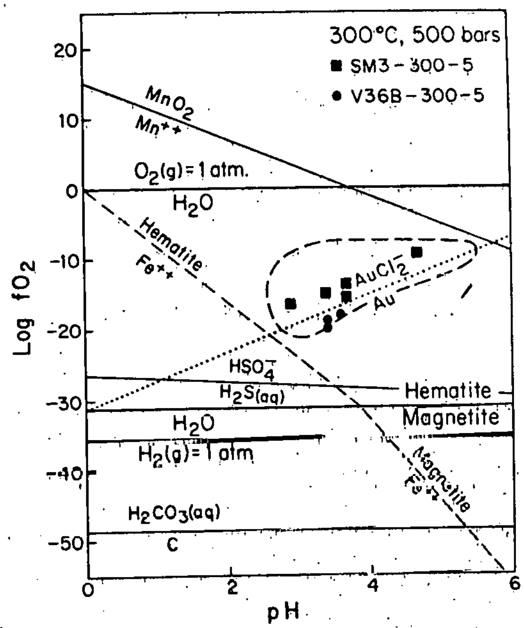
Figure 9. Photograph of the bottom ("hot" zone) portion of the sediment core from temperature gradient experiment.

Figure 10. SEM photomicrograph ($\simeq$ 800X) of sediment from the "cool" zone ($\simeq$ 100°C) from the temperature gradient experiment.

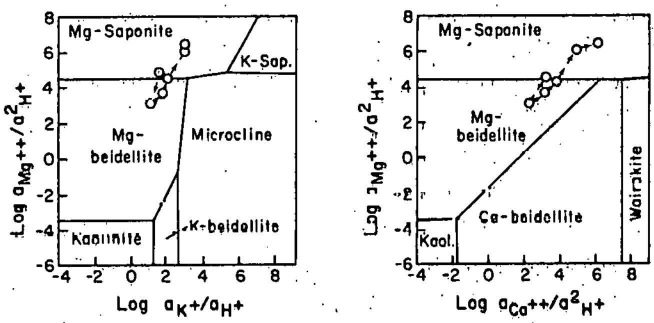
Figure 11. SEM photomicrograph ($\simeq$ 800X) of sediment from the "hot" zone ($\gtrsim$ 200°C) from the temperature gradient experiment.

Figure 12. Relfected light photomicrograph of waste simulant from the temperature gradient experiment.

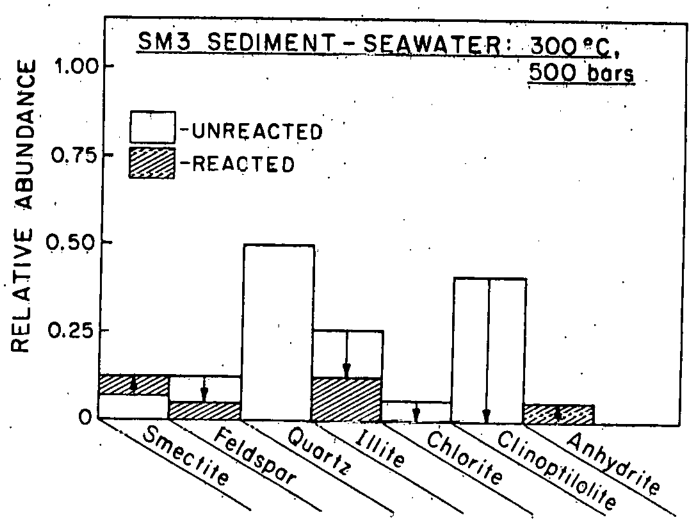
Figure 13. SEM photomicrograph (750X) of waste simulant from the temperature gradient experiment.



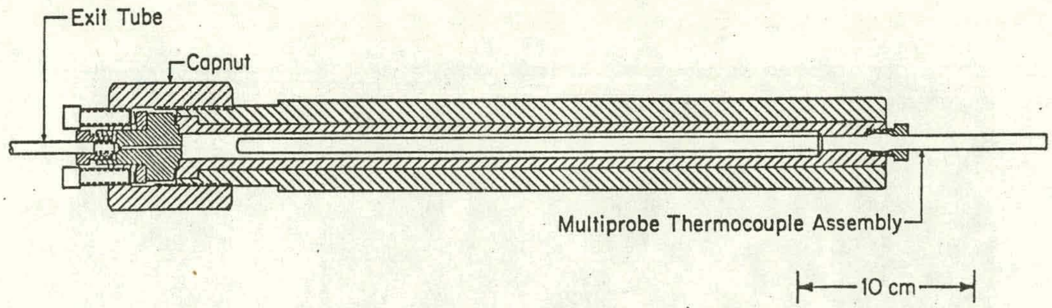
300°C, 500 bars
SM3-300-5
V36B-300-5
MnO2
Mn++
O2(g)=1 atm.
H2O
Hematite
Fe++
AuCl2-
Au
HSO4-
H2S(aq)
Hematite
Magnetite
H2O
H2(g)=1 atm
Magnetite
Fe++
H2CO3(aq)
C
Log fO2
pH

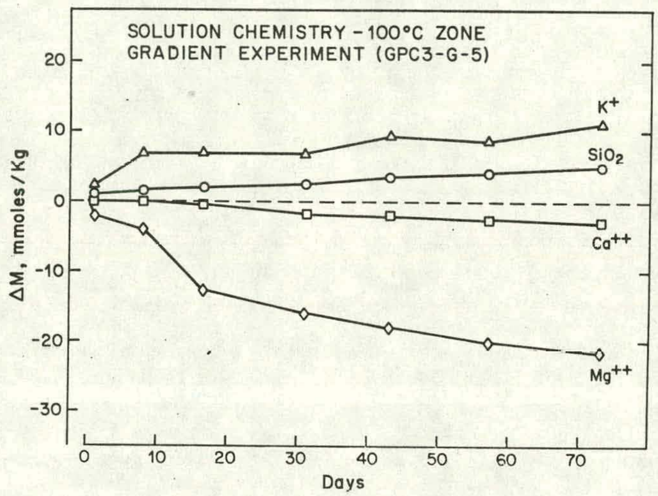


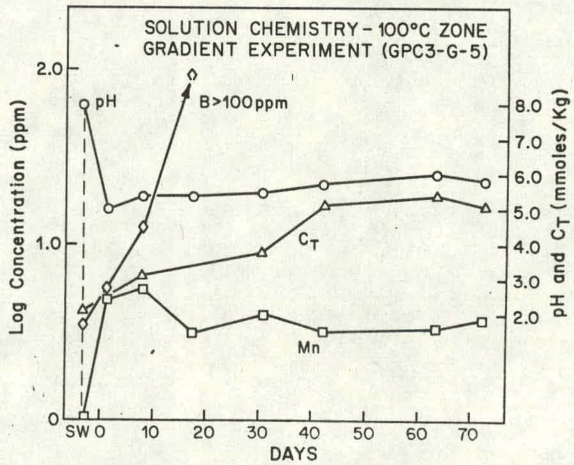
Mg-Saponite
K-Sap.
Mg-beidellite
Microcline
Kaolinite
K-beidellite
Log aMg++/a2H+
Log aK+/aH+
Mg-Saponite
Mg-beidellite
Ca-beidellite
Wairakite
Kaol.
Log aMg++/a2H+
Log aCa++/a2H+

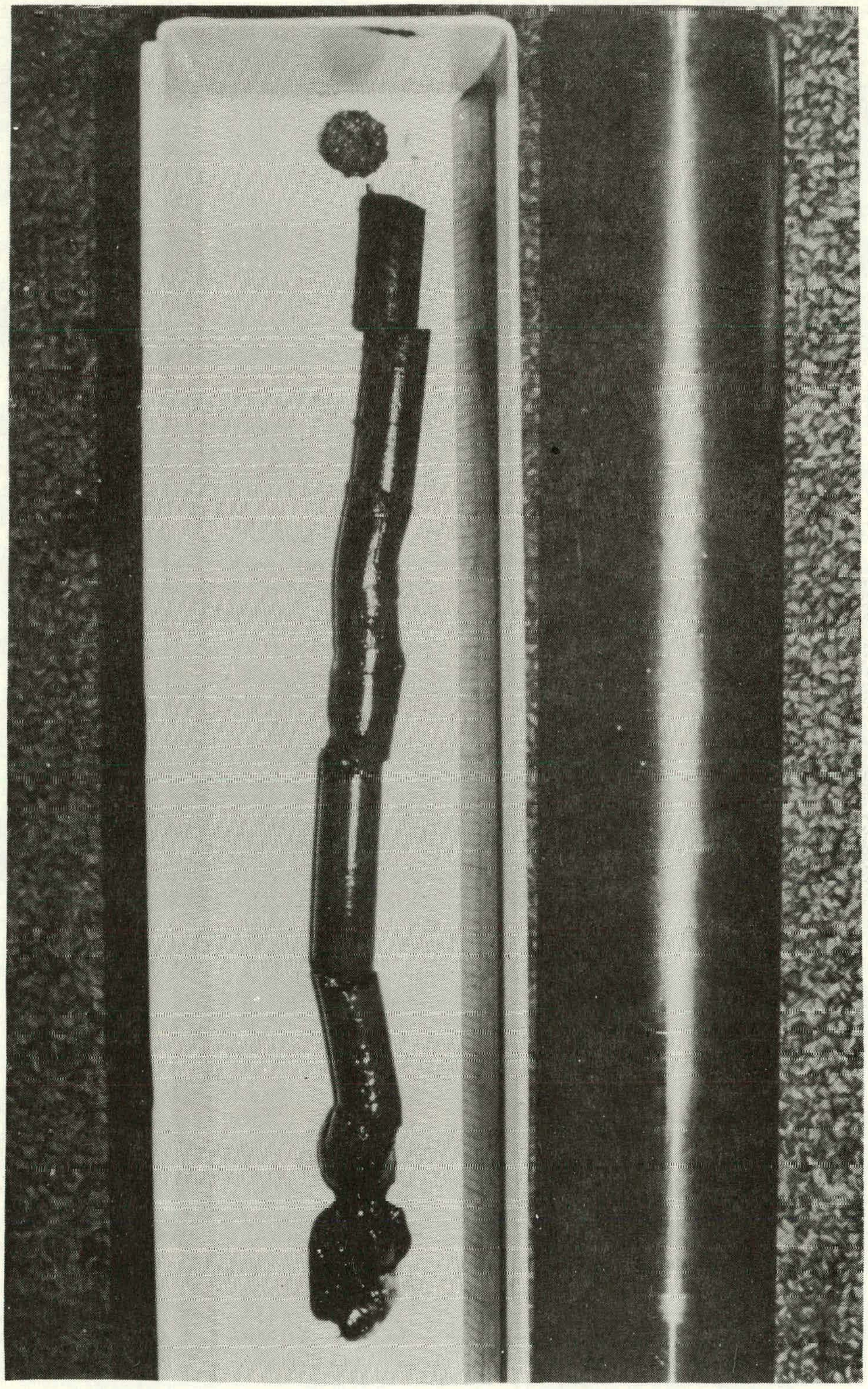


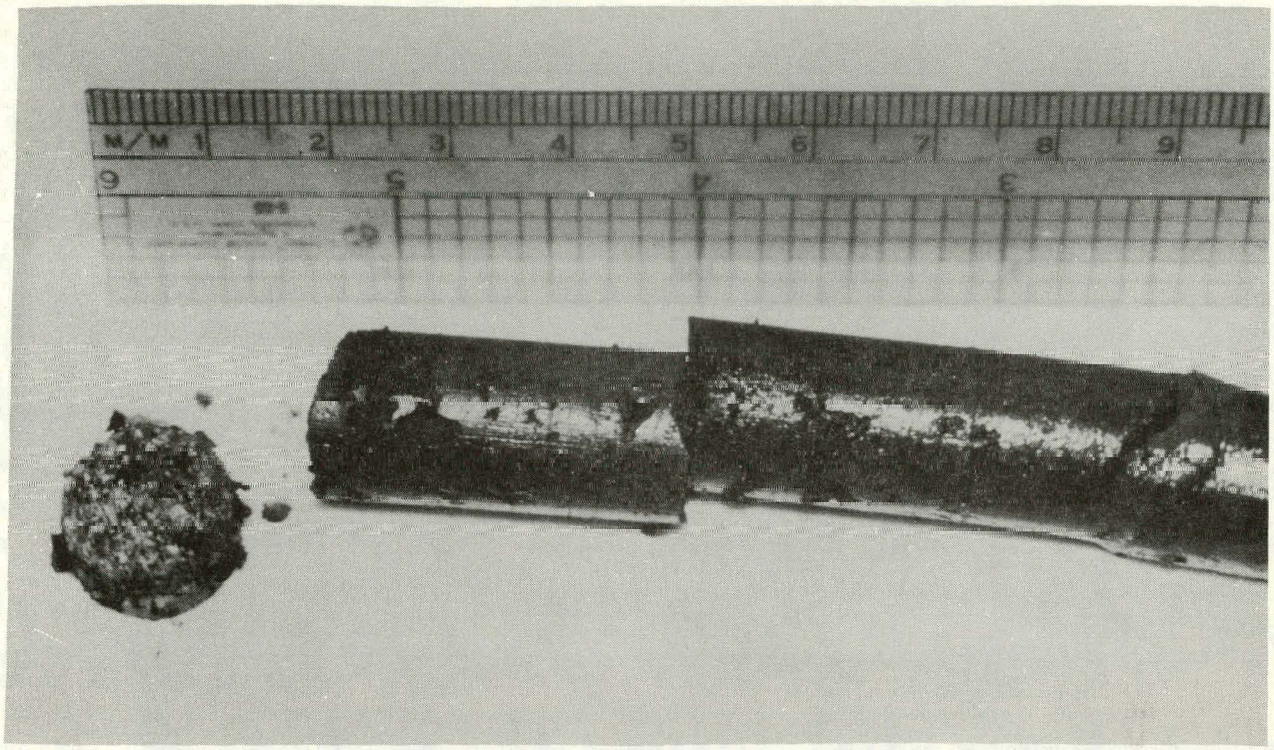
SM3 SEDIMENT - SEAWATER: 300 °C, 500 bars
-UNREACTED
-REACTED
RELATIVE ABUNDANCE
Smectite
Feldspar
Quartz
Illite
Chlorite
Clinoptilolite
Anhydrite

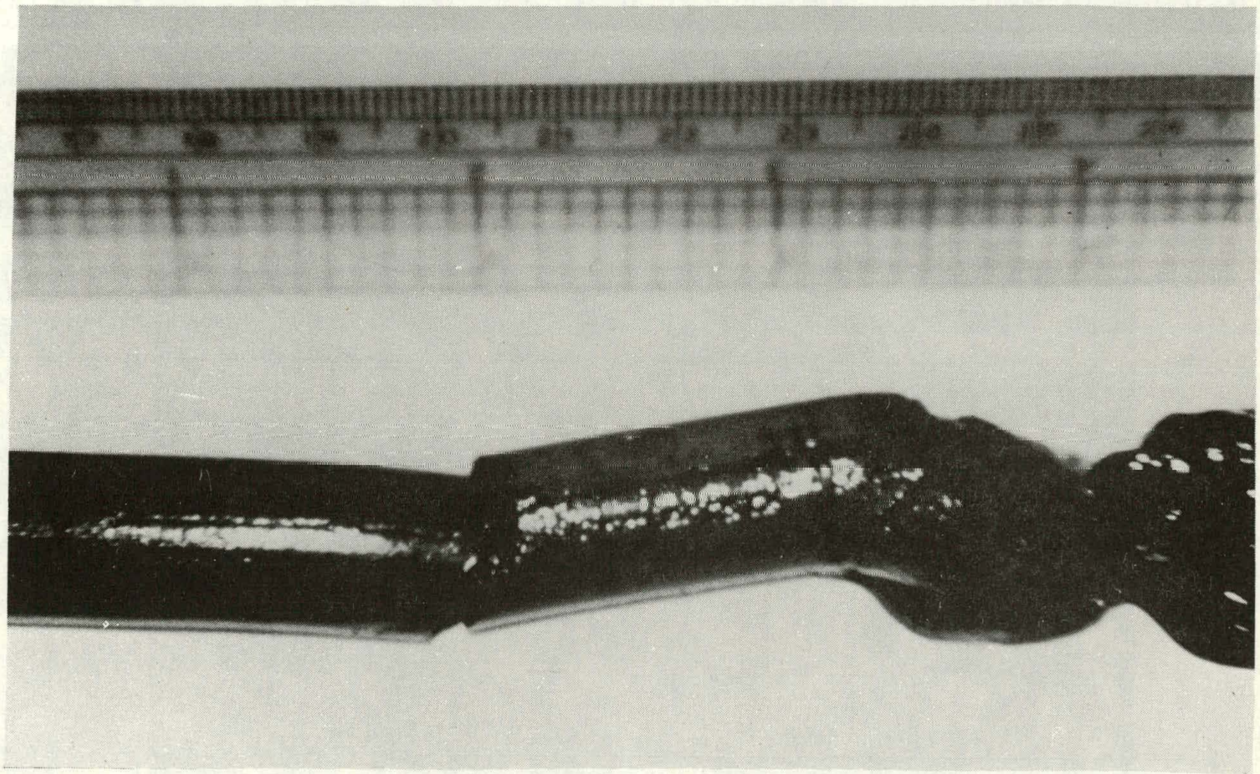

Exit Tube
Capnut
Multiprobe Thermocouple Assembly
10 cm

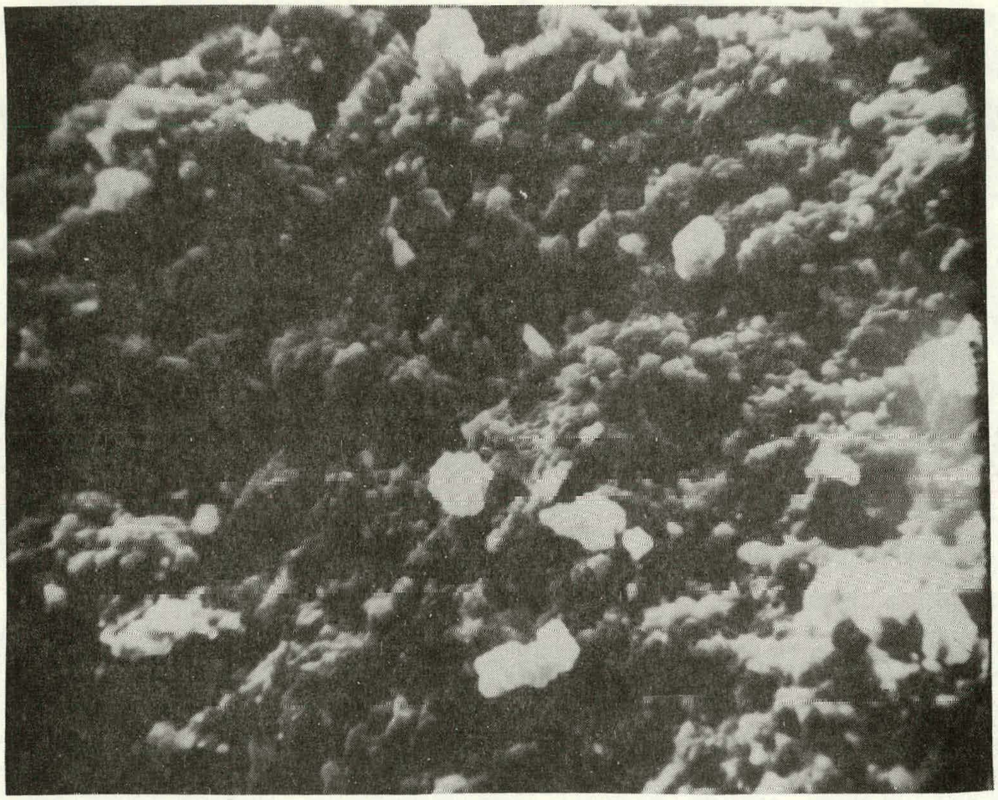

SOLUTION CHEMISTRY - 100°C ZONE
GRADIENT EXPERIMENT (GPC3-G-5)
ΔM, mmoles/Kg
Days
K+
SiO2
Ca++
Mg++

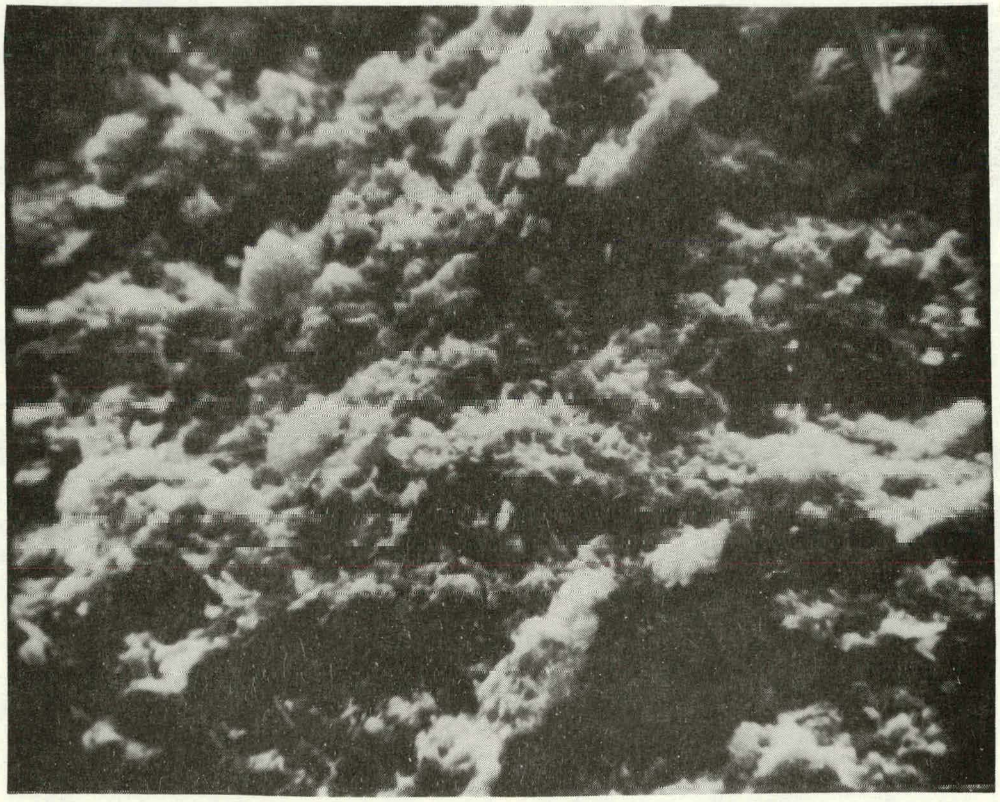

SOLUTION CHEMISTRY - 100°C ZONE
GRADIENT EXPERIMENT (GPC3-G-5)
Log Concentration (ppm)
pH and CT (mmoles/Kg)
pH
B>100ppm
CT
Mn
DAYS
SW

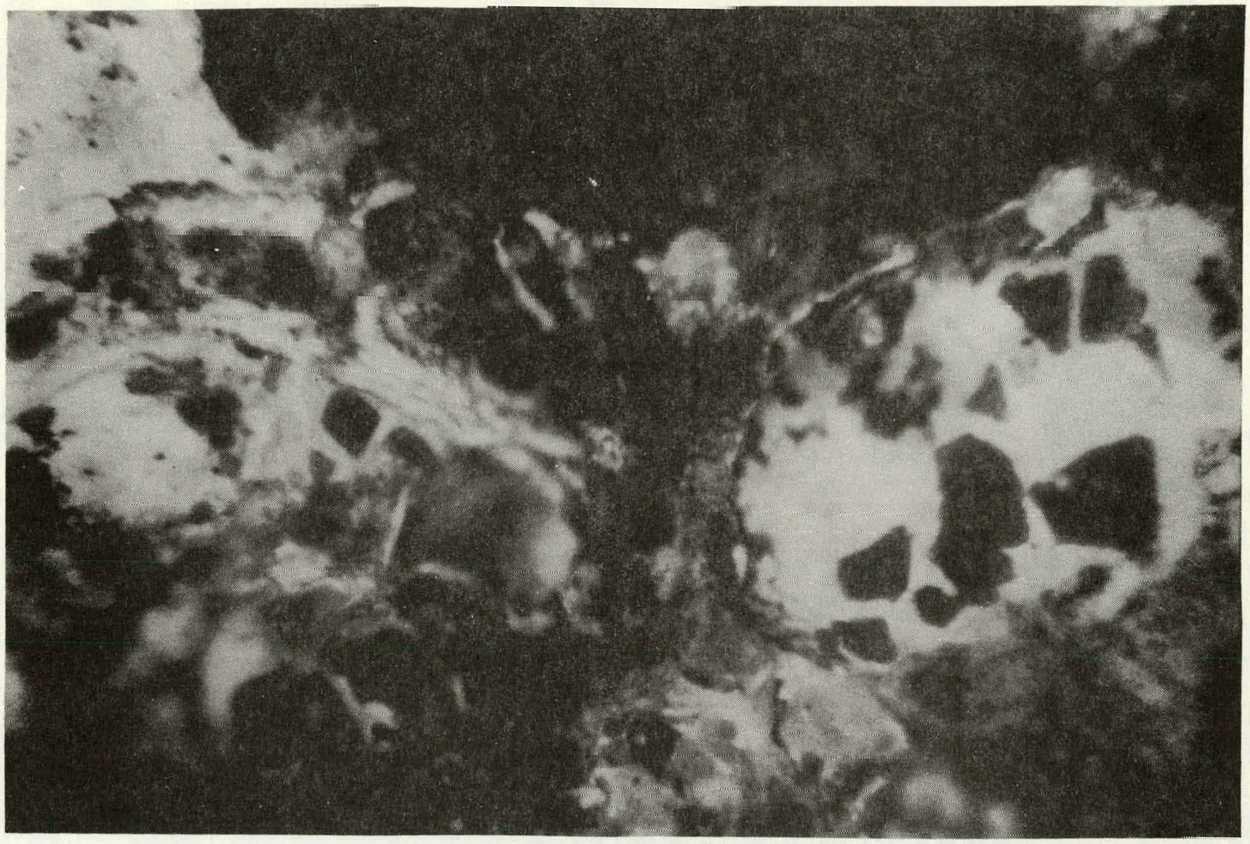


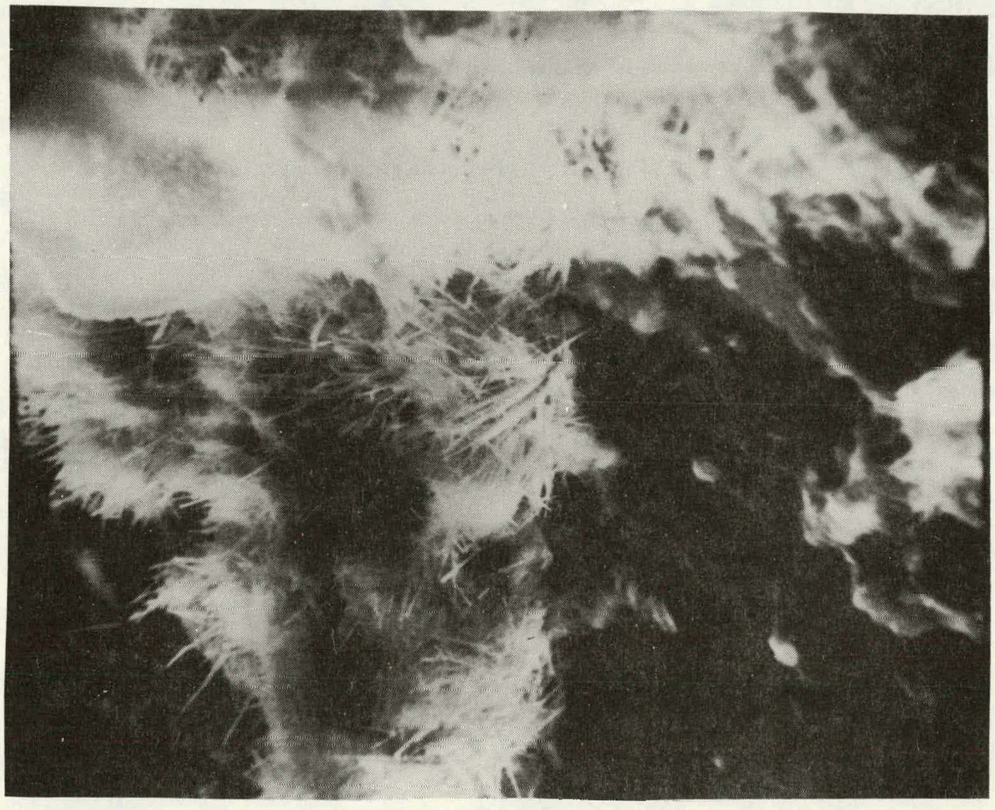












SYNPOSIS OF FY81 ACTIVITIES

J. L. Krumhansl (Sandia)

Over the last year activities have focused on three areas relevant to predicting the response of the near-field environment. The first task undertaken was the improvement of the thermochemical data base used in modeling sediment-seawater interactions. A Dickson Hydrothermal Apparatus has been brought on line and procedures have been established for characterizing solid run products. The second area of investigation concerns the effects of gamma radiation on sediment-seawater mixtures. Dry samples have been submitted for irradiation to assess whether significant structural damage occurs to the clay lattices in such an environment. A method has also been devised that employs small TiCode sample containers for irradiating solutions and recovering gaseous radiolysis products. A third area of experimentation concerns the possible uranium phases which may form in a hydrothermal marine environment. To date a variety of well crystallized phases have been synthesized at 250°C. A partial indexing of the x-ray diffraction patterns generated by these materials indicates that with increasing solution pH there is a tendency for the Na/U ratio in some of the precipitated phases to increase.

URANIUM PHASE STUDY

(J. L. KRUMHANSL: 100-260°C)
(L. BRUSH: 25-100°C)

OBJECTIVES

1) DEFINE PHASES FORMED IN THE SYSTEM: U^{+6}-SEAWATER-SEDIMENT
2) DETERMINE STABILITY FIELDS FOR VARIOUS $Na_X(UO_2)_Y(OH)_{X+2Y}$ PHASES

PROGRAMMATIC APPLICABILITY

1) URANIUM MIGRATION - PHASE PRECIPITATION COMPLEMENTS SORPTION
2) PROVIDE A MODEL FOR THE BEHAVIOR OF OTHER HEXAVALENT ACTINIDES

FY 81 ACCOMPLISHMENTS

1) PRELIMINARY RUNS COMPLETED AT 250°C IN THE SYSTEMS:
   1) H_2O - UO_3
   2) SEAWATER - UO_3
   3) UO_2Cl_2 - NaOH - NaCl - H_2O
   4) UO_2Cl_2 - NaOH - SEAWATER
2) A VARIETY OF PHASES PRECIPITATED WELL FORMED CRYSTALS - SOME OF WHICH ARE IDENTIFIABLE

ACTIVITIES - FY 82

1) IDENTIFY REMAINING PHASES
2) VARY TEMPERATURE, pH AND Na/U RATIO
3) INITIATE SOLUBILITY STUDIES?

PRELIMINARY RESULTS - 250°C, Na^+/UO_2^{++} = 12.5

0.5 M NaCl + 0.5 m NaOH + UO_2Cl_2

	Initial pH	Final pH	Phases Observed Optically	X-Ray Characterization
34	4.1	4.0	A >> B	$\alpha UO_2(OH)_2$
35	4.2	4.4	A >> B	$\alpha UO_2(OH)_2$
36	4.4	4.6	D >> B	SPIII
37	7.0	4.3	D >> B	SPIII
	Seawater + 0.5 m NaOH + UO_2Cl_2			
40	4.1	3.8	C, E >> B	SPI, II
41	4.3	4.0	E > B, C	SPI, II
42	4.5	4.2	E > B	SPI, II
43	6.8	4.4	D > F	SPIII
44	7.8	4.6	G > F	SPIII

A = $\alpha UO_2(OH)_2$ Rhombohedral Blocky Crystals, Yellow

*B = Yellow Needles

*C = Yellow Blades - Hexagonal and Rhombohedral

D = Pseudohexagonal Twinned Plates - Yellor or Orange

E = Rectangular or Square Orange Plates

*F = Yellow Blades - Dove Tailed

G = Very Fine Grained Yellow Precipitate

*May be different growth habits of the same material

RADIATION EFFECTS STUDY

OBJECTIVES

1) ASSESS EFFECTS OF γ RADIATION ON CLAY CRYSTAL CHEMISTRY
2) ASSESS NATURE OF RADIOLYSIS PRODUCTS GENERATED IN THE SYSTEM SEDIMENT-SEAWATER-TICODE 12

PROGRAMMATIC APPLICABILITY

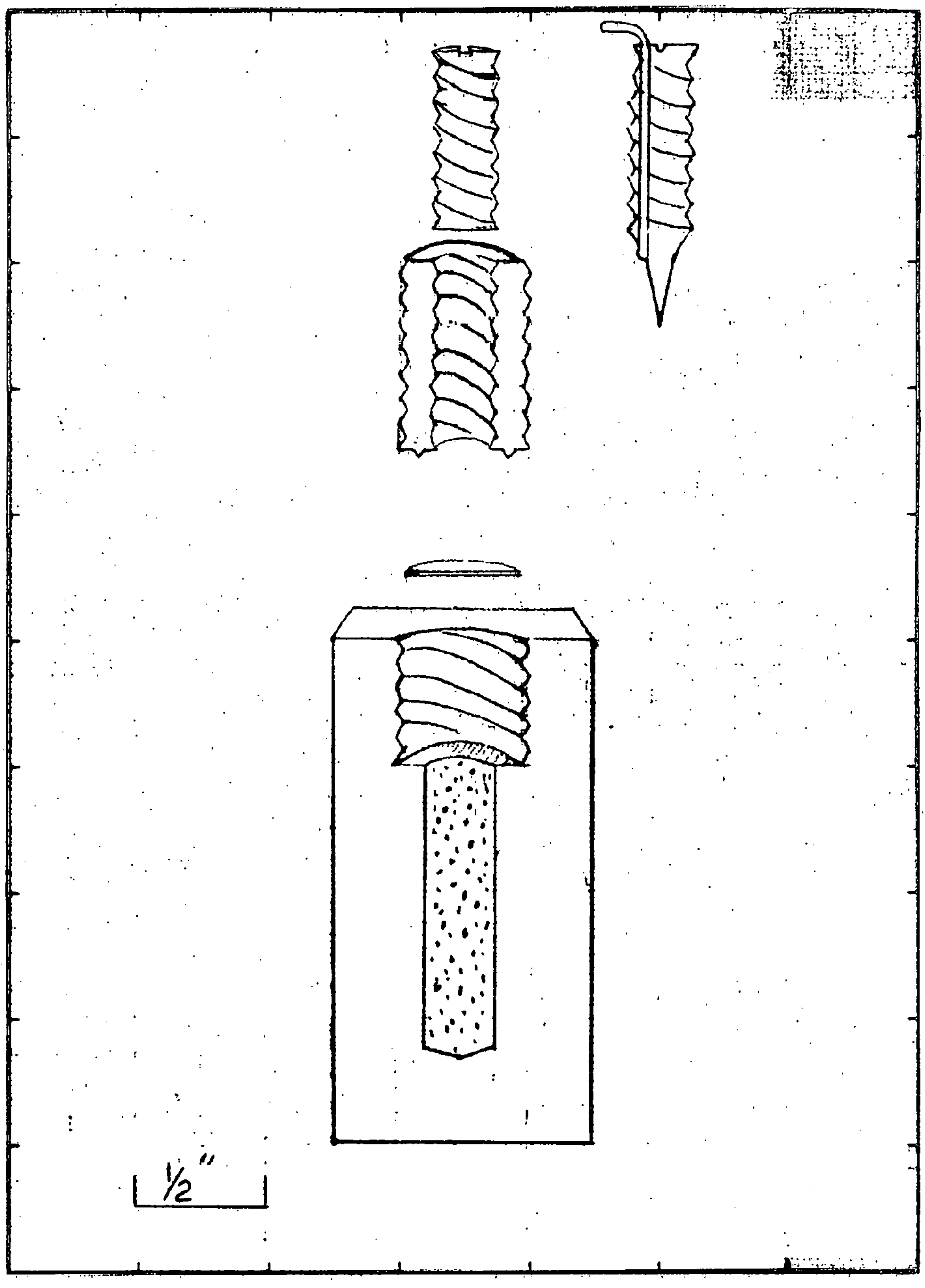
1) DETERMINE THE EXTENT RADIATION ALTERS SEAWATER-SEDIMENT (CHEMICAL) INTERACTIONS
2) METALLURGY

FY 81 ACCOMPLISHMENTS

1) DRY CLAY SAMPLES SUBMITTED FOR IRRADIATION
2) 1.2 CM^3 TICODE 12 VESSELS DESIGNED AND FABRICATED FOR IRRADIATION OF SOLUTIONS AND SEDIMENT-SEAWATER SLURRIES

ACTIVITIES - FY 82

1) ASSESS STRUCTURAL DAMAGE IN DRY IRRADIATED SAMPLES
2) IRRADIATE SEDIMENT-SEAWATER SLURRIES AND IDENTIFY RADIOLYSIS PRODUCTS
3) DETERMINE WHETHER THE PRESENCE OF SEDIMENTS EFFECTS RADIOLYSIS PRODUCT GENERATION



½"

SMECTITE STABILITY STUDIES

Objectives

1) Factors Effecting Rates of Solution and Precipitation of Smectite
2) Thermodynamic Data as a Function of Clay Composition

Programmatic Applicability

1) Check on the ΔG° Values Being Used to Model Clay-Water Interactions
2) Provide Kinetic Constraints for Use in Modeling Near Field Mineralogic Processes

FY 81 Accomplishments

1) Dickson Hydrothermal Apparatus Operational (And a Second on Order)
2) Solution Analytic Equipment Delivered
3) Test Materials Purchased
4) Solid Analysis Techniques Identified
    - X-Ray Diffraction for Bulk Structure
    - TEM - Morphology
      - Crystal Structure
      - Composition

Activities FY 82

1) Bring New Equipment on Line
2) Study Montmorillonite Solubility from 200 to 300°C
3) Study Nontronite Solubility from 200 to 300°C

CALIBRATION FOR THIN FOIL E.D.S.

(RELATIVE WEIGHT PERCENT)

	MG	AL	SI	K	CA	FE
E.D.S.	3.4	25	62	1.4	1.8	6
LITERATURE (SWY-1)	4.1	23	65	1.0	2.6	4

ASSESSMENT OF EXCHANGE CAPACITY USING Cs

	AL	SI	FE	CS
E.D.S.	22	57	4.7	16
LITERATURE (SWY-1)	20	56	4.9	19

1 76.4 MEQ/100 G OR 0.57 EQ PER O_{22} $(OH)_4$ FORMULA UNIT

COMPARATIVE E.D.S. ANALYSES OF SED 2-1 (BEFORE) AND SAN-300-5 B (AFTER)

	MG	AL	SI	K	FE
SMECTITE?					
BEFORE (6 POINTS)	5 ± 3	24 ± 3	47 ± 6	7 ± 3	17 ± 5
AFTER (16 POINTS)	7 ± 3	26 ± 2	47 ± 4	9 ± 3	11 ± 4
ILLITE?					
BEFORE - 1 (3 POINTS)	N.D.	26 ± 3	45 ± 0.7	17 ± 0.5	12 ± 3
BEFORE - 2 (10 POINTS)	2 ± 1	33 ± 3	48 ± 2	11 ± 2	6 ± 3
AFTER (9 POINTS)	3 ± 2	34 ± 3	48 ± 3	10 ± 2	5 ± 3
CHLORITE?					
BEFORE (6 POINTS)	22 ± 9	21 ± 3	35 ± 5	1 ± 0.9	21 ± 10
AFTER (4 POINTS)	19 ± 2	21 ± 2	37 ± 2	2 ± 0.8	21 ± 5

THE ABOVE ANALYSES ACCOUNT FOR 97% OF THE POINTS EXAMINED IN SAN-300-5 B AND 83% OF THE POINTS EXAMINED IN SED 2-1. ANALYSES ARE RELATIVE WEIGHT PERCENT

SAND81-2426A

FAR FIELD RADIONUCLIDE TRANSPORT INVESTIGATIONS*

K. L. Erickson
Sandia National Laboratories**
Albuquerque, New Mexico 87185

Studies of sorption and diffusion of radionuclides in smectite-rich red clay are providing the Subseabed Disposal Program with essential data for predicting far-field radionuclide transport. Previously, sorption equilibrium data for Rb, Cs, Sr, Ba, Cd, Ag, Ce, Pm, Eu, Gd, U, Pu, Am and Cm were reported, and concentration profiles from diffusion experiments with Na, Cs, Ba, Ce, and Eu were determined. In general, the results from the diffusion experiments were consistent with predictions based on solutions to the diffusion equation using appropriate boundary conditions and the sorption equilibrium data. However, a small fraction, usually much less than one percent, of the total amount of the nuclide used in each diffusion experiment migrated much further than predicted. The anomalies in the diffusion data for europium were considered to be of most concern and have been investigated during the past year. In particular, additional experiments were conducted to examine development of the anomalous profiles as a function of time and of the method for initially introducing the diffusing nuclide to the clay samples. Analogous experiments with other sorbents also were performed. Although a single mechanism for accelerated transport may not be appropriate for all nuclides, it appears that the anomalous europium concentration profiles represent the effects of competing chemical

* This work supported by the U. S. Department of Energy under contract DE-AC04-76-DP00789.

** A U. S. Department of Energy facility.

reactions, probably hydrolysis, which produce small amounts of transient, weakly sorbing species. It further appears that the decay times for such transient europium species are sufficiently small so that such competing reactions will have negligible impact on long-term, far-field radionuclide transport.

DIFFUSION OF NEPTUNYL(V)- AND PERTECHNETATE IONS IN MARINE SEDIMENTS*

F. SCHREINER, S. FRIED AND A. FRIEDMAN
Chemistry Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

ABSTRACT

The diffusion of the $^{235}NpO_2^+$ and $^{95m}TcO_4^-$ -ions has been measured directly in sample cylinders of two different sediments from the floor of the deep sea. In smectite-rich sediment not shielded from contact with atmospheric oxygen the following values were obtained for the effective diffusion coefficients of neptunyl- and pertechnetate-ions, respectively: $D_{eff}(NpO_2^+) = 1.5 \times 10^{-12}$ m^2s^{-1} and $D_{eff}(TcO_4^-) = 3.2 \times 10^{-10}$ m^2s^{-1}. Under anoxic conditions in sediment with known reducing properties, the pertechnetate ion appears to undergo slow reduction and the effective diffusion coefficient of the reduced species of $D_{eff}(Tc,red) = 1.1 \times 10^{14}$ m^2s^{-1} reflects a substantial decrease of the mobility of the lower-valent technetium.

INTRODUCTION

The disposal of nuclear waste in the sediment of the deep sea relies on the sediment to provide a natural barrier preventing leached radionuclides from reaching the biosphere. It is therefore essential to verify the mobility behavior of those radionuclides that represent a hazard to the environment.

A method for the direct measurement of ionic migration rates in sea-floor sediments has been reported previously along with effective diffusion coefficents for the transuranium elements plutonium and americium [1]. The same method has now been applied to determine the mobility behavior of the pertechnetate and neptunyl(V)-ions in ocean floor sediments of different origin. The experimental procedure for the determination of effective diffusion coefficients involves the following steps: First, samples of the sediments are made up in the shape of right cylinders, 12.5 mm high and 14.4 mm in diameter. At the time of sample preparation a suitable quantity of tracer nuclide is added to the top half of the cylinder and placed in intimate contact with the bottom half at a cross-sectional plane. During preparation and storage these samples are contained in polyethylene tubes and prevented from drying out by keeping them in an atmosphere of saturated vapor of sea water.

After an appropriate time span during which the radionuclide tracer has the opportunity to diffuse, the concentration profile of the tracer in the sample cylinder is measured, and an effective diffusion coefficient is determined by matching the observed concentration distribution to the expected calculated curve. In order to measure the activity as a function of cross-sectional level in the sample the sediment is rubbed off on long strips of filter paper, which are later divided into small squares 2 x 2 cm in size for assay of the activity. In the case of ^{95m}Tc the 204 keV γ-radiation was recorded with a germanium-lithium detector, while the low-energy radiation of ^{235}Np (approximately 20 keV) was measured with a silicon-lithium X-ray detector.

*Based on work performed under the auspices of the Sandia National Laboratory Program Contract Number 74-1160.

RESULTS

Technetium. Diffusion samples containing ^{95m}Tc as radionuclide tracer were made up with two different sediments, a smectite-rich red clay from MPG I and a sediment with reducing properties stemming from shallower depths. The reducing sediment was supplied by R. Heath, Oregon State University, Corvallis, Oregon. It was kept in an inert atmosphere of nitrogen throughout the experiment to avoid interference from atmospheric oxygen until the samples were processed for counting of the radioactivity.

The distribution of the technetium in the smectite-rich sediment was determined after diffusion had taken place for 4.7 hours and for 17.24 days, respectively. The sample that had been left for 17.24 days showed a uniform distribution of radioactivity throughout, showing the pertechnetate ion, which was the chemical form in which the tracer was applied to the sediment, to have a fairly high mobility. The data obtained from the short-time sample are shown in Fig. 1. In matching a calculated curve to the observed data points it is important to fit the section of low activities near the front end of the sample. The solid curve in Fig. 1 represents the expected distribution of a tracer moving with an effective diffusion coefficient of $D_{eff} = 3.0 \times 10^{-6}\ cm^2s^{-1}$.

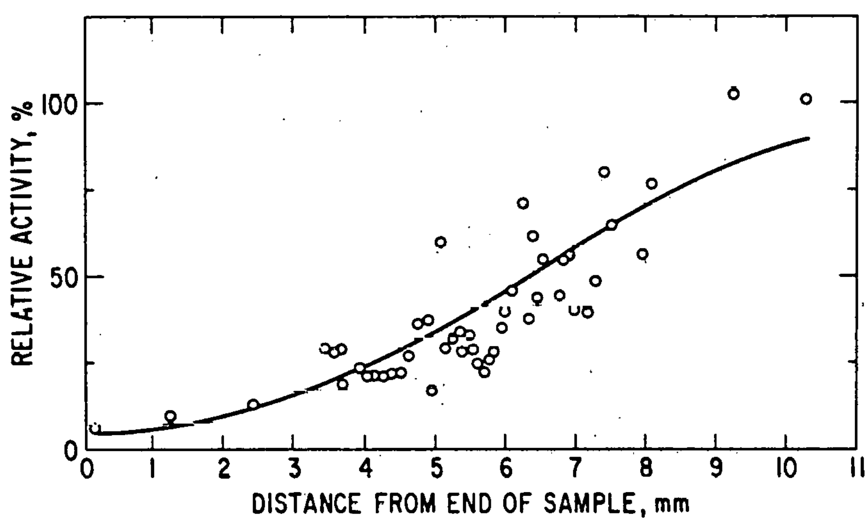


Fig. 1. Relative activity of ^{95m}Tc in smectite-rich sediment from MPG I. Diffusion time: 4.7 hours. Solid line: calculated distribution for $D{*}t = 5 \cdot 10^{-2}\ cm^2$.

In the samples made up with reducing sediment and in the absence of oxygen a more complex activity distribution is observed. Fig. 2 shows data obtained after a diffusion time of 1.12 days. The movement of the pertechnetate ion through the sediment is clearly evident from the activity near the front end of the sample. However, the data points cannot be matched by a simple diffusion curve because the transition from low to high activity in the region of the original interface between active and inactive sediment occurs at a rate which is too large to be compatible with the concentration profile in other parts of

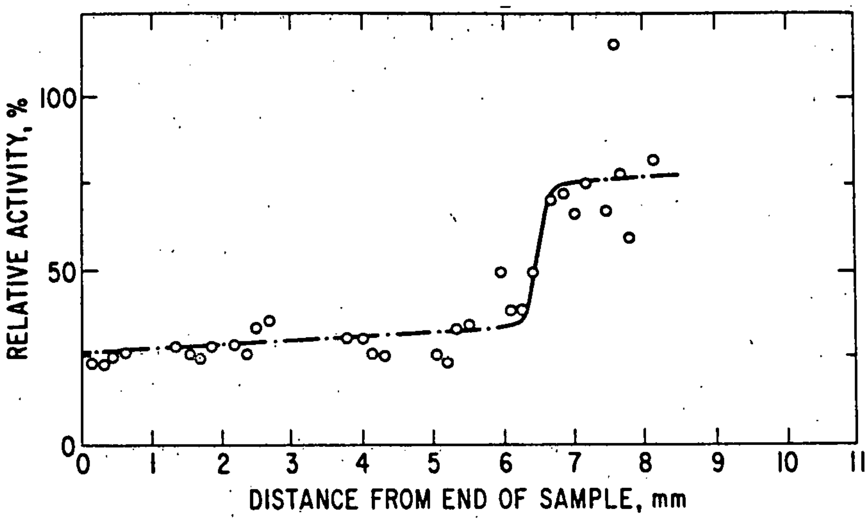


Fig. 2. Relative activity of ^{95m}Tc in oxygen-free reducing sediment, diffusion time 1.12 days.

the sample. This behavior suggests an immobilizing process in competition with diffusion. Further evidence for the immobilization of the technetium is obtained from the data shown in Fig. 3.

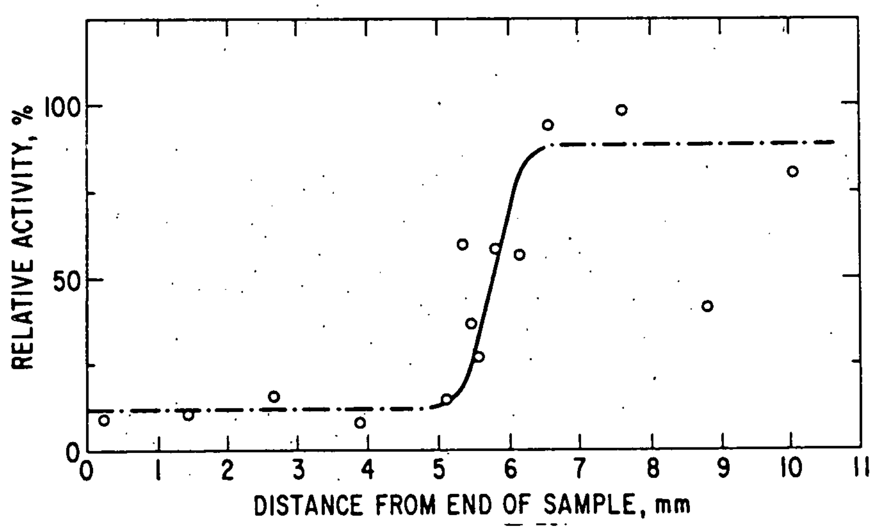


Fig. 3. Relative activity of ^{95m}Tc in oxygen-free reducing sediment; diffusion time; 65.13 days.

In a sample left for 65.1 days the bulk of the technetium is still in the upper half of the sample and only a minor fraction of the activity shows up in the lower part. The process of immobilization at work in this case is most likely the reduction of the heptavalent technetium to the tetravalent state, leading to the precipitation of insoluble technetium dioxide. This chemical reaction, however, must occur slow enough to permit a fraction of the pertechnetate to diffuse into the inactive region of the sediment.

Neptunium. As in the case of pertechnetate diffusion, samples with ^{235}Np as tracer nuclide were made up with the smectite-rich MPG I clay, and with the reducing sediment. The valence state of the neptunium when it was applied to the sediment was 5, i.e. the neptunium was present in the stock solution as NpO_2^+ ion.

While no movement of the neptunium is discernible after allowing 5.1 hours for diffusion, a longer time shows the tracer to migrate. Figure 4 represents

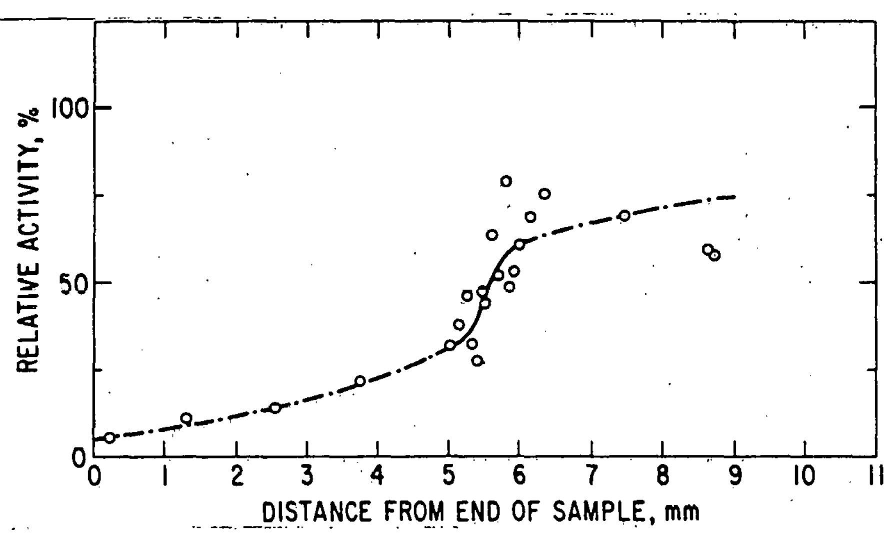


Fig. 4. Relative activity of ^{235}Np in smectite-rich sediment from MPG I; dashed sections of curve: calculated distribution for $D^*t = 6 \cdot 10^{-2}$ cm^2; solid section of curve: calculated distribution for $D^*t = 5 \times 10^{-3}$ cm^2.

data obtained from a sample of smectite-rich MPG I clay that was processed after 46.2 days. In this case, even though atmospheric oxygen is not excluded and the sediment cannot be considered a reducing type, a similar pattern of activity is obtained as for the Tc in the reducing sediment. Part of the neptunium activity is clearly evident at the front end of the sample, but the concentration curve does not have the shape expected for simple diffusion. For neptunium the tracer distribution curves look similar under non-reducing and under reducing conditions. This is evident from a comparison of Fig. 4 with Fig. 5, which shows the neptunium activity in a sample of reducing sediment in an anoxic environment. By interpreting the observed shapes of the concentration curves as being the result of the simultaneous operation and two processes, viz. diffusion and chemical immobilization, an estimate for the effective diffusion coefficient of the mobile fraction can be given. The number obtained from the data of Figs. 4 and 5 is $D_{eff}(Np) = 2 \times 10^{-8}$ cm^2s^{-1}, and is presumably characteristic for the mobility of the neptunyl(V)-ion. The process responsible for the immobilization of the neptunium has not been identified. It may be conjectured that the pentavalent neptunyl species undergoes slow reduction in the slightly alkaline medium of the sea water and forms an insoluble product, or that perhaps a strong interaction with the constituent minerals of the sediment leads to the gradual fixation of the radionuclide.

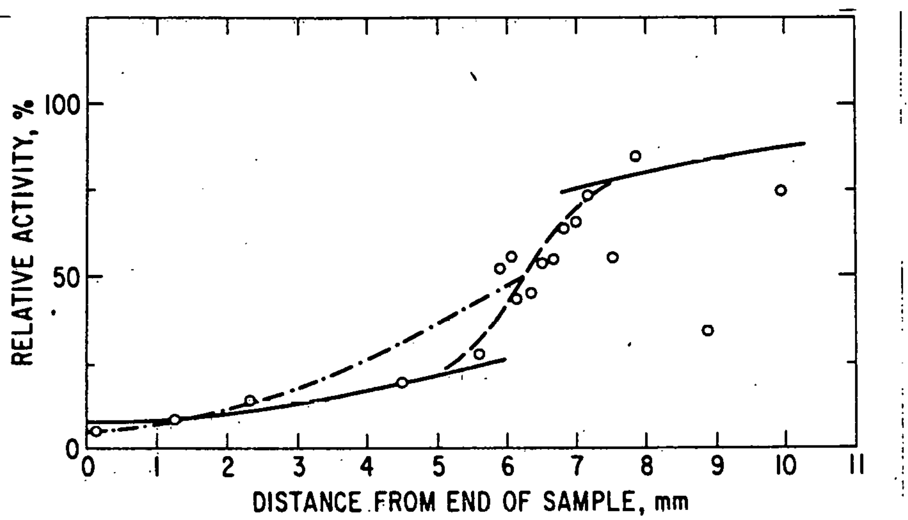


Fig. 5. Relative activity of ^{235}Np in oxygen-free reducing sediemnt; diffusion time: 50.17 days; solid line: calculated distribution for $D^{*}t = 9\cdot10^{-2}$ cm^2; dashed line: calculated distribution for $D\cdot t = 2\cdot10^{-2}$ cm^2; dashed-dotted line: calculated distribution for $D\cdot t = 6\cdot10^{-2}$ cm^2.

CONCLUSIONS

The study of the mobility of technetium in the ocean-floor sediments shows the pertechnetate ion to be sufficiently stable to permit diffusion with an effective diffusion coefficient of $D_{eff}(TcO_4^-) = 3 \times 10^{-6}$ cm^2s^{-1}. This value is of the same magnitude as the effective diffusion coefficient of highly mobile species such as Na^+ and I^-. It is consistent with the known lack of interactive retardation for anionic species. Observations in the reducing sediment indicate clearly that technetium can be effectively immobilized by chemical reduction.

The results of measurements with neptunium show this element to be substantially more mobile than the transuranium elements plutonium and americium. On the other hand, the neptunyl(V)-ion undergoes a chemical change that leads to the fixation of the radionuclide in non-reducing and in reducing sediments.

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RADIOLYTIC OXIDATION OF TECHNETIUM DIOXIDE*

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Abstract

Samples of the insoluble technetium dioxide (TcO_2) were slurried in distilled water and in seawater and allowed to oxidize under the influence of their own radiation

$$^{99}Tc \xrightarrow[0.293\ keV]{\beta^-} {}^{99}Ru.$$

Under these conditions only about 10-15% of the Tc was oxidized. When the technetium solutions were subjected to greater radiation fields by addition of ^{244}Cm the oxidation of the technetium to pertechnetate was virtually complete.

In the case of TcO_2 slurries without added radioactivity it was found that the concentration of pertechnetate ion, TcO_4^-, reached a maximum and then declined to about one-half of that maximum value.

*Work performed under the auspices of Sandia National Laboratory under contract number 74-1160.

Introduction

Design of an effective radioactive waste repository requires considerable knowledge of the solution chemistry and sorptive behavior of the radioactive species to be isolated. Many fission products and the important actinide elements exhibit multiple oxidation states in environmental media necessitating knowledge of the behavior of each of the potential terms. One aspect of the environment surrounding a repository shown to be important to the speciation of actinide elements is radiolysis of the water surrounding the repository.

In a continuation of studies of the effect of radiolysis on the speciation of important radioactive species, the present report outlines the results of a study of the radiolytic oxidation of TcO_2 by alpha radiation from ^{244}Cm. Previous results[1,2] on the effect of radiolysis on plutonium and neptunium speciation indicated that both oxidation and reduction occurred in those systems. Plutonium was stabilized primarily in the tetravalent state in distilled water and seawater, though small amounts of the higher oxidation states were also present. Neptunium was stabilized in the pentavalent state and was quite soluble in both media. In a saturated brine, both plutonium and neptunium were present primarily in the hexavalent state.

Among the long-lived fission products, technetium and iodine are of great concern, because they exist in aqueous solutions as anionic species and as such, exhibit high mobility through most rocks. In the case of technetium, the two most stable forms are Tc(IV) - (TcO_2 solid) and Tc(VII) (TcO_4^- - pertechnetate anion). In this investigation, the effect of radiolysis on a solution contacting solid TcO_2 was determined.

Experimental

A 0.15 M stock solution of NH_4TcO_4 was analyzed spectrophotometrically using spectral bands at 246 nm (ε=6220) and 289 nm (ε=2360). Technetium dioxide $TcO_2 \cdot 2H_2O$ was prepared by reduction of NH_4TcO_4 using granulated zinc and concentrated HCl[3]. Black solid $TcO_2 \cdot 2H_2O$ was washed with dilute ammonium hydroxide to remove traces of zinc then centrifuged and air dried. The quantity of $TcO_2 \cdot 2H_2O$ prepared in each of four test tubes was inferred by using measured aliquots of the stock solutions. Eight milliliters of distilled water were introduced into each of two tubes while eight milliliters of Copenhagen seawater were added to each of the other two. The amount of Tc in each test tube was calculated to be 535 μg in the case of the distilled water sample and 840 μg in the case of the seawater sample. Into one each of the distilled water and the seawater samples sufficient ^{244}Cm was introduced to give an alpha radiation dose of 1.39 x 10 d/min/ml. Each test tube was equipped with a micromagnet, sealed with a serum cap and stirred on a specially modified magnetic stirrer. The pH changes were insignificant. Periodic samples were withdrawn to allow determination of soluble technetium by radiochemical techniques. The experiments were allowed to continue for five months.

Technetium was assayed radiometrically using liquid scintillation methods. A calibration curve was prepared by making dilutions of a spectrophotometrically assayed solution of NH_4TcO_4, sampling these dilutions, and counting. The counting efficiency via this method was found to be greater than 96% in the concentration range 2×10^{-7} to 2×10^{-4} M.

In the experiments containing ^{244}Cm, the amount of activity in the periodic samples attributable to ^{244}Cm alpha particles saturated the counting system. This problem was solved by preextracting the sample with a ten-fold volume excess of 10% Aliquat 336 in toluene after first acidifying the sample with a small amount of concentrated $HClO_4$. This method gave 99% TcO_4 extracted while only 0.04% ^{244}Cm was extracted. Any extracted ^{244}Cm was at a sufficiently low concentration to allow discrimination against the high energy alpha radiation in the counting system. Aliquat 336 caused no quenching of the scintillations.

Results and Discussion

In each of the unirradiated experiments, an increase in the soluble technetium concentration (to 5.3×10^{-5} M in distilled water and 6.3×10^{-5} M in seawater) was observed in the 30-50 day interval of the experiment. After 50 days, the concentration of technetium in solution declined and leveled off at about 3.0×10^{-6} M in both media. The unexpected rise and decline in soluble technetium may be attributable to the normal solubilization of TcO_2 (with some radiation-induced oxidation to TcO_4^- included) to an equilibrium level, followed by co-precipitation with silica leached from the glass vessel by radiolysis products of water.

The addition of ^{244}Cm has a dramatic effect on the speciation of technetium. At equilibrium, technetium was found completely oxidized to TcO_4^- and achieved the molarity calculated from the amount of solid TcO_2. As shown in

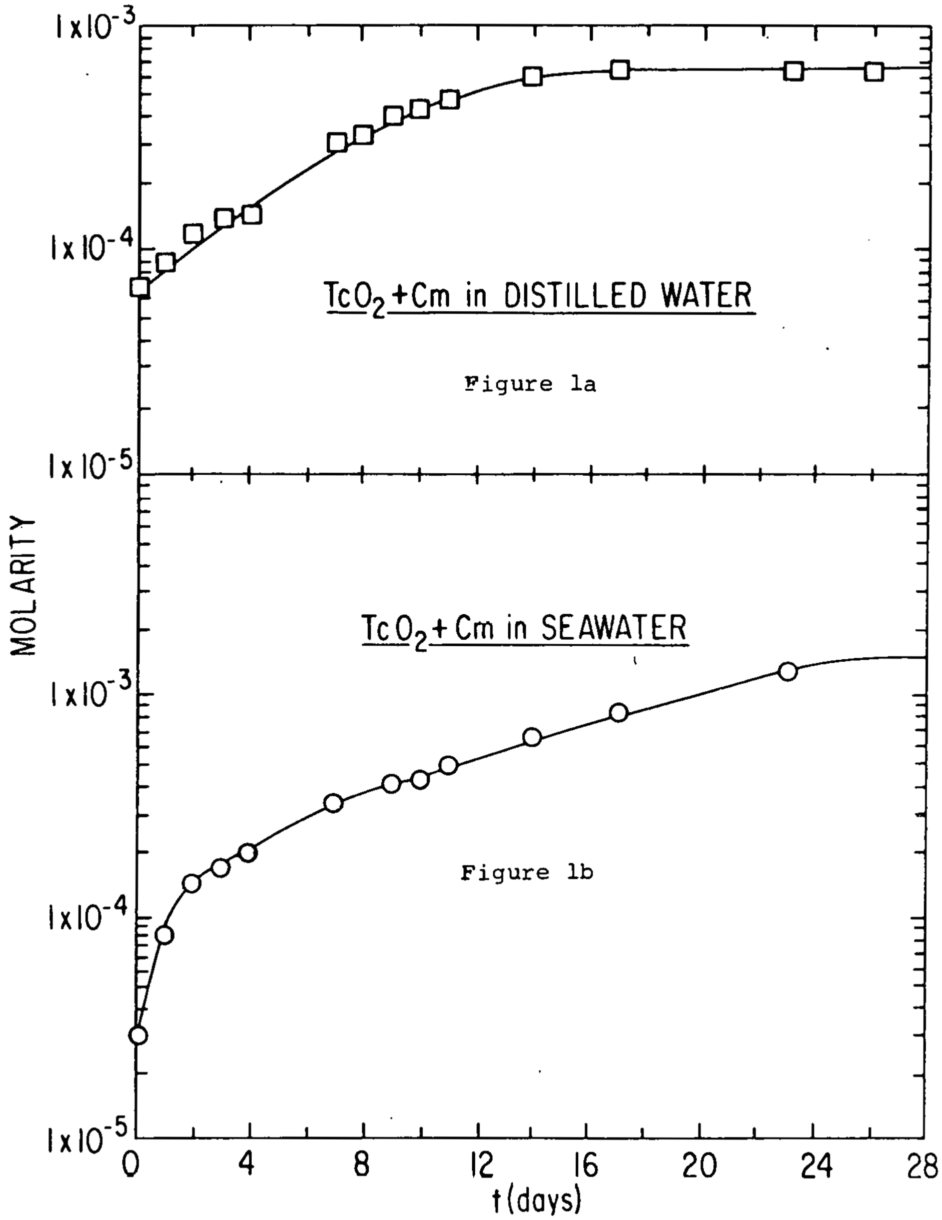

Figure Captions

Figure 1a. First order plot of technetium solubilized by alpha radiolysis of $TcO_{2(s)}$ in distilled water (pH = 6.77(±0.12)).

Figure 1b. First order plot of technetium solubilized by alpha radiolysis of $TcO_{2(s)}$ in seawater (pH = 8.27(±0.041)).

Chemical Experiments on ISHTE

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1. Introduction

Two chemical experiments are planned for incorporation on ISHTE to provide verification of laboratory data and modelling. These experiments will directly address three aspects of the behavior of sediments undergoing heating. Chemical tracers will be used to test predictions of migration rates and adsorption behavior based upon laboratory experiments. The tracers will also be used to monitor physical transport of both fluid and particles in the near-field. These experiments are based upon the deployment of tracer implantation probes in the near-field and, for control, in the far-field. To verify predictions of the chemical modification of the sediment matrix as a result of heating, two pore water sampling devices are being developed for deployment from ISHTE. Because of the extreme temperature conditions existing in the near-field and the water depth of the experiment, in situ sampling devices are essential. Pore water sampling will be done in both near-field and far-field, the latter to serve as a control.

2. Equipment Design and Development

a) Pore Water Samplers - The basic technology for pore water sampling in the deep sea has been developed over the past decade. These fundamental concepts are directly applicable to sampling from ISHTE. Development requirements are limited to activation devices and implantation cylinders. Activation is planned to utilize timers to reduce demands on the onboard computer. Preliminary design of the implantation cylinders to permit retraction after sampling is complete.

A sampling unit to meet the small scale of the ISHTE simulation experiment has been designed and built. This will be used in the November NSRDC tests. The unit will collect six pore water samples of approximately 13 ml. The sampling is spaced to cover the temperature range of 200°C to 5°C. The relationship of the sampling to predicted isotherms is indicated in Figure 1. The filter units are of monel, 0.5 μ pore size, the spacers of polysulfone and teflon.

b) Tracer Diffusion Probes - The tracer probe design is based upon utilization of the "peeper" concept to determine concentrations of species in pore water. The concept relies upon diffusion of species across a permeable membrane to equilibrate solution inside the probe with the solution of the adjacent sediment. When a series of separate chambers are cut into a single probe, a profile of composition with depth can be obtained by analysis of the solutions from the individual chambers. By adding tracers to one of the chambers, usually mid-length along the probe, the migration of tracers can be monitored in one dimension (vertically). This device has been designed and developed for use on ISHTE and for general use in the deep sea as a free vehicle to determine diffusive and advective processes in sediments.

Design of a prototype probe has been completed and several units have been built and deployed in Buzzards Bay, Mass. The salient features of the probe are summarized in Figure 2.

Originally, deployments involved addition of the tracer spike, ^{36}Cl in all experiments to date, prior to implantation. This was found to lead to a loss of spike during transit to the seafloor from the support ship, and, more serious, a small but detectable release of tracer during implantation. This affects all analyses above the source as $C \neq 0$ at $t = 0$, but has no significant effect on distributions below the source. To remedy the leakage problem a remote release has been built and incorporated into the probes. The spike of ^{36}Cl is now released to the source chamber only after the probe is implanted in the sediment.

3. Experimental Results

a) Tracer Experiments in Buzzards Bay - Analyses of samples obtained from a number of deployments of tracer probes in Buzzards Bay have been completed. Exposure times averaged about 14 days, this period being sufficient for migration of on the order of 20 cm. The objectives of the studies to date have been to investigate the behavior of the peeper probes, to develop coring techniques adequate to preserve original geometry, to develop and refine sediment sampling techniques consistent with geometric constraints, and to modify the probes and sampling as required to make possible accurate assessment of the three-dimensional distribution of tracers about a source.

In testing the validity of the peeper concept for monitoring tracer distribution it is most useful to compare the composition of solutions in the passive (as opposed to source) probe chambers with that in the adjacent sediment. Data from two experiments in which the probe was overcored at the end of the two week deployment are presented in Figure 3. The data for 05 August include two sets of sediment samples collected from different vertical sections of sediment. The concurrence of the data sets is excellent, with the exception of a single data point. The chambers actually yield concentrations that are intermediate between the two sediment values, although the differences in all cases are insignificant. A difference between chamber and adjacent sediment can be seen in the 25 September experiment; however, the differences are small and have only marginal influence upon the estimation of diffusion coefficients. This small difference appears to be linked to post-deployment movement rather than failure of the chamber equilibration concept.

A primary objective in the design of these experiments is the characterization of migration through diffusion coefficients. The data of Figure 3 portray the diffusion coefficients of the sediments into which the probes were inserted, the slope of the plots being equal to $-1/4Dt$. Diffusion coefficients calculated from the data of Figure 3 are summarized in Table 1. The values for the 05 August experiment agree within a few per cent, well within the estimated overall error. The 25 September values are only slightly more divergent, with the agreement being entirely satisfactory.

The cores were sampled to provide a series of horizontal sections (i.e., at fixed depth) down the length of the probe. This was done in order to investigate variations in diffusivity with depth below the interface. The diffusion coefficients determined for each horizon are summarized in Table 2. They are subdivided at a depth of 24 cm. This has been done somewhat arbitrarily, but reflects the fact that all calculated diffusion coefficients above 24 cm are less than those at greater depth. This is the reverse of what would generally be expected as porosity, and usually decreases with depth. A single lower diffusion coefficient is not consistent with the model as lnC is not a linear function of r^2 (Figure 4) for data collected 2 or more cm above the source. Some of the non-linearity may be due to releases of ^{36}Cl during implantation, but the generally lower values of lnC, as compared to those below the source, must reflect real variation in diffusion coefficient with depth. Experiments employing remote release of tracers, eliminating es- cape of ^{36}Cl during implantation, are under way and will help resolve the origin of the unusual behavior in the upper 20 cm of sediment.

The results give some indication of being influenced by processes beyond that of simple diffusion. Although the lower diffusion coefficients in the upper sediments would lead to an asymmetry in the inventory about the source, the maximum relative concentration should still be observed in the plane of the source. This appears not to be true (Figure 5) in one case. The maximum values of C/Co are seen to be deeper than the source in three of four sediment columns. The chamber does not show this. We believe that this has occurred as a result of "flotation" of the probe of about 2 cm during sampling as a result of the repeated shocks given the sediment during the driving of the overcore. It is noteworthy that a probe recovered from the sediment without coring does not show such an offset. Further, while the effect is quite marked for the polyethylene probe with a density of < 1.0 (data of Figure 5), it is barely detectable with a polysulfone probe with a density close to that of wet bulk sediment.

b) Stability Tests - In order to meet our objectives we must not only have the hardware, but we must also know the concentration of all tracers used in the chamber at any time. Losses of the tracers should occur only as a result of diffusion and reaction outside of the probe chambers. It is therefore essential to test the behavior of the spikes in the chamber at their working concentration. Experiments to do this have been run for some two months under three conditions: 1) an acid solution of high concentration that will be released to the chamber after attainment of a thermal steady state held at 84°C; 2) a seawater solution of (1) diluted 20-fold at room temperature and 3) solution (2) maintained at 84°C. The tracers being studied include ^{137}Cs, ^{89}Sr, ^{238}Pu, ^{241}Am, ^{155}Eu, ^{55}Fe, and ^{60}Co.

The results of the first stability tests indicate that this is the aspect of the overall experiment that will require the most attention. In the acid solution the species are stable at 84°C and can be stored for the requisite time (Figure 6). In the heated seawater, however, losses from solution of both the transition metals and europium are rapid (Figure 7). Pu and Am follow Eu. At room temperature losses are slower but are clearly underway (Figure 8). The apparent loss of Sr is believed to be spurious.

New experiments are being initiated in which the spikes are being added in different order to minimize pH effects. In addition, the solutions have been filtered (0.1 μ) to eliminate heterogenous nucleation sites insofar as possible. We do not know, presently, if these efforts will be successful. We are trying them as the simplest approach to take. Should losses still occur, then an investigation of the pH range of stability will be undertaken and the chamber buffered to meet these requirements. We prefer to avoid the latter if possible as this could produce a slight perturbation of pH in the immediate vicinity (~ 1 cm) of the source chamber in field deployments.

Table 1

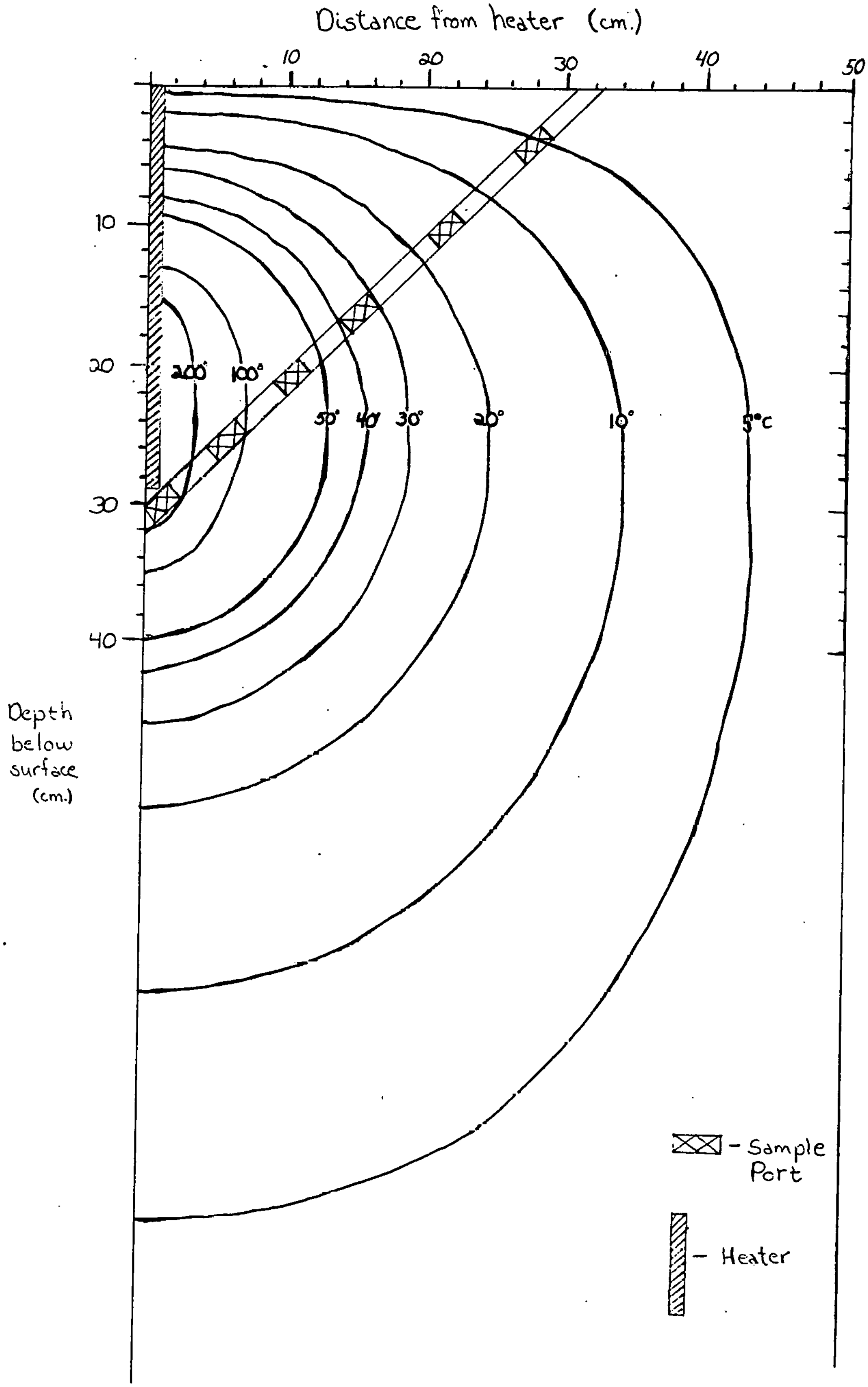
Comparison of diffusion coefficients determined from peeper chamber analyses with analyses of pore waters from sediment adjacent to the chambers. Sampling of the pore waters utilized sediment over a 2 cm interval from the probe chamber. Values in units of 10^{-6} cm^2/sec.

05 August	25 September
Probe - D = 10.7	Probe - D = 11.4
0-2 cm Section A - D = 10.5	0-2 cm - D = 12.1
0-2 cm Section B - D = 10.8	

Table 2

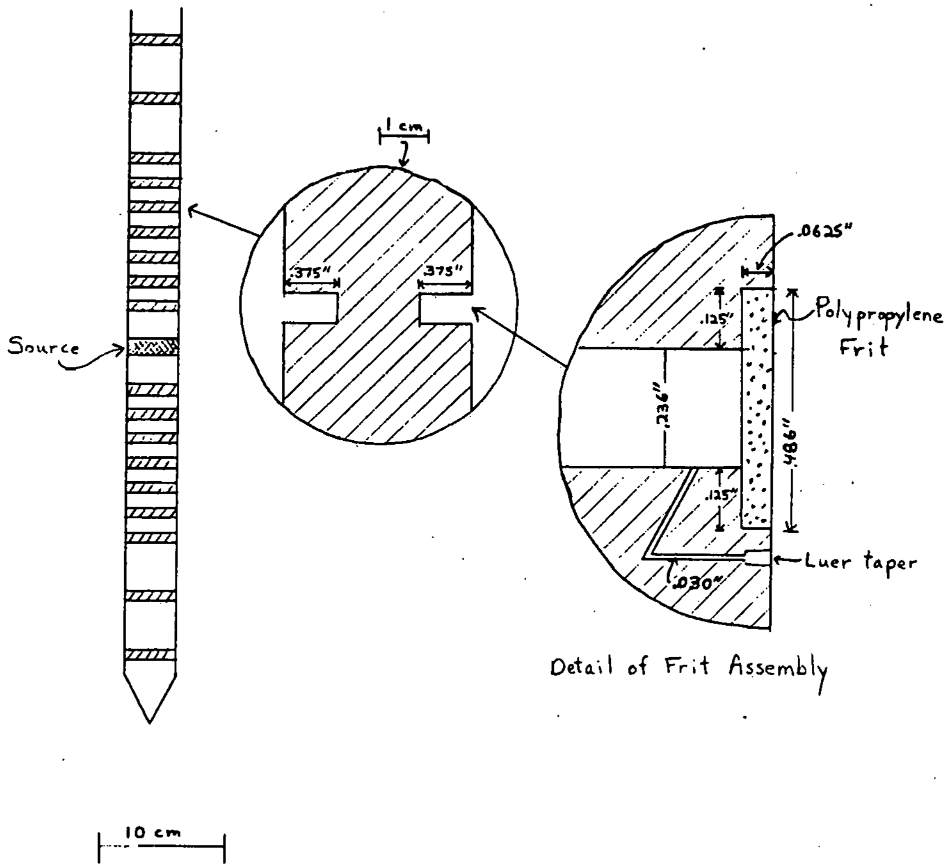
Diffusion coefficients determined in horizontal sections at various depths in the sediment below the water sediment interface. Values in units of 10^{-6} cm^2/sec.

Depth Below Interface (cm)	D (10^{-6} cm^2/sec)
7.1	7.84
11.5	6.87
15.7	5.74
19.1	7.11
20.9	7.46
22.8	8.04
Avg	7.2
24.8	9.08
27.0	10.4
30.7	8.80
35.0	11.9
Avg	10.0



Distance from heater (cm.)
10
20
30
40
50
10
20
30
40
Depth below surface (cm.)
200°
100°
50°
40°
30°
20°
10°
5°C
- Sample Port
- Heater

TRACER INJECTION PROBE



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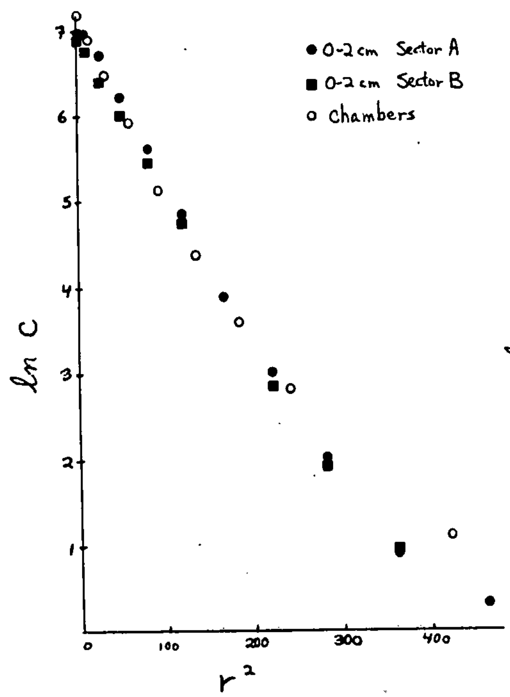

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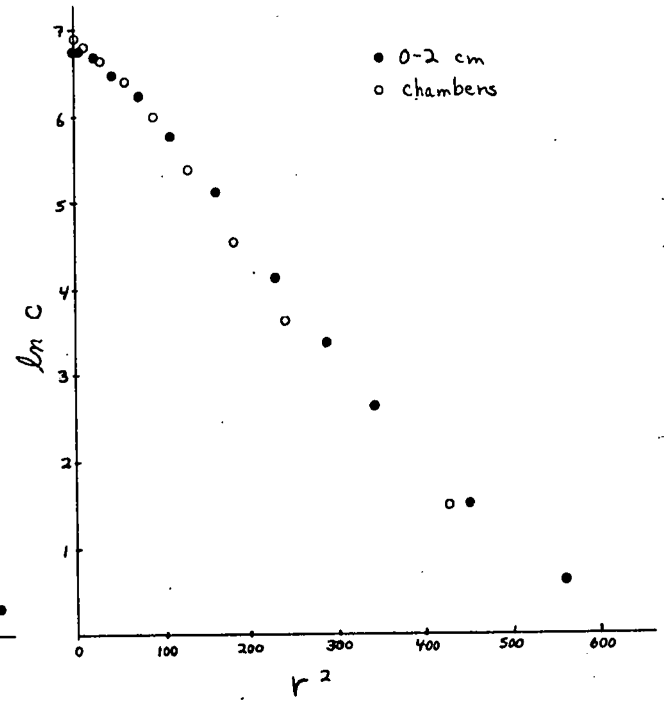

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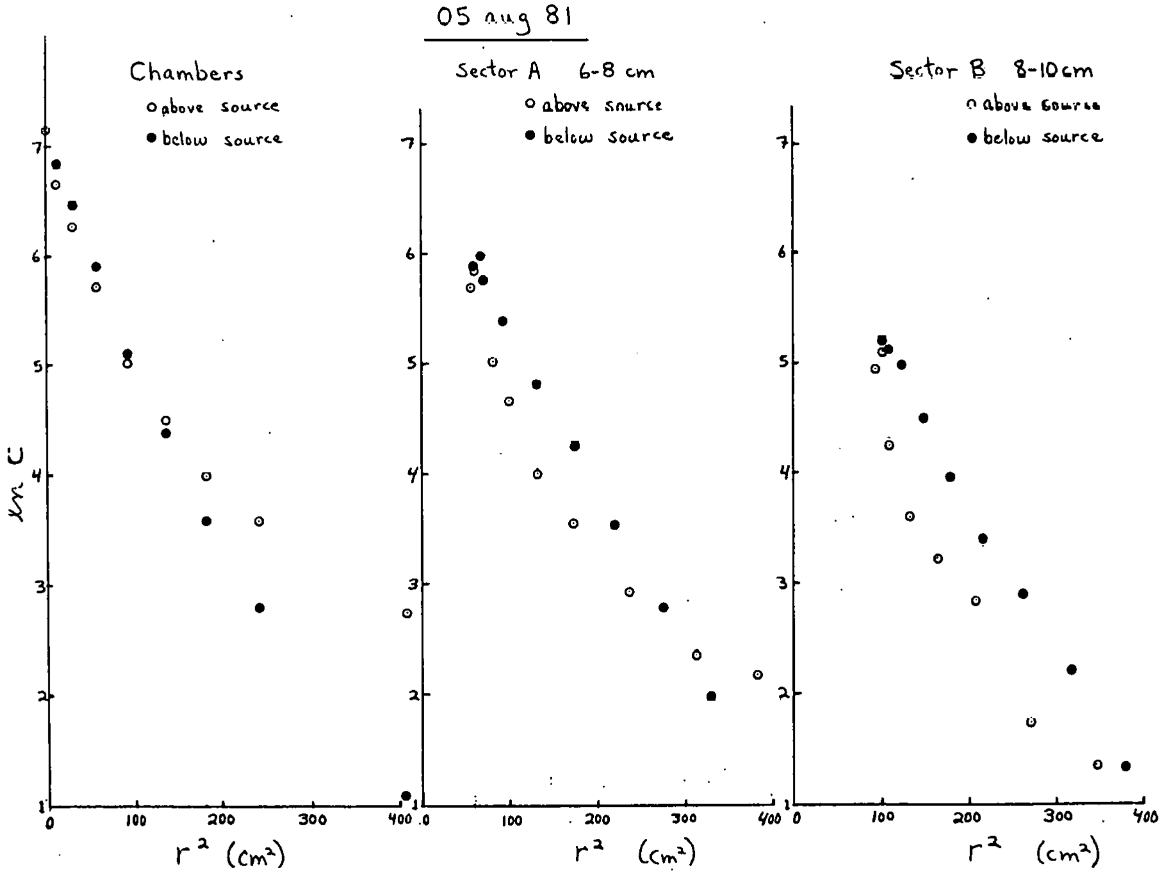

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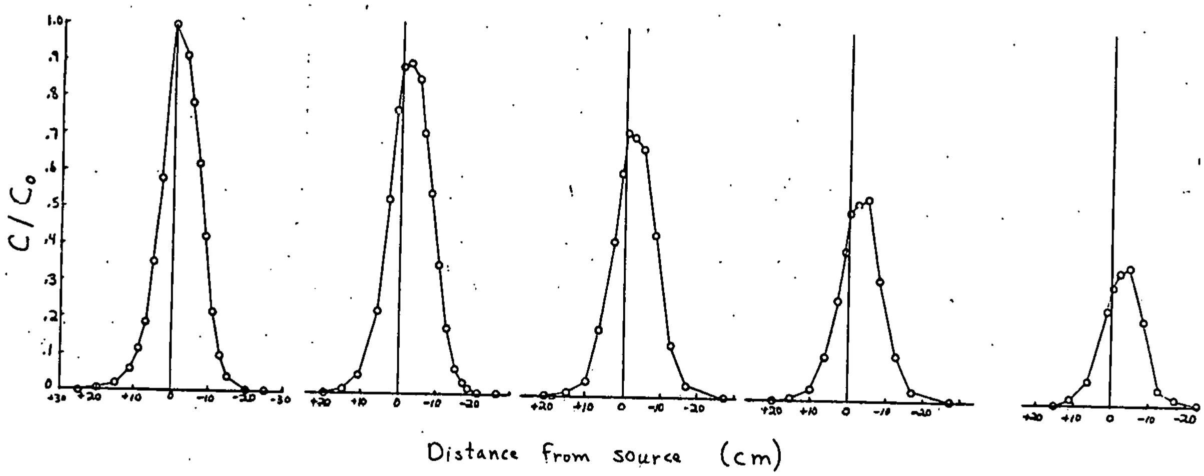
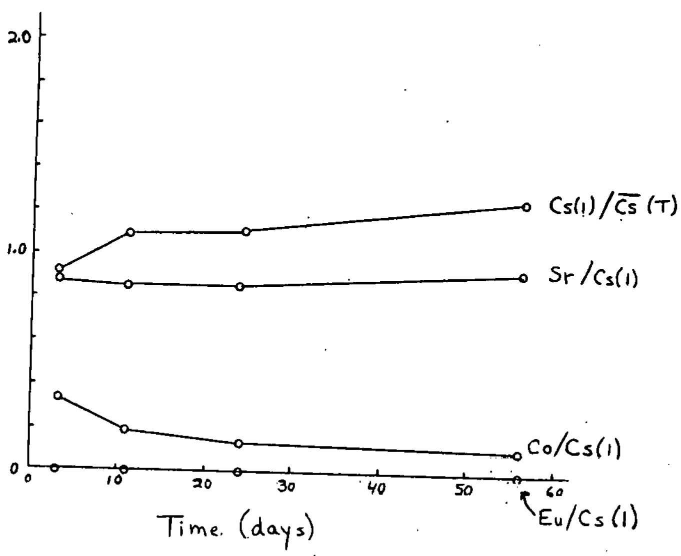
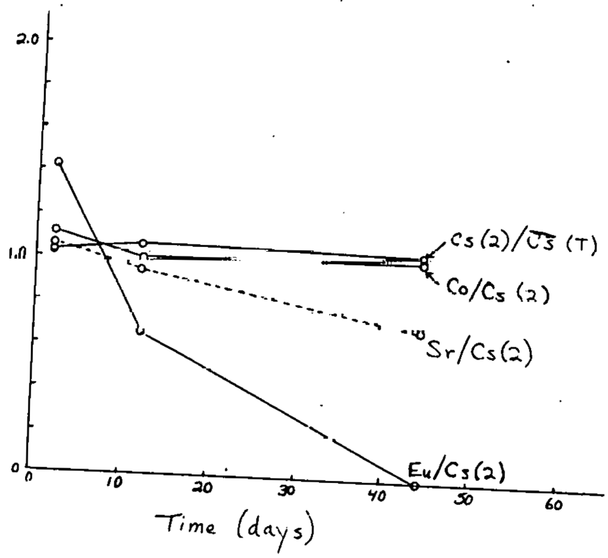


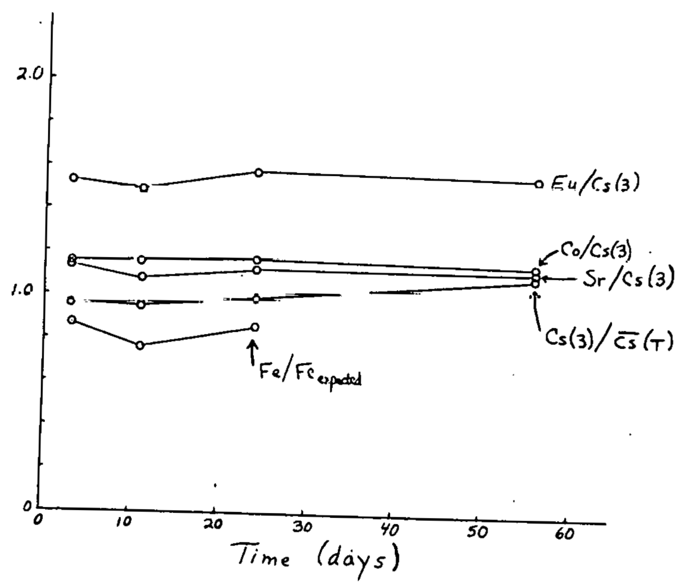
(1) Seawater 84°C



(2) Seawater 22°C



(3) Dilute Acid 84°C



IX. BIOLOGICAL OCEANOGRAPHY STUDIES

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Overview - Biological Workshop

L. S. Gomez, SNLA

Introduction

The Subseabed biology program is concerned with ecosystem transport to man as well as with effects on man and biota of radionuclides which may be released from canisters of high-level nuclear waste. We are primarily concerned with possible accident scenarios ranging from ship accidents in port to accidents in which canisters are not implanted in the deep-sea sediments.

The biology program consists of model development and biological data acquisition. Data acquisition research will be discussed during this session. M. G. Marietta will discuss biological modeling during his presentation on Environmental Studies Modeling.

Figure 1, an outline of the Multicompartmental Foodweb Transport Model illustrates areas of research being conducted by principal investigators at Scripps Institution of Oceanography. Benthic biology research being performed by R. R. Hessler's group will be discussed by Camilla Ingram. She will report on a) the characterization of various organisms found in deep-sea benthic communities, b) work on amphipod energetics studies and c) the relevance of amphipod studies to the Subseabed Disposal Program.

A. A. Yayanos will report on deep-sea biophysics research in the following areas: a) isolation of bacteria from new and old deep-sea samples and incorporation of them into the deep-sea microbial culture collection, b) reproductive rates of selected bacteria as a function of temperature and pressure, c) sensitivity of bacterial strain CNPT-3 to increased temperatures and to doses of x-rays, 4) thermal inactivition studies, e) isolation of an obligately barosphilic bacterium, and f) continuing the development of techniques to determine the standing stock of microbes in the ocean. A. A. Yayanos will also report on K. L. Smith's research over the past year dealing with measurement of metabolic activity rates of abyssal populations and communities and with sampling the abyssopelagic fauna which occupy the deep-sea benthic boundary layer. L. S. Gomez will summarize reports submitted by V. T. Bowen, Woods Hole Oceanographic Institution on fallout radionuclides and bioavailability. Kirk Smith from the East-West Center in Hololulu, Hawaii, will report on derivation of hazard indices for nuclear wastes. Finally, L. S. Gomez will discuss biological research recommendations for the Subseabed Disposal Program and outlined in the report of the Jackson Hole Workshop. The title and contents of the report are shown in Figure 2.

An international group of approximately 50 oceanographic scientists met at Jackson Hole, Wyoming, from 12 to 16 January, 1981, under the sponsorhip of Sandia National Laboratories (SNL) to consider the biological and related chemical research which will be needed to assess the potential hazards of disposl of high-level radioactive waste (i.e. waste with radioactivity concentrations of hundreds of thousands of curies per liter in the form of vitrified solid encased in metallic canisters and implanted several tens of meters into the sediment of the abyssal (>4 km depth) sea bed).

The steering committee for this workshop consisted of Michael Mullin (chairman) (Scripps Institution of Oceanography), William Pearcy (Oregon State), C. Ross Heath (Oregon State), Peter Jumars (University of Washington), Vaughan Bowen (Woods Hole Oceanographic Institution, and Leo Gomez (SNL). Of this committee, V. Bowen and G. R. Heath receive financial support for research from SNL. The majority of the invitees receive no salary or research support from SNL. Several SNL employees and contractors and graduate students at Scripps Institution of Oceanography, served as reporters of the proceedings as well as contributing to the discussions, and SNL program managers were available for consultation. Also attending, as observers, were four scientists from Bettis Atomic Power Laboratory, one from the U. S. Environmental Protection Agency, one from Interstate Electronics Corporation, and one from Marine Ecological Consultants.

The first day of the meeting was devoted to providing background information on the U. S. Subseabed Disposal Program (SDP). D. R. Anderson presented an overview and discussion of the program's current status; M. Marietta described the development of models for predicting dispersal of radioisotopes in the sea; and A. Yayanos discussed the current state of biological research in the program. Also, J. Rider outlined plans for seabed disposal of the reactorless hulls of nuclear submarines.

A series of plenary talks was then given in order to bring the diverse participants in the meeting to a common level of understanding in several areas of science. The topics reviewed were distribution patterns of deep-water organisms (R. Hessler); transfer between benthic (the bottom) and pelagic (the water column) regions (B. Hargrave); the turnover and physical/chemical modification of sediments by organisms (R. Aller); and radioecology, radiation effects, and concentration of radioisotopes in marine organisms (S. Fowler). Abstracts of the plenary talks are presented in Section III of the report.

Thereafter, the work of the meeting was conducted by four subgroups, each led by a previously designated chairman, dealing with radioecology, chemical and microbial processes, the benthic region and its organisms, and the water column. Each group attempted to identify important gaps in our understanding, and to suggest research to eliminate these gaps, bearing in mind the following possibilities, which had no probabilities assigned to them: 1) successful emplacement of canisters; 2) correct emplacement but premature release of material due to breaching or unanticipated corrosion and leaching; 3) emplacement at depth but incomplete closure of the penetration hole; 4) canisters, either intact or breached, lying on or near the surface of the abyssal seabed but not necessarily at the disposal site; 5) canisters, either intact or breached, lying on the bottom in shallow water (continental shelf or slope, seamount, etc.) due to accident during transport.

The marine environment which the conference considered consists, in simplest terms, of abyssal sediments (to a depth of 50 m below the ocean floor) and the interstitial pore water within the sediments; the layer of water immediately above the bottom and affected strongly by it (the benthic boundary layer, several tens of meters thick); the midwater regions (3-4 km); the uppermost several hundred meters, the oceanic shelves and slopes; and the organisms in each of these regions. The primary concerns of the steering committee were 1) possible pathways and rates of movement of radioisotopes in the ocean, and 2) how organisms contribute to or control these pathways and rates. Given the orientation of the participants, the conference devoted more effort to these issues than to the related (and important) problems of the effects of subseabed disposal on the environments themselves (an "environmental impact" approach) or attempts to calculate potential doses of radiation to man (a "radiation protection" approach).

The subgroups each prepared a preliminary set of comments and recommendations which were discussed by the whole group and subsequently revised for incorporation into this report. The comments and recommendations here presented result from intensive discussion within subgroups and some suggestions from the whole group, but were not necessarily agreed upon even by all members of a subgroup. They thus represent majority opinions within subgroups, but not necessarily unanimous ones. As the subgroups worked rather independently, the format of presentations differed somewhat from group to group, but cross references to topics discussed by more than one group have been inserted. The remainder of the report consists of a list of recommendations drawn from the subgroup reports, arranged according to the environment where research is required (Section II); abstracts of the plenary talks (Section III); the reports of the subgroups themselves (Section IV); and appendices (Section V).

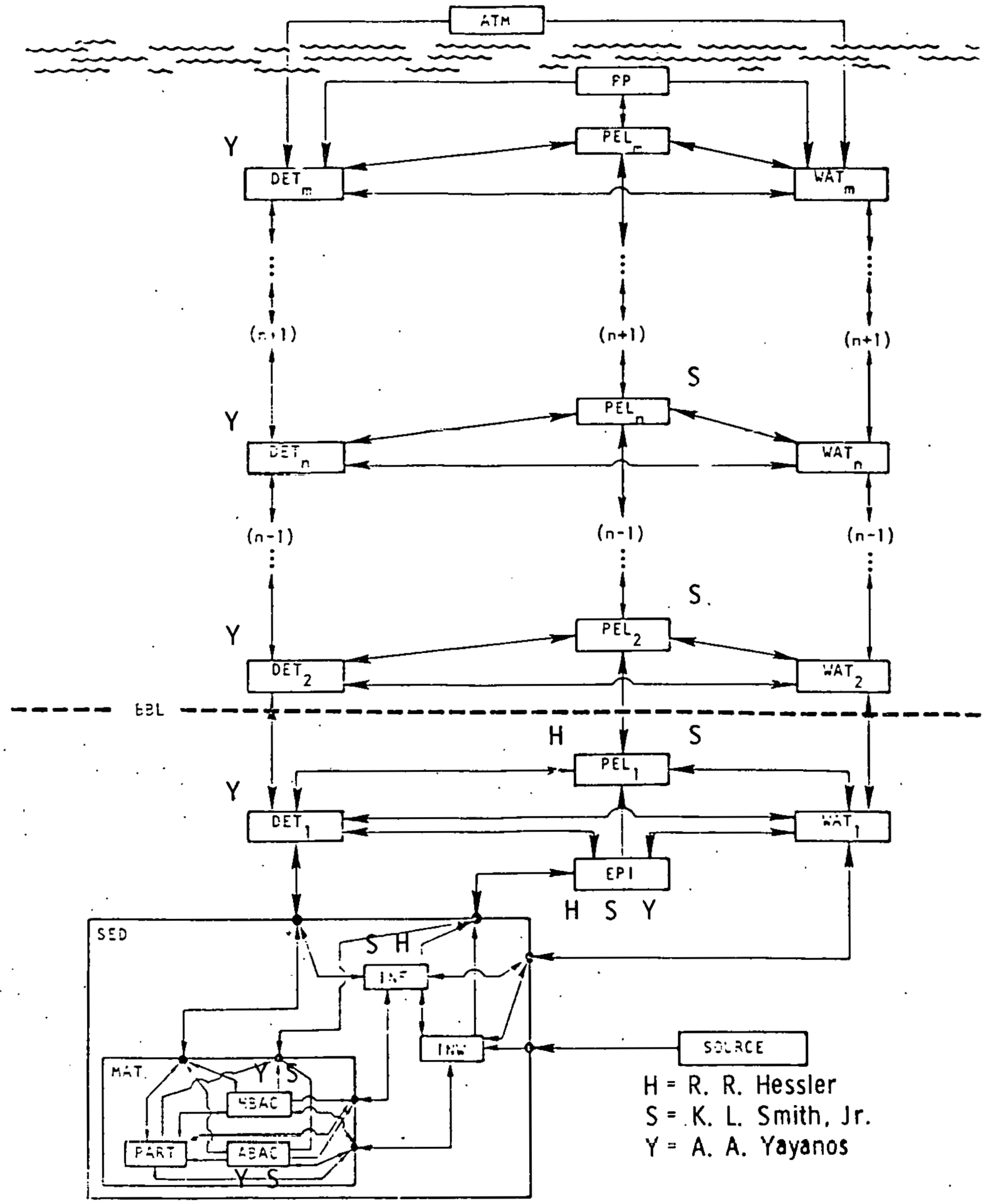

Figure 1. Multicompartmental Foodweb Model. This model represents programmatic structuring of the biological transport processes and data for future interfacing with physical dispersion models and for selected dose-to-man calculations. Areas of research by principal investigators at Scripps Institution of Oceanography are indicated by investigator's initial.

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Biological and Related Chemical Research Concerning Subseabed Disposal of High-Level Nuclear Waste: Report of a Workshop at Jackson Hole, Wyoming, January 12-16, 1981

Michael M. Mullin, Leo S. Gomez

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SUBSEABED DISPOSAL PROGRAM

ANNUAL MEETING, OCTOBER 1981

BENTHIC BIOLOGICAL STUDIES

Robert R. Hessler

As a first step in assessing the importance of the biological community for dispersal and incorporation of radionuclide wastes, it is necessary to determine the composition of the biological community, the abundances, and functional roles. The elements which compose the benthic community are listed below with a brief summary of the status of our knowledge regarding them. The nanobiota (procaryote and eucaryote organisms ~2-50 μm) have been partially characterized for types, volumn and distribution within the sediment. The meiofauna (Foraminifera and metazoans ~50-300 μm) and the macrofauna (metazoans ~300 μm - 2 cm) have been adequately characterized for taxonomic category, density, and horizontal and vertical distribution on and in the sediment. As a result of our amphipod trapping program, we have determined the species composition and many aspects of the behavior and population dynamics of this portion of the highly motile organisms. Methods for estimating amphipod density have been developed, but such determinations await future cruises.

Organisms which we know very little about and that we plan to study in the future are manganese nodule fauna, sessile or slowly motile megafauna (metazoans >2 cm), highly motile megafauna such as fish and organisms which are not scavengers, and epibenthic plankton. Each of these last groups can be investigated (at least partially) utilizing photography. A free vehicle camera system for studying time course activities of sessile and slowly motile megafauna has been developed this year. A towed fish/sled stereocamera system has been partially designed, but has been deferred due to lack of funds. Epibenthic plankton would be best studied using a near bottom, opening/closing plankton net.

In addition to determining species composition and abundance, we have sought to understand the functional rôles of the more abundant members of the deep-sea community. The amphipod energetics study was designed with this purpose in mind. This study has utilized a shallow water analog to identify physiological pathways of particular importance to radionuclide dispersal and incorporation by amphipods. Of the various experiments performed this last year, the most interesting showed that the rate at which organisms process food is dependent on the availability of additional food. This is an obvious adaptation to a sporadic food source and is likely to be a physiological behavior that deep-sea amphipods also have. Due to lack of funds this work has been terminated.

The majority of our work this past year has centered on functional roles amphipods captured at MPG-I probably have. We have been able to determine fundamental characteristics of these populations including vertical distribution patterns which correlate with physical features of the benthic boundary layer. The motile scavenging amphipods may be divided into two guilds: the demersal guild composed of the smaller species, and the pelagic guild composed of Eurythenes gryllus. These guilds have been separated on the basis of physical size, position in the water column, and their horizontal distribution patterns.

The vertical distributions of these two guilds appear to be correlated with physical features of the benthic boundary layer, specifically the Ekman layer and the rate of vertical eddy diffusion. The benthic boundary layer is defined as a mixed layer of water adjacent to the sediment, characterized by uniform salinity and temperature and bounded above by stratified water. Within the lower portion of the benthic boundary layer a turbulent Ekman layer exists which is the result of frictional drag and Coriolis forces decreasing the mean current velocity from some background velocity to zero (in theory) at the sediment water interface. Based on data from GEOSECS Sta. 212 (30°N 160°W), the benthic boundary layer at MPG-I extends to 500-550 m and has a weakly stratified upper boundary. Utilizing the formulas in Armi 1977 and a mean background current velocity of 2 $cm\ s^{-1}$, the approximate height of the Ekman layer is 4 m.

The two guilds appear to have two different feeding strategies for exploiting food falls and other nutritional sources. The demersal guild (with rare exceptions) remains within one meter of the sediment. These amphipods probably interact continuously with the sediment and are in a position to be aware of and utilize small food falls such as fecal pellets and carcasses of small fish and crustaceans.

Eurythenes gryllus, as the sole member of the pelagic guild, appears to have developed a strategy that enables them to primarily exploit large food falls. This is suggested by three factors: (1) The primary distribution of E. gryllus is 3-50 m above the sediment. (2) The density of E. gryllus doubles near the top of the Ekman layer, where the current velocity increases relative to the water below. (3) The density increases to a peak at 20 m, decreases above that, and above 50 m falls to less than one individual caught per trapping effort. This correlates with the rate of vertical eddy diffusion for MPG-I ($22 \pm 12\ cm^2 s^{-1}$). Using the formulas developed by Kupherman and Moore (1981) for calculating the vertical extent of an odor trace, 2/3 of the odor would be below 20 m after two tidal cycles (1 tidal cycle = 12.4 h). With the rate of vertical eddy diffusion found at MPG-I, organisms above 50 m would be aware only of expeptionally large food falls. This means E. gryllus above 50 m probably rely on predation to fill most of their nutritional needs.

Armi, Laurence 1977 The dynamics of the bottom boundary layer of the deep ocean. In: Bottom Turbulence, Proc. of the 8th Int. Liege Colloq. on Ocean Hydrodynamics, J.C.J. Nihoul, Editor, Elsevier Scientific Publishing Company.

Kupherman, Stuart L. and Douglas E. Moore 1981 Physical oceanographic characteristics influencing the dispersion of dissolved tracers released at the sea floor in selected deep ocean study areas. SAND80-2573

BIOLOGY OF THE CENTRAL NORTH PACIFIC

Study Areas	Status
1. Nanobiota (2-50 μm)	Partially Characterized
2. Meiofauna (50-300 μm)	Adequately Characterized for Now
3. Macrofauna (300 μm - 2 cm)	Adequately Characterized for Now
4. Manganese Nodule Fauna	Needs To Be Investigated
5. Sessile or Slowly Motile Megafauna	Needs To Be Investigated
6. Highly Motile Megafauna	Amphipod Portion Partially Characterized
7. Epibenthic Plankton	Needs To Be Investigated

Relevance of Amphipod Studies to the Subseabed Disposal Program

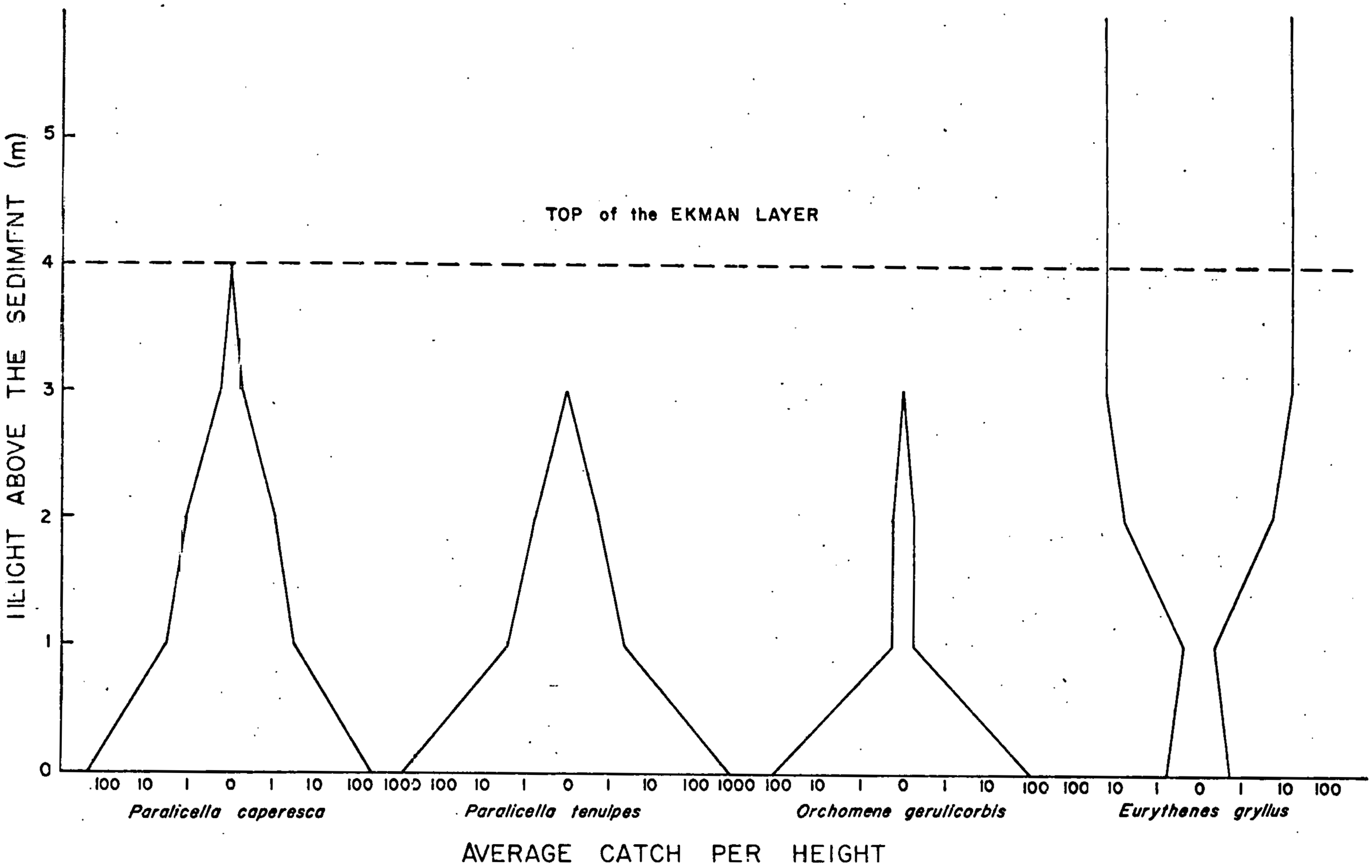
1. Dominant members of the highly motile megafauna in all deep-sea areas
2. Important source of transfer of material from sediment to the water column
3. Have the demonstrated potential of providing a direct link between the deep-sea and surface water
4. Easy to obtain and study

AMPHIPOD GUILDS

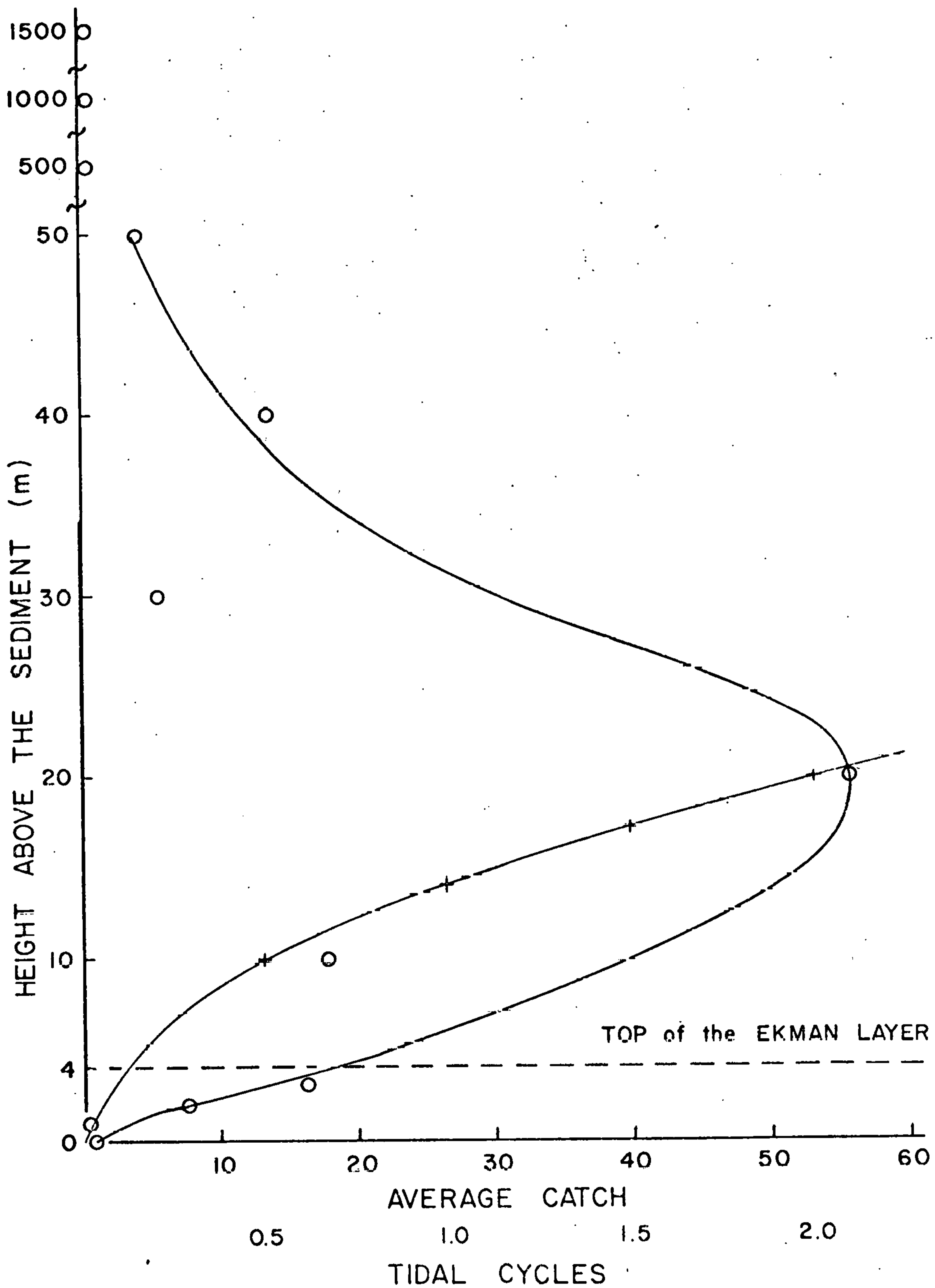
Separated on the Basis of:

1. Physical Size
2. Position in the Water Column
3. Horizontal Distribution Patterns

	DEMERSAL GUILD	PELAGIC GUILD
Species Composition	*Paralicella caperesca* *Paralicella tenuipes* *Orchomene gerulicorbis* and probably other small species	*Eurythenes gryllus*
Total Body Length	3 - 20 mm	1 - 140 mm
Primary Bathymetric Range	0 - 1 m	3 - 50 m
Total Bathymetric Range	0 - 910 m	0 - 1700 m
Probable Horizontal Distribution	Highly Aggregated	Occur as Individuals



HEIGHT ABOVE THE SEDIMENT (m)
0
1
2
3
4
5
TOP of the EKMAN LAYER
100 10 1 0 1 10 100
Paralicella caperesca
1000 100 10 1 0 1 10 100 1000
Paralicella tenuipes
100 10 1 0 1 10 100
Orchomene gerulicorbis
100 10 1 0 1 10 100
Eurythenes gryllus
AVERAGE CATCH PER HEIGHT


HEIGHT ABOVE THE SEDIMENT (m)
1500
1000
500
50
40
30
20
10
4
0
TOP of the EKMAN LAYER
10
20
30
40
50
60
AVERAGE CATCH
0.5
1.0
1.5
2.0
TIDAL CYCLES

A. A. Yayanos

ABSTRACT
DEEP-SEA BIOPHYSICS 1980-81

(1) A collection of deep-sea heterotrophic bacteria has been established and is now being maintained at deep-sea pressures and 2 C. Rigorous measures have been taken to minimize the probability of loosing the cultures due to cold room equipment failure or human error. The bacteria originate from depths between 2,000 and 10,500 m. Thus the studies of the depth dependence of bacterial function and properties can be addressed.

(2) A very detailed study has almost been completed on the depth dependence of the rate of reproduction of deep-sea heterotrophic bacteria in nutrient media under simulated deep-sea condition in the laboratory. Among the characteristics of these bacteria are: that they all prefer elevated pressures for growth; that they have a pressure for optimum growth that is less than that at their depth of origin; that the values for their generation times are between 5 and 25 hours; and, that they do not grow above 15 C at deep-sea pressures.

(3) Preparatory work has been done to determine the rates of thermal inactivation of a few selected deep-sea isolates as was done with isolate CNPT-3.

(4) An instrument has been constructed and is being used to study bacterial processes along thermal gradients at high pressures. The apparatus accomodates eight pressure vessels along the same temperature gradient.

(5) The radiosensitivity of bacteria at simulated deep-sea conditions continues to be studied when time permits. It would be premature to draw any conclusions but it does not appear that deep-sea bacteria are unusually radiosensitive.

(6) It is important to be able to determine how many bacteria there are in various parts of the water column and sediments. An epifluorescence microscope was converted into a flow fluorocytometer. This instument will allow for the detailed evaluation of the use of fluorescent dyes for detecting all bacteria, particular strains of bacteria and other microorganisms. Flow fluorocytometry is chracterized by a high data rate of about 1,000 paticles per second.

DEEP-SEA MICROBIOLOGY

IDENTIFY TYPES OF DEEP-OCEAN SAMPLES
IDENTIFY CONSTRAINTS ON SAMPLING
DESIGN AND FABRICATE SAMPLING DEVICES
BEGIN A PROGRAM OF SAMPLING THE DEEP-SEA
OBTAIN AXENIC CULTURES FROM SAMPLES
BUILD A COLLECTION OF DEEP-SEA MICROBES
LABORATORY STUDIES OF DEEP-SEA MICROBES
BEGIN MICROBIAL ECOLOGY

TYPES OF SAMPLES

WATER

SEDIMENTS

ANIMALS

RETRIEVAL CONSTRAINTS

ISOTHERMAL TRANSFER TO LABORATORY
USUALLY 2 C

MAINTAIN AT HIGH PRESSURE-ALWAYS?
AS GREAT AS 1,070 ATM

AXENIC PROCEDURES
WHEN NECESSARY?

SAMPLING DEVICES

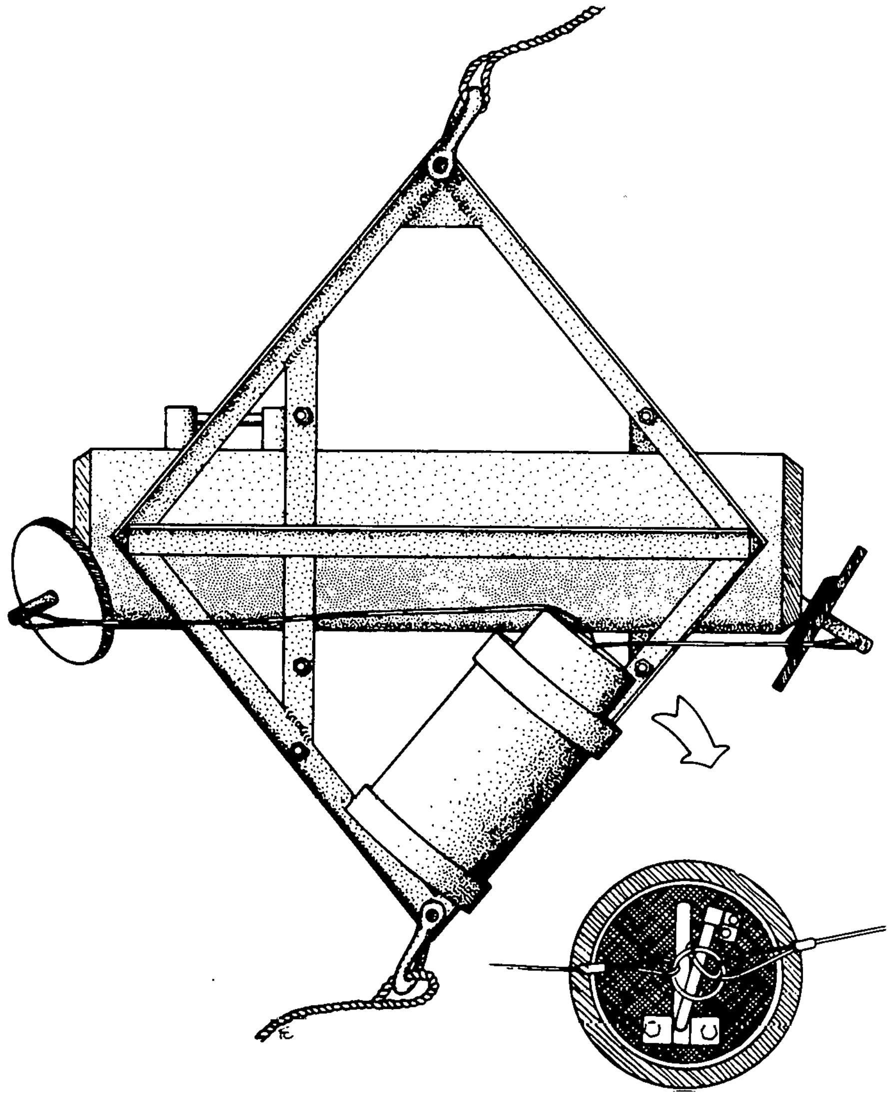
POLYVINYLCHLORIDE WATER BOTTLES

POLYVINYLCHLORIDE GRAVITY CORERS

THERMALLY INSULATED FREE VEHICLE TRAP

INSULATED PRESSURE-RETAINING ANIMAL TRAP

TIFT (Thermally Insulated Free-vehicle Trap)



SUMMARY OF TIFT DEPLOYMENTS: THERMAL HISTORY AND CATCHES

DEPLOYMENT	LOCATION		DEPTH	TEMPERATURE			CATCH
	LATITUDE-LONGITUDE	LOCALE	(METERS)	AT DEPTH	IN TIFT	SURFACE WATERS	
Aug 20, 1978	30° 9.6'N 157° 59.2'W	central North Pacific	5,821	~2 C	8.5 C	~27 C	3 amphipods
Dec 13, 1978	11° 20.5'N 142° 25.8'E	Mariana Trench	10,476	<2 C	~5.5 C	~28 C	1 amphipod
Dec 21, 1978	11° 36.2'N 142° 18.0'E	Wall of Mariana Trench	5,672	~2 C	<6	~28 C	4 amphipods
Dec 11, 1979	31° 39.0'N 119° 47.0'W	Patton Escarpment (Eastern Pacific)	3,800	~2 C	<5 C	~16 C	Water
Jan 7, 1980	32° 26.0'N 118° 7.0'W	San Clemente Basin	1,829	~2 C	<5 C	~16 C	Amphipods, benthic worm, fish (*Paraliparus melanurus*)
Feb 27, 1980	32° 26.0'N 118° 7.0'W	San Clemente Basin	1,975	~2 C	<5 C	~16 C	Water
May 22, 1980	32° 25.0'N 118° 6.0'W	San Clemente Basin	1,975	~2 C	<5 C	~16 C	Water
Jun 3, 1980	31° 53.0'N 119° 54.0'W	Patton Escarpment	3,584	~2 C	3 C	~16 C	1 amphipod
Aug 20, 1980	32° 26.0'N 118° 7.0'W	San Clemente Basin	1,957	~2 C	<5 C	~16 C	Amphipods (>500)
Nov 9, 1980	10° 29.2'N 126° 21.8'E	Wall of Philippine Trench	6,163	~2 C	5.9 C	~28 C	Amphipods
Nov 10, 1980	10° 32.6'N 126° 33.6'E	Philippine Trench	8,639	~2 C	6.7 C	~28 C	Amphipods
Nov 11, 1980	10° 28.2'N 126° 30.3'E	Wall of Philippine Trench	7,111	~2 C	8.5 C	~28 C	Amphipods
Nov 13, 1980	10° 35.2'N 126° 35.5'E	Philippine Trench	9,695	~2 C	9.5 C	~28 C	Amphipods
Nov 14, 1980	10° 34.3'N 126° 38.6'E	Philippine Trench	9,563	~2 C	6.2 C	~28 C	Amphipods
Nov 20, 1980	11° 36.0'N 142° 8.6'E	Wall of Mariana Trench	6,790	~2 C	13.2 C	~28 C	Amphipods
Nov 21, 1980	11° 17.0'N 142° 13.4'E	Mariana Trench	10,015	~2 C	5.4 C	~28 C	Amphipods
Nov 26, 1980	11° 27.1'N 142° 12.8'E	Wall of Mariana Trench	8,961	~2 C	2.6 C	~28 C	Water sample
Nov 27, 1980	11° 29.4'N 142° 11.2'E	Wall of Mariana Trench	7,981	~2 C	7.4 C	~28 C	Water sample
Nov 28, 1980	11° 29.3'N 142° 12.2'E	Wall of Mariana Trench	8,058	~2 C	4.8 C	~28 C	Amphipods
Nov 29, 1980	11° 28.1'N 142° 15.0'E	Wall of Mariana Trench	9,257	~2 C	3.5	~28 C	Amphipods
Feb 3, 1981	32° 13.0'N 118° 20.0'W	San Clemente Basin	1,829	~2 C	<5 C	~16 C	Amphipods

SITES SAMPLED TO DATE

SAN CLEMENTE BASIN-2,000 METERS

PATTON ESCARPMENT-3,800 METERS

CENTRAL NORTH PACIFIC-5,900 METERS

PHILIPPINE TRENCH-6,000 TO 10,000 METERS

MARIANA TRENCH-6,000 TO 10,700 METERS

LABORATORY PROCEDURES

KEEP SAMPLES COLD

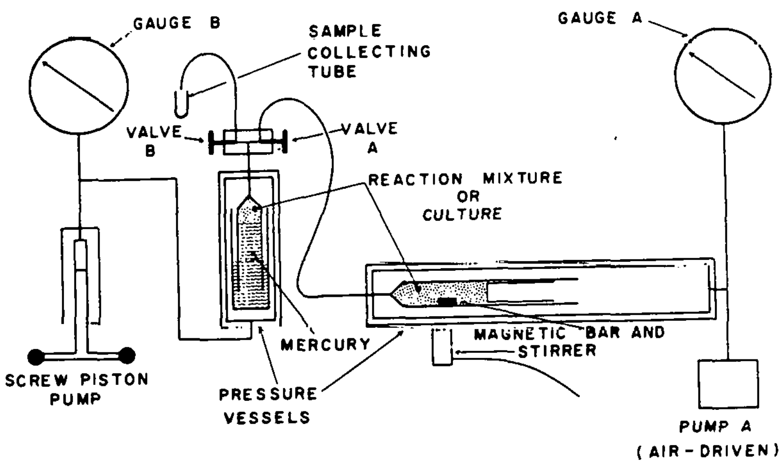
KEEP SAMPLES AT HIGH PRESSURE MOST OF THE TIME

GET AXENIC CULTURES WITH NUTRIENT MEDIA SOLIDIFIED WITH SILICA GEL

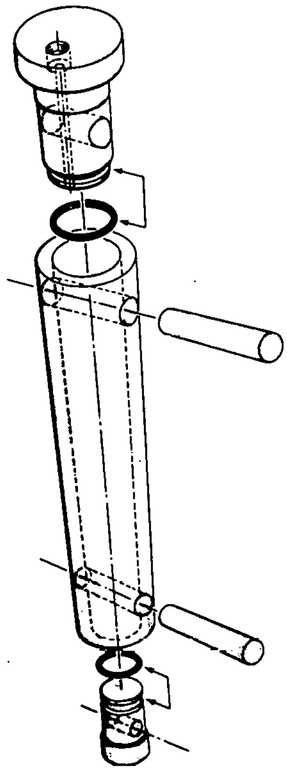
MAINTAIN CULTURES AT HIGH PRESSURE AND LOW TEMPERATURE (2 C)

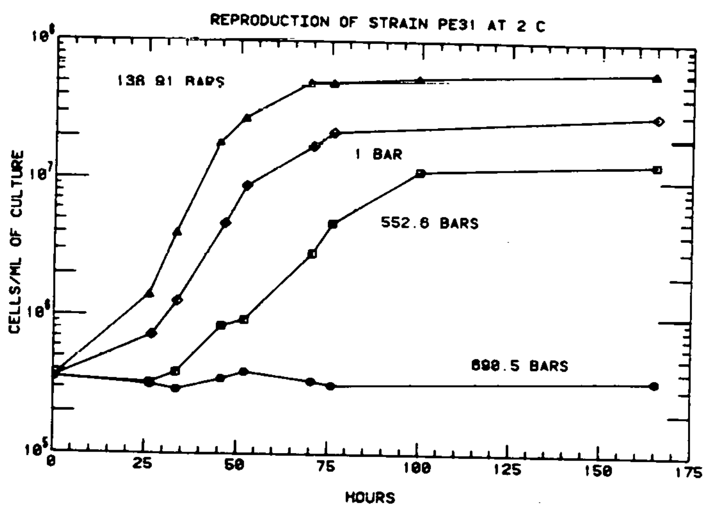
INSURE CULTURE COLLECTION IS NEVER WARMED

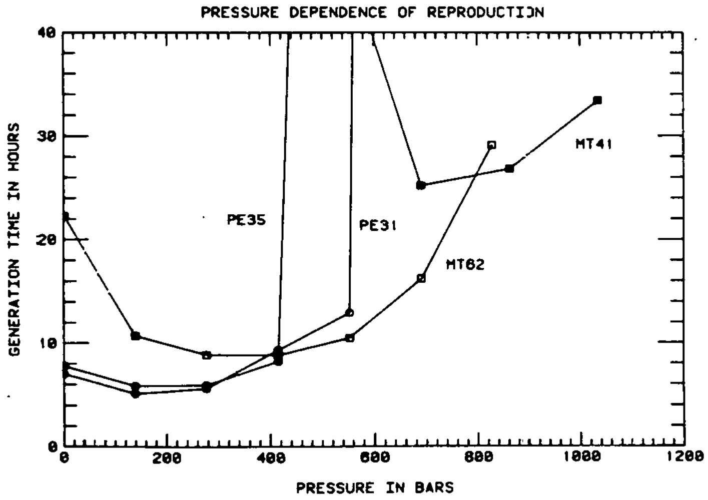
STUDY CULTURES UNDER SIMULATED DEEP-SEA CONDITIONS IN THE LABORATORY

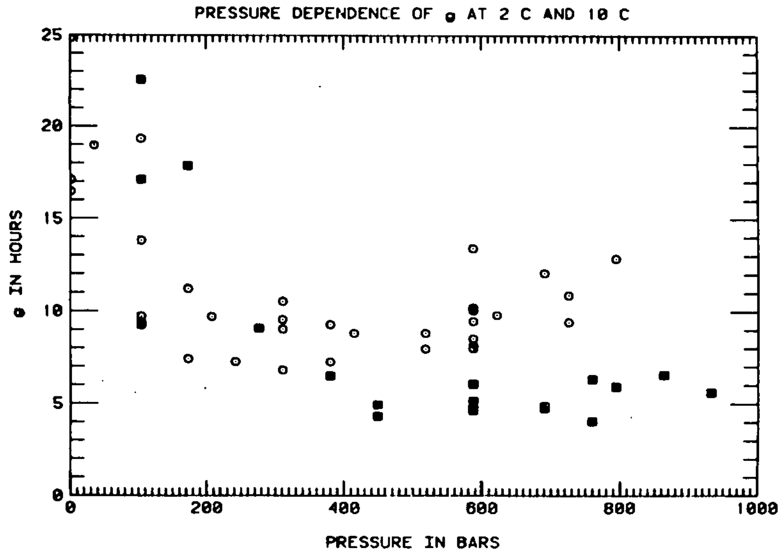


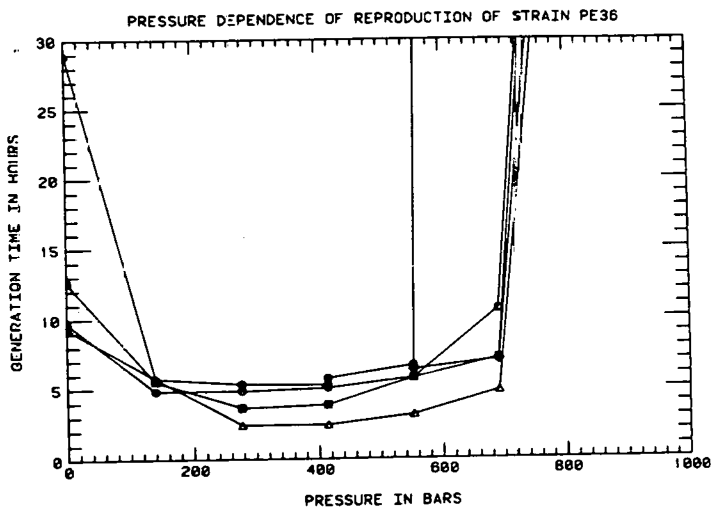
PIN CLOSURE PRESSURE VESSEL

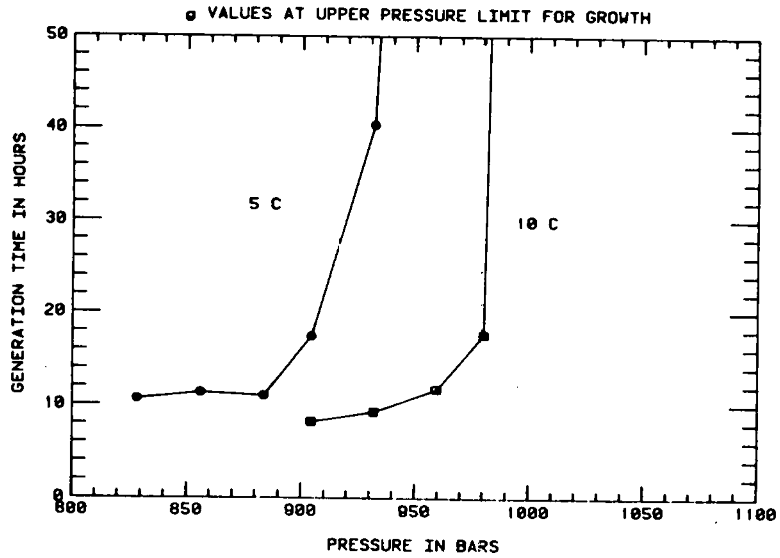





PRESSURE DEPENDENCE OF REPRODUCTION
GENERATION TIME IN HOURS
PRESSURE IN BARS
PE35
PE31
MT62
MT41


PRESSURE DEPENDENCE OF g AT 2 C AND 10 C
g IN HOURS
PRESSURE IN BARS


PRESSURE DEPENDENCE OF REPRODUCTION OF STRAIN PE36
GENERATION TIME IN HOURS
PRESSURE IN BARS


g VALUES AT UPPER PRESSURE LIMIT FOR GROWTH
GENERATION TIME IN HOURS
PRESSURE IN BARS
5 C
10 C

EVALUATION OF SOME TYPICAL PROCEDURES FOR STUDYING DEEP-SEA MICROBES

		WATER	*in situ* CONDITIONS		RETRIEVAL CONDITIONS				INCUBATION CONDITIONS			
TYPE OF SAMPLE	LOCATION	DEPTH	T AT DEPTH	P AT DEPTH	T_{max}	TIME AT T_{max}	P_{min}	TIME AT P_{min}	T	P	p(SURVIVAL)	REF.
Sediments from gravity and piston corers	central North Pacific Ocean	1,707 to 5,942 m	*ca.* 2.5 C	173 to 601 bars	*	*	1 bar	Always	*	1 bar	0	24
Sediments from cores and grabs	Philippine Trench	1,023 to 10,462 m	*ca.* 2.5 C	104 to 1,060 bars	*	*	1 bar	Hours to always	2.5 and 30 C	1 and 1,013 bars	0 to 1	40
Water and sediments	Pacific Ocean	To over 5,000 m	20 to 2.5 C	A few bars to over 500 bars	>22 C	Always	1 bar	Always	22 C	1 bar	0	16
Water taken with a Niskin bag sampler	Indian Ocean	To 2,000 m	20 to 2 C	Up to 200 bars	>20 C	Always	1 bar	Always	25 C	1 bar	0 to 1	7
Sediment from a core	Western Atlantic Ocean	4,490 m	*ca.* 3 C	500 bars	*	*	1 bar	always	4 C	1 bar	0 to 1	29
Sediments from gravity corers	Puerto Rico Trench	8,130 m and 7,750 m	*ca.* 2.5 C	825 and 786 bars	*ca.* 8 C	*	1 bar	*	3 C	826 and 785 bars	0 to 1	28
Gut contents of an amphipod	Aleutian Trench	7,050 m	*ca.* 1.5 C	715 bars	*	*	1 bar	*	3 C	760 bars	0 to 1	30
Sediments and Mn nodules from dredges and cores	Atlantic and Pacific Oceans	396 to 5182 m	*ca.* 2.5 C	4 to 525 bars	*	*	1 bar	Always	14 to 18 C	1 bar	0	26
Water under pressure	Atlantic Ocean	3,550 to 5,225 m	*ca.* 2.5 C	360 to 529 bars	3 C	Always	360 and 529 bars	Always	3 C	360 and 529 bars	1	33

a) * Denotes lack of data. b) p(SURVIVAL) was estimated from eqn. 3 or from Fig. 5.

CONCLUSIONS

DEEP-SEA BACTERIA ARE EXTREMELY PSYCHROPHILIC

ALL TRUE DEEP-SEA BACTERIA FROM DEPTHS GREATER THAN 2,000 METERS ARE BAROPHILIC

THOSE BAROPHILIC BACTERIA THAT GROW AT ATMOSPHERIC PRESSURE ARE ADVERSELY AFFECTED BY INCREASING TEMPERATURE

INCREASING TEMPERATURE ACCELERATES THEIR GROWTH AT DEEP-SEA PRESSURES

THE PRESSURE OPTIMAL FOR CELL DIVISION AT 2 C IS A PRESSURE LESS THAN THAT AT THE DEPTH OF ORIGIN

THE PRESSURE OPTIMAL FOR CELL DIVISION IS DIAGNOSTIC FOR DEPTH OF ORIGIN

MUCH (MOST?) PREVIOUS DEEP-SEA MICROBIOLOGY HAS BEEN DONE WITH SPURIOUS DEEP SEA MICROBES

MORE CONCLUSIONS

HETEROTROPHIC DEEP-SEA BACTERIA GROWING WITH GENERATION TIMES OF BETWEEN 5 AND 30 HOURS CAN BE GOT FROM COLD DEEP-SEA WATER, SEDIMENTS AND ANIMALS

APPLIED DEEP-SEA MICROBIOLOGY IS A VIRGIN FIELD

Activity Rates of Abyssal Communities

(K. L. Smith)

Task #1

a. Benthic boundary layer in the central and eastern North Pacific.

I. A chemical and biological characterization. Deep-Sea Research (submitted).

Nitrogenous nutrient profiles immediately above and below the sediment-water interface as well as sediment organic carbon, total nitrogen, and macrofaunal abundance and biomass were evaluated on a transect of 5 stations across the central and eastern North Pacific. This transect extended from the central gyre area north of Hawaii to the Santa Catalina Basin off the southern California coast. A free vehicle grab respirometer was used to collect nutrient water samples at close intervals from 48 cm above to 15-20 cm below the sediment-water interface. This free vehicle was also used to recover undisturbed sediment samples for macrofaunal and organic carbon and total nitrogen analyses. Bottom water hydrocasts and gravity cores supplemented the free vehicle samples. Ammonium and nitrite profiles above the sediment-water interface revealed considerable variability up to 48 cm at all stations and were distinctly different from bottom water hydrocast samples taken at 2 m altitude. Nitrate profiles were more uniform. Sediment nutrients, organic carbon and total nitrogen profiles were also erratic in these oxygenated surface sediments (15-20 cm) suggesting the heterogeneity of the sediments and of the overlapping reactions occurring in the diagenesis of organic matter. Macrofaunal abundance and biomass, and surface organic carbon and total nitrogen increased from west to east, with a trend towards larger animals at the eastern stations. These longitudinal gradients from west to east, corresponded to increasing surface primary productivity.

b. Benthic boundary layer in the central and eastern North Pacific.

II. Sediment community oxygen consumption and nutrient exchange. Deep-Sea Research (submitted).

Oxygen consumption and nutrient exchange rates of the sediment community were measured at five stations (13 substations) on a transect traversing the central and eastern North Pacific. These in situ measurements were made using the free vehicle grab respirometer (FVGR) on four cruises from summer 1978 to winter 1981.

Oxygen consumption of the sediment community along the transect ranged over two orders of magnitude from a low of 0.08 ml O_2 m^{-2} h^{-1} at Sta. CNP (MPG-I) to 2.7 ml O_2 m^{-2} h^{-1} at Sta. SCB. There was an obvious trend of increasing oxygen consumption rates from west to east.

Nutrient flux rates across the sediment-water interface was highly variable at the five transect stations. However, the general trend was one of increased release rates of combined nitrogenous compounds (nitrate, nitrite, and ammonium) from west to east. Nitrate and ammonium were the most significant contributors to the flux of nitrogen we measured with the intermediate compound, nitrite, being evolved in lesser concentrations.

Task #5

Aquarium energetics of the sablefish, Anoplopoma fimbria. Jour. Fish. Res. Bd. Canada (in press).

Ingestion, growth, respiration and excretion rates and white muscle chemical composition (lipid, protein and water content) were measured on laboratory-held Anoplopoma fimbria. This species is a common benthopelagic fish along the Pacific coast of North America occurring at depths between 100 and 1550 meters.

A. fimbria were collected off southern California at a depth of 470 meters and maintained alive in aquaria for over six months. In most experiments *A. fimbria* were fed a large ration (14% of wet body weight) every 7 - 10 days. Growth rates of aquaria-held fish were two to three times higher than those reported for field fish. *A. fimbria* on a reduced ration level (4% of wet body weight) grew at rates similar to growth rates of field fish, but the white muscle composition varied significantly from that of field fish. Respiration rates were sensitive to size and oxygen tension at a constant temperature of 8^oC. Oxygen consumption for a 0.25 kg fish was 137.4 ± 29.8 ml $O_2 \cdot kg^{-1} \cdot h^{-1}$ compared to 44.1 ml $O_2 \cdot kg^{-1} \cdot h^{-1}$ for a 2.78 kg fish. Oxygen consumption rates for one fish dropped 78% as the oxygen saturation dropped from 100% to below 10%. An estimate of energy allocation for different size classes of *A. fimbria* based on expanded energy in growth, metabolism and nitrogenous excretion showed 22% on ingested calories were spent on respiration. 60% on growth, and 4.7% on nitrogenous excretion for a 0.25 kg fish. In contrast, a 2.78 kg fish spent 21% of ingested calories on respiration, 10% on growth and 9.3% in nitrogenous excretion; the remaining calories may be contributed to gonadal development and other production products (e.g. mucus) in larger fish.

TASKS

1. MEASURE SEDIMENT COMMUNITY METABOLISM (MPG-1)

2. CHARACTERIZE ABYSSOPELAGIC FAUNA - FVMNT (MPG-1)

3. DEVELOP FREE VEHICLE GIANT CONICAL NET (GCN)

4. DEVELOP FREE VEHICLE ACOUSTICAL ARRAY FOR ABYSSOPELAGIC POPULATION ASSESSMENT

5. MEASURE ABYSSOPELAGIC ANIMAL METABOLISM

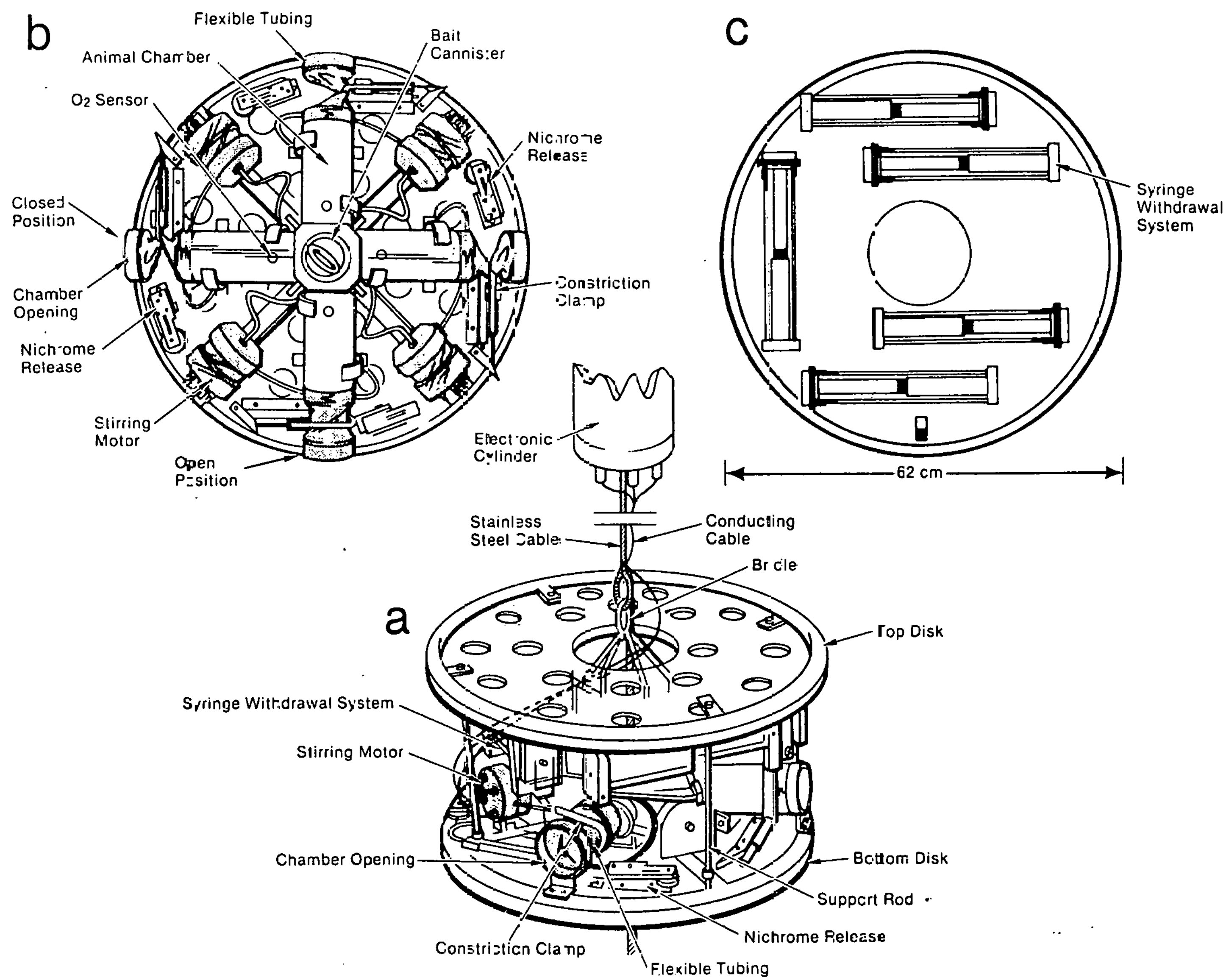
TASK # 5

MEASURE ABYSSOPELAGIC/BATHYPELAGIC ANIMAL METABOLISM

1. DEVELOP FREE VEHICLE TRAP RESPIROMETERS (IN SITU MEASUREMENTS)
   - A. AMPHIPOD TRAP RESPIROMETER
   - B. FISH TRAP RESPIROMETER

2. DEVELOP FISH TRAP RESPIROMETER/AQUARIUM FACILITY (IN SITU/LABORATORY MEASUREMENTS)

3. AQUARIUM STUDIES (LABORATORY MEASUREMENTS)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Constriction Clamp
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62 cm
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Stainless Steel Cable
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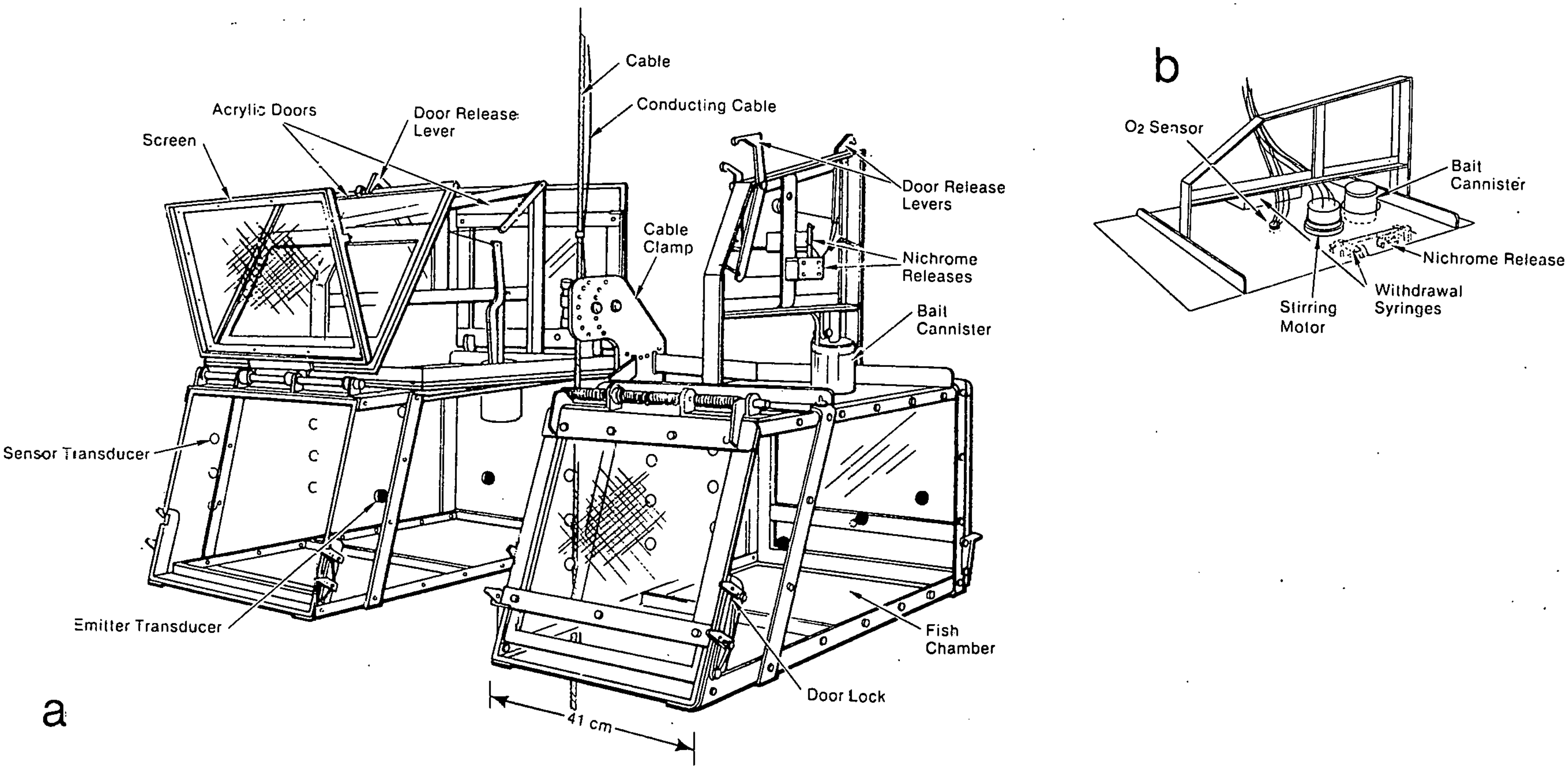

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Nichrome Release
Withdrawal Syringes
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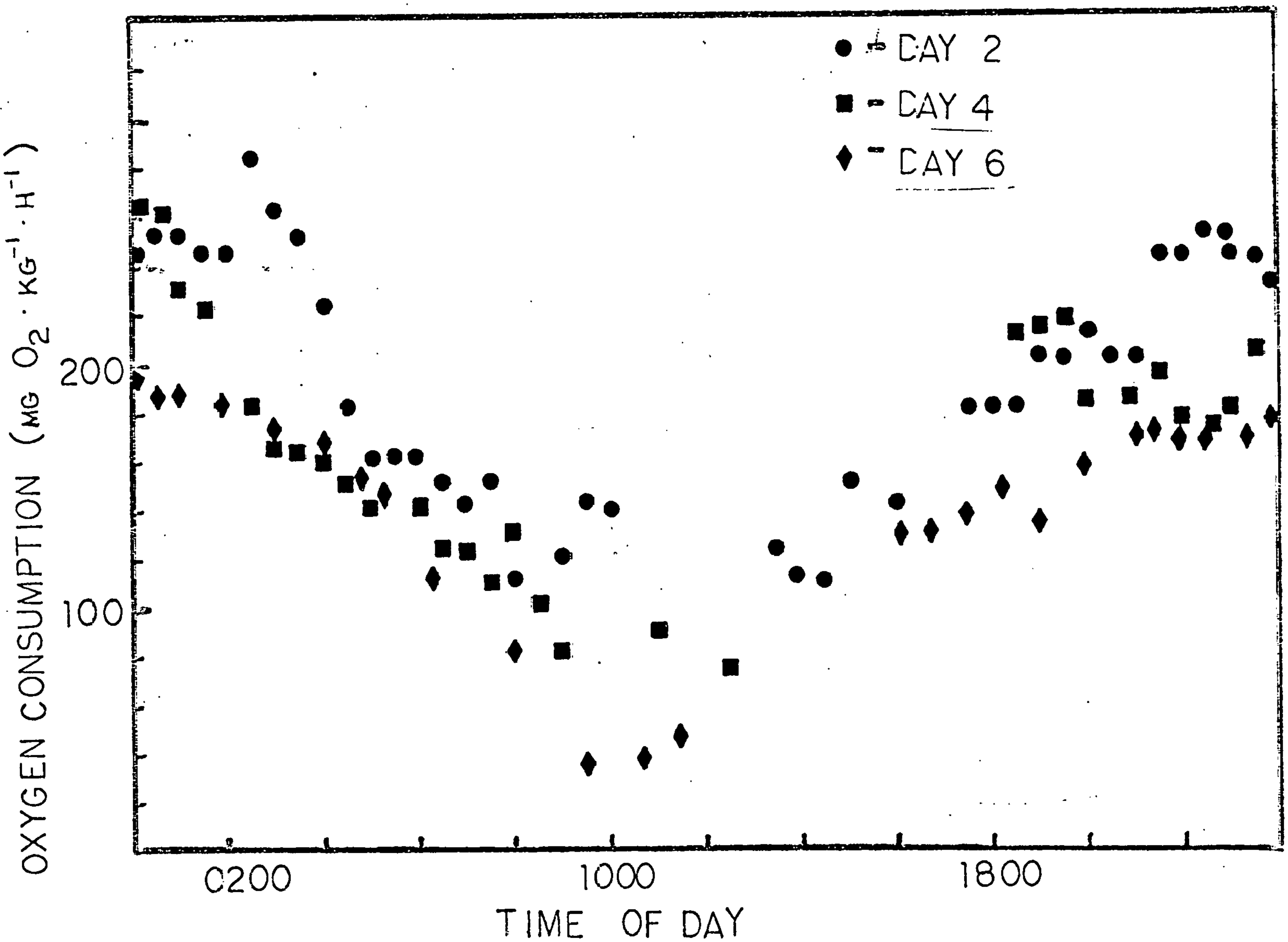
DAY 2
DAY 4
DAY 6
OXYGEN CONSUMPTION (MG O2 · KG-1 · H-1)
200
100
0200
1000
1800
TIME OF DAY

Bacteria and Plutonium in Marine Environments

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ABSTRACT

We have looked for correlations, positive or negative, between the concentrations of fallout plutonium and of living bacterial cells in a number of oceanic water or sediment columns. The absence of clear-cut relationships suggests that bacterial biomass cannot be a major variable either in the sedimentation of plutonium downward in the water column, or in plutonium remobilization in the sediments. In vitro studies of Pu uptake by cultured sediment bacteria show that the bacterial cell surface is less attractive to Pu in solution than is, for instance, that of diatoms. Arguments are presented suggesting that any relationship between bacteria and Pu must be mediated by physiological and chemical effects.

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9/30/81

Plutonium and some other transuranium elements have been released world-wide especially as components of fallout from atmospheric testing of nuclear weapons, from the SNAP-9A burnup (Hardy et al. 1973), and locally as low level liquid wastes from nuclear generation of electric power (Hetherington 1976; Health and Safety Directorate, CEC, 1978; Livingston et al. 1982); a variety of other sources, lesser and more local, have been described. Field studies conducted by our laboratory have indicated that the marine sedimentation of plutonium is mediated largely by biogenous particulate matter (Noshkin and Bowen 1973; Labeyrie et al. 1976; Bowen et al. 1976). Recent discussions have also emphasized the probable importance of bacterial production of exometabolites, and control of Eh conditions, in the remobilization of Pu in marine sediments (Bowen et al. 1976; Livingston and Bowen 1979; Bowen et al. 1980). High sediment inventories of fallout Pu appear to correlate with high local bioturbational activity (Bowen et al. to be published) where sedimented, particle-associated Pu is rapidly removed down away from the possibility of horizontal transport. Sediments in such areas tend also to be high in organic content, and, by inference, may contain greater concentrations of bacteria.

Bacteria are known to be important in the geochemical cycling of many other metals. They are known to oxidize and/or reduce iron (Kucera and Wolf 1957), manganese (Nealson 1978), mercury (Jernelov 1969) and copper (Beswick et al. 1976). Bacteria are thought to be involved in the mobilization of tin in the estuarine environment (Hallas and Cooney 1980). That bacteria might be important in the biogeochemistry of Pu and other actinides was of interest to us, and led us to conduct this study.

To examine the role of bacteria in the marine geochemistry of Pu, we conducted field studies in which we measured Pu concentrations in water and sediment columns, and in these same samples enumerated total bacterial numbers. In addition, we began laboratory experiments designed to determine the rates and amounts of bacterial uptake of ^{237}Pu, an isotope which does not occur in the environment. The results of these two complimentary studies have shed some new light upon the role of marine bacteria in the biogeochemistry of Pu.

This work would not have been possible without the kind cooperation of many of our colleagues. In particular we would like to thank J. E. Andrews, L. Brady, B. J. Brockhurst, and W. R. Clarke, who performed the radiochemical analyses of sediment and water samples; D. M. Bishop, who assisted with microscopy; D. A. Dion and K. H. Nealson, who provided cultures of the bacteria used in this study; J. C. Burke, S. A. Casso, W. R. Clarke, A. G. Gordon, J. E. Goudreau, D. R. Mann and D. L. Schneider who assisted in the collection of water and sediment samples; and the officers and crew of R/V KNORR and R/V THOMAS WASHINGTON.

Materials and Methods

Field sampling for this study was done on R/V KNORR cruise 69, leg 2, from Halifax, Nova Scotia, to Woods Hole, Massachusetts, in September and October 1977. The station locations are shown on the chartlet as Figure 1. Detailed bathymetry could not be reproduced on this scale, but it should be noted that core 18 was located in a small, shallow basin. Water samples were obtained with a 140-liter sampler (Bodman et al. 1961). Sediment cores were obtained using a 21-cm diameter gravity coring device in a tripod frame (Burke et al. 1982). Immediately after collection, water samples for radiochemical analysis were pumped into acid-washed 55-liter linear-polyethylene Deldrums and 10-ml aliquots for microbial assay were removed by sterile pipette, fixed with 0.1 ml 8% glutaraldehyde and refrigerated. Cores were extruded immediately after collection (Bowen et al. 1976). Sediment aliquots (1 cc) were obtained, after the cores were subdivided into slices, with a 3-cc plastic syringe whose end had been cut off with a clean razor blade. These samples were diluted with 9 ml of sterile 3% NaCl, fixed with 0.1 ml 8% glutaraldehyde and refrigerated. Sediment samples for radiochemical analysis were stored in 16 ounce polystyrene jars whose screw caps were sealed with plastic tape.

An additional series of water samples were obtained, by identical procedures, in the central North Pacific on R/V THOMAS WASHINGTON, cruise RAMA-02 in April-May 1980.

Radiochemical analyses of Pu in water and sediment were performed according to the methods described by Livingston et al. (1975). After radiochemical separation, plutonium was electrodeposited on polished stainless steel discs and the isotopic composition determined by alpha spectrometry.

Epifluorescent microscopy was used to make direct counts of acridine-orange stained bacteria, according to the method of Hobbie et al. (1977), as modified by Watson et al. (1977).

Cultures for uptake studies were grown in medium K, composed of 750 ml inshore seawater and 250 ml distilled water, enriched with 2 g peptone, 0.5 g yeast extract, 200 mg $MnSO_4 \cdot H_2O$ and 1 mg $FeSO_4 \cdot 7\ H_2O$. One liter flasks containing 500 ml of culture medium were inoculated with 1 ml of a stationary phase culture and incubated, with shaking, at 18 ± 2°C for 48 hours. Cells were harvested by centrifugation in sterile linear polyethylene 250 ml bottles at 5500 rpm (4920 x G) at 5°C in a Sorval RC-2B centrifuge for 20 minutes. The cells were washed twice with 50 ml sterile Sargasso Sea water, and resuspended in 20 ml sterile Sargasso Sea water. Then 3 ml of this cell suspension were added to 500 ml of sterile-filtered Sargasso Sea water in sterile 1-liter tared flasks. Before filtration, the pH of the sea water had been raised to 9.1 by the addition of $NaCO_3$, to pre-compensate for the acidic tracer solution, added later (Fisher et al. 1980).

Dead cells were prepared by heating 5 ml of the washed cell suspension in a sterile 20 ml screw cap tube in a 45°C water bath for 20 minutes. Serial dilution and plating showed that the cells were no longer viable after this treatment. However, the cells appeared intact upon microscopic examination.

Dry weights were determined by filtration of small aliquots of the cell suspension through tared, 25 mm diameter, 0.2 μm pore-size Nuclepore filters, rinsing the filters with 3 5-ml portions of 3.2% NH_4COOH and drying to constant weight at 60°C (Fisher and Schwarzenbach 1978).

Plutonium used in laboratory experiments was ^{237}Pu obtained from Argonne National Laboratory. Production and purification of this radionuclide have been described by Fowler et al. (1975). Plutonium-237 decays by electron capture to ^{237}Np, emitting X-rays of 101 keV. These X-rays were measured by a Harshaw 7.5 cm well-type crystal of NaI(Tl) and data stored in a Nuclear Data 130 512-channel pulse-height analyzer set to analyze pulses corresponding to 10-820 keV over the first 128 channels. The energy range used to integrate the ^{237}Np X-rays was from 80 to 140 keV.

Ten μCi of ^{237}Pu as a dry nitrate residue were taken up in 10 ml 1N HNO_3 to prepare a primary stock. Then 0.15 ml of this stock was diluted to 10 ml in 1N HNO_3 to give a working stock solution containing 88.54 ± 0.97 counts/second/gram. The ^{237}Pu is unavoidably contaminated with ^{236}Pu and ^{238}Pu, byproducts of its production. These longer-lived alpha-emitting nuclides do not interfere with the use of ^{237}Pu as a photon-emitting tracer.

Plutonium prepared in this manner was determined to be trivalent or tetravalent by the method of coprecipitation on neodymium fluoride (Nelson and Lovett 1978). Plutonium was added to cultures via glass microvolumetric pipettes in 100 μl to 250 μl volumes. Addition of the acidic ^{237}Pu solution resulted in a final pH of the seawater medium of approximately 7.5.

Flasks were sampled periodically by removing 40 ml aliquots which were then filtered by vacuum through 47 mm diameter 0.2 μm pore-size Nuclepore filters. The filtrates were retained in 50 ml plastic centrifuge tubes. Filters were put into separate soda-lime glass tubes and covered with 5 ml of 0.5 N HNO_3 for gamma counting, as described above. At the end of each experiment, 10% or less of the total added ^{237}Pu could be recovered from the walls of experimental flasks. Blank flasks (to which no cells were added) were handled in the same manner as experimental flasks. About 3% of the ^{237}Pu was associated with each blank filter.

The organisms used were Gram negative, heterotrophic marine bacteria. Strain 37B was isolated from a Pacific manganese nodule by K. H. Nealson of Scripps Institution of Oceanography. Strain BB15 was isolated from a shallow water sediment core taken from Buzzards Bay, Massachusetts, by D. A. Dion at WHOI.

Results

For convenience in interpretation we have presented most of our data in graphical form.

In Figure 2a are shown the profiles, vs depth, of concentration of $^{239,240}Pu$ and of abundance of bacteria in the water column at two stations whose locations are shown in Figure 1. Bars around each point indicate the one sigma uncertainties, calculated from the counting statistics for $^{239,240}Pu$ and from the variability of counts of a number of replicate fields for the bacterial numbers. In Figure 2b are shown the same set of data at an open-ocean N. Pacific station.

In Figure 3 are shown similarly profiles vs depth in sediment, of concentration of $^{239,240}Pu$ and of abundance of bacteria, in the four sediment cores whose locations are shown in Figure 1. Around each point vertical bars indicate the represented sampling interval, while horizontal bars indicate uncertainties calculated as above. Also, for each core, we have plotted the wet weight to dry weight ratio of each section analyzed, and have indicated both the depth of the overlying water and the inventory of $^{239,240}Pu$ calculated to reside in the whole sediment column. The results of these bacterial enumerations in sediments represent minimum numbers, due to the inherent difficulties in counting cells on sediment particles, because of the inability to see cells underneath sediment particles.

In addition to the four cores represented in Figure 3, we had data for the two upper centimeters of three other cores, whose locations also are shown in Figure 1. We have collected in Table 1 the measured $^{239,240}Pu$ concentrations and bacterial numbers of the upper sections of all 7 cores.

Figure 4 shows the curves versus time of ^{237}Pu uptake by bacterial isolate 37B. Vertical bars around each point indicate the 1 sigma uncertainty calculated from the counting statistics. The initial rates of uptake are similar for live and for killed cells. After 72 hours, however, the dead cells had taken 50% of the available tracer, while the living cells had taken only 40%.

Figure 5 shows, similarly, the curves, versus time, of ^{237}Pu uptake by bacterial isolate BB15. In this case, the curves for live or for dead cells are essentially indistinguishable.

Discussion

Our laboratory has considerable data, collected over the past 25 years, on the concentrations of Pu and other fallout-derived artificial radionuclides in marine water, sediments, and macroorganisms. Because of the near impossibility of collecting samples of natural populations of microorganisms from the open ocean in sufficient quantities to analyze for low levels of artificial radionuclides, our field studies have been supplemented with laboratory studies of uptake of Pu by marine microorganisms in culture. Recently, our colleagues (Fisher et al. 1980) reported data on Pu uptake by marine phytoplankton in culture. They concluded that much of the Pu introduced to the marine environment would quickly associate with particles which could then act as vectors for Pu transport to the sediments. Diatoms seem to serve as efficient collectors and transporters of Pu (Fisher et al. 1980). Bacteria, while lacking any sort of potentially long-lived tests like the silica frustules of diatoms, might still be intermediaries in the transfer of Pu to inorganic detritus and sediments.

It seemed possible to us that the numbers of bacteria in marine waters and sediments might be correlated with the concentrations of Pu. This might be expected either if Pu association with non-sedimenting or slowly sedimenting bacteria were involved in the sort of mid-depth Pu maxima that have been described (Noshkin and Bowen 1973; Labeyrie et al. 1976; Bowen et al. 1980), or if association with bacteria on the surface of sedimenting particles were important in mediating the transfer of water column Pu to the sediments. In the first case we would expect a positive, in the second a negative, correlation of bacterial abundance with Pu concentration. Thus we undertook this study to determine whether bacteria in the water column associated with detrital particles affected the distribution of Pu in seawater, or whether the total numbers of bacteria could act as indicators of the processes affecting Pu retention in marine sediments. This type of study was only recently made possible through the use of acridine orange staining and epifluorescent microscopy: techniques (Hobbie et al. 1977; Watson et al. 1977) that allow differentiation of bacteria from nonliving detrital particles or from sediment particles; and make their enumeration relatively easy and independent of culture techniques.

Examination of Figure 2a shows there is no concordance in these water columns between Pu concentration and bacterial abundance. In both cases, as expected, the surface water contains by far the greatest number of bacteria; at station 14, in the Strait of Belle Isle, the surface Pu concentration was as low as observed, whereas at station 8, on the Nova Scotia shelf, surface Pu was at an intermediate concentration. At both stations, bacterial concentration was lowest at 100 m, but this corresponds neither to maxima nor minima in the Pu curves.

The data summarized in Figure 2b refer to a different situation. As Bowen et al. (1980) have shown, the North Pacific Ocean is almost everywhere characterized by a shallow mid-depth maximum in Pu concentration, that is both strongly pronounced (more than 10 X surface Pu concentrations) and very stable in position (probably no change in depth between 1972 and 1979). Somewhat less widely dispersed across the N. Pacific is a second, lesser, Pu concentration maximum in the water close to the sediment surface. Both of these features were sampled at the station represented in our Figure 2b, but neither shows any convincing association with fluctuation of bacterial numbers.

Evidently, if bacteria are involved in processes that result either in the retention of Pu in the water column or in its removal by sedimentation, other factors also involved obscure any obvious correlations between the two abundances.

There seems to be no correlation of Pu concentration with bacterial numbers in sediment cores either. Figure 3 shows that of the four cores examined, the highest bacterial numbers were found in core 29, a sandy sediment from a near-shore location, just off Gay Head, MA, in 37 m of water. At the surface of this core, we measured only 42 ± 1.3 dpm ^{239}Pu/kg dry weight, less than half the concentrations of ^{239}Pu measured at nearby sites in Buzzards Bay, MA (Livingston and Bowen 1979) where sediments had a greater amount of clay (Sholkovitz and Carey unpublished data). Livingston and Bowen (1979) reported two other Gay Head cores, from 1974, one ranging about 48-57 dpm Pu/kg in the upper (mixed) 8 cm, and the other ranging 76-80 over the same depth range. These cores, also, are indicated by their low wet to dry ratios, to have been lower in clay content than is typical of Buzzards Bay. The small surface to volume ratio of the sandy Gay Head sediments appears simply to provide less area for Pu attachment. Clearly, however, the occurrence on the sediment grains of bacteria in much greater numbers was not effective in overcoming that deficiency.

In cores 13, 18, and 22 (Figures 3-5) the surface $^{239,240}Pu$ values range from 50 to 150 dpm/kg, yet the bacterial numbers are essentially the same for all three cores, 7.5 to 9.7 x 10^8 cells/cc sediment. The $^{239,240}Pu$ inventory in core 13 is 1.1 mCi/km^2, and in core 18 the inventory is 2.5

mCi/km^2. There is a difference in these inventories of a factor of 2.3, yet the mean bacterial numbers are 8 x 10^8 and 7.5 x 10^8 cells/cc of sediment, an insignificant difference between the two cores. The higher inventory of Pu in core 18 is partly related to its position (at station 8) in a small, shallow depression that may be collecting fine sediment particles deposited over a larger area; that this is not the whole story is shown by the relatively high Pu in the surface sediment, by the fact that this concentration extends through the upper 5-6 cm (in contrast to the quasi-exponential decrease of Pu, with depth in core, in core 13), and by the high wet-to-dry ratios. These last, 3.6 at the surface, do not fall below 3.2 until the 10 cm level, in contrast, for instance, with core 13, where this ratio was 3.18 at the sediment surface. Bacterial numbers show no correlation with any of these differences. We had expected that the higher proportion of fine grained material in core 18 (shown by the higher wet-to-dry ratio), and the intense biological activity that has resulted in mixing Pu uniformly down to 6 cm or so, would each have favored higher concentrations of bacteria. It is evident that, however bacteria may be involved in the delivery or immobilization of Pu to shallow water marine sediments, the absolute abundance of live bacterial cells is no indicator of such involvement.

It should be noted that core 18 is by no means typical of continental shelf, closed basin, cores. Livingston and Bowen (1979) reported a series of cores taken in 1974 in the Wilkinson Basin, in the Gulf of Maine just north of Cape Cod. Although this series includes cores with surface sediment wet-to-dry ratios as high as 4.8 and as low as 1.5, none shows as high Pu at the sediment surface, as great a depth of uniform mixing, or as high a Pu inventory, as our core 18. In fact our core 13 comes closer in all respects to looking like a member of this series.

Of course, none of our data concerning bacterial abundances speaks to questions of qualitative differences between bacterial populations at various depths in either water column or sediment. Bowen et al. (1976; 1980) followed arguments that Stephens (1975) had raised in other connections to suggest that Pu remobilization in sediments may be mediated by its interaction with specific organic exometabolites of those sediment bacteria that are restricted to the narrow interface (zero O_2, zero H_2S -- or very nearly) between oxygenated and reducing zones.

Work by Aller and Yingst (1980) showed that in near-shore marine sediments the type of substrate available for bacterial oxidation, rather than the total number of cells present, controls the rates of biogeochemical processes like sulfate reduction and ammonia production. Jørgensen (1977) found that in a shallow, brackish fjord, the numbers of sulfate-reducing bacteria did not correlate with the sulfate reducing activity in the sediment. He also found that the sulfate reducers were responsible for about half of the carbon metabolized in those shallow sediments (4-12 meters), while Aller and Yingst (1980) found that the sulfate reducers were responsible for metabolizing slightly less of the carbon in sediments at two stations (15 and 34 meters depth) in Long Island Sound. These workers also concluded that a substantial proportion of the available carbon is metabolized as part of the sulfur cycle in shallow, marine sediments. The organic compounds which serve as substrates for Desulfovibrio are few (lactate, pyruvate, succinate, and malate) and are oxidized to acetate and then excreted (LeGall and Postgate 1973). Oxidation of most of the organic matter in sediments by sulfate reducing bacteria requires the initial degradation of organic matter to these simple organic acids by fermentative organisms (Jørgensen 1977). One could imagine this process of organic matter fermentation to lactate, malate, etc., occurring in the zones of low O_2 and low H_2S postulated by Bowen et al. (1976; 1980) as active zones of Pu remobilization.

It did seem worthwhile to examine, in vitro, the interaction of Pu in solution with bacterial cells. For our initial experiments we chose four-valent Pu, and two bacterial strains, 37B from a deep ocean ferromanganese concretion, and BB15 from shallow water sediment in Buzzards Bay, MA. The curves versus time of uptake of ^{237}Pu tracer from seawater solution by live, but not growing, or by killed cells of these bacteria are shown, respectively, in Figures 4 and 5. Tracer concentrations were within, but close to the upper end of, the range of Pu concentrations that have been reported in nature, as discussed briefly by Fisher et al. (1980). At these tracer concentrations, however, an acceptable signal to background ratio for the uptake measurements required the use of quite unnatural concentrations of bacteria: whereas, as shown in Figure 2, we have measured bacteria in the coastal ocean only in concentrations in the range $5 \cdot 10^4$ to $5 \cdot 10^5$ per ml (compared to results of Watson et al. (1977, also unpublished results) who have measured bacterial numbers of 1×10^6 per ml in open ocean surface waters and as high as 6×10^6 per ml in upwelling waters off the southwest coast of Africa), we have used 10^8 cells per ml for our experiments. Yet even these large numbers of bacterial cells accumulated at most 50% of the added tracer after 3 days exposure. Fisher et al. (1980) found that diatom cells would accumulate most of the added Pu in far shorter exposure periods than employed in our experiments.

In most of their experiments, Fisher et al. (1980) had 10^5 diatom cells/ml, presenting an area of $7{\cdot}5 \times 10^6\ \mu m^2$ cell surface/ml. In our experiments we used 10^8 bacterial cells/ml, which provided an area of $1{\cdot}6 \times 10^8\ \mu m^2$ cell surface/ml. So there was about 20 times more bacterial cell surface available for Pu attachment, but there was still far less Pu adsorption by the bacterial cells.

Comparisons of Pu accumulation by live or by killed cells show that the results are similar in the two organisms used in this study (and other results not shown here). We feel that initially, at least, Pu-association with bacterial cells is primarily a passive phenomenon. Other results (Carey and Bowen, in preparation) show that cells which had deposited MnO_2 had greater amounts of Pu associated with them than did cells which had not formed MnO_2 deposits.

Bacterial activity in sediments is a primary factor in controlling the geochemistry of many elements, as discussed in the introduction. Oxidation of organic compounds by bacteria in sediments, where oxygen can become depleted, results in sufficient lowering of the Eh to allow reduction of metals, most notably iron and manganese. The resulting ferrous and manganous ions become mobile in the pore waters and can be transported upwards to regions where the redox conditions are oxic enough to cause oxidation of metals and precipitation as oxides and hydroxides. Plutonium, which is known to be adsorbed strongly onto oxyhydroxides of both Fe and Mn, could be solubilized in the pore waters when the solid phase to which it had been adsorbed is dissolved at low Eh. In addition, upward transport of Mn and Fe ions in the pore waters can result in the displacement of Pu adsorbed onto clay minerals, and effectively solubilize Pu in this fashion. This "displaced" Pu may be mobile in the pore waters also.

The reducing conditions created by bacterial activity might also serve to cause Pu reduction. Hexavalent Pu, of all Pu species, is probably the most soluble in seawater. Reduction to pentavalent may change its affinity for carbonate ions, and effect the solubility somewhat. Reduction to tetravalent probably would decrease the mobility of Pu in pore waters, because this species is less soluble in seawater than either of the more oxidized species. Reduction of potentially mobile Pu (VI) to Pu (IV) probably fixes the Pu and prevents its transport in the pore waters.

Simple organic acids are also capable of complexing Pu effectively. Pu (IV) forms stable complexes with acetic or oxalic acids. It also can be complexed by phosphate, which is produced by bacterial action upon organic matter at depth in near-shore sediments. So the mobility of Pu (IV) in reducing conditions may be enhanced by microbial activity in sediments.

Edgington et al. (1976) found that 50-100% of Pu is solubilized after a 20-minute exposure to a citrate-dithionite solution. A citrate-dithionite solution would solubilize easily reduced compounds like Mn and Fe hydrous oxides. Their data imply that Pu could be dissolved and mobilized if sediments become anoxic and reducing.

In their study of Pu in an alkaline, freshwater pond, Bondietti and Trabalka (1980) found that Pu was associated with UV-absorbing organic matter of apparent molecular weight 6000-10000, which they concluded to be fulvic acid. At the Bhabha Atomic Research Centre, India, much effort has been devoted to the study of the interactions of humic and fulvic acids with both artificial and naturally occurring actinide elements in nearshore sediments. In general the work has shown additions of humic acids to be effective solubilizers of actinides, including Pu, holding them mostly in non-ionic form that resists uptake by ion-exchange resins. Precipitating humic acids, or humates, on the other hand, can carry actinids from solution with the sediment, in forms that are quite resistant to chemical or biological attack. These investigations are reported by Pillai et al. (1977), Joshi and Ganguly (1977), Desai (1980), and Mathew and Pillai (1980).

Conclusions

The results of these experiments and field studies imply that bacteria are not primary vectors in the delivery of Pu to marine sediments. The affinity of Pu for the bacterial cell is much less than its affinity for diatoms, as reported by our colleagues, Fisher et al. (1980). That bacteria have a role in Pu attachment to or removal from particles in the water column is still a possibility, but the role is probably minor. Plutonium delivery to sediments is most likely on larger biogenic particles like fecal pellets, as demonstrated by Higgo et al. (1977), or diatoms, as suggested by Fisher et al. (1980) and by Olson and Bowen (1980).

However, it is reasonable to expect that once Pu has been transported to the sediments, the role of bacteria in Pu biogeochemistry becomes more prominent. The types of reactions mediated by fermentative and sulfate reducing bacteria in sediments are likely to affect Pu mobility in sediments. Changes in redox conditions and chelation by compounds produced by fermentative reactions of bacteria in sediments are probably among the primary means of bringing about changes in Pu geochemistry in sediments.

Important work to be done in the future to examine further and with luck to elucidate the role of marine bacteria in Pu geochemistry includes studies of the effects of bacterial exometabolites on the reduction of Pu and the efficacy of bacterial exometabolites in solubilization of Pu in sediments. Studies such as these should help to predict Pu behavior in the marine environment.

TABLE 1

$^{239,240}Pu$ and Bacterial Cell Counts from Surface Sediments of Nearshore North Atlantic Cores

Core Number	Cm depth in core	Cells/cc sediment	$^{239,240}Pu$ dpm/kg
13	0-1	$8.02 \pm 1.29 \times 10^8$	106 ±3
	1-2	$5.34 \pm 1.51 \times 10^8$	83.4 ±2.6
18	0-1	$7.49 \pm 3.75 \times 10^8$	158 ±5
	1-2	$7.46 \pm 2.19 \times 10^8$	153 ±5
19	0-1	$1.19 \pm 0.47 \times 10^9$	107.3±3.4
	1-2	$8.57 \pm 3.19 \times 10^8$	113.2±3.1
20	0-1	$6.17 \pm 2.71 \times 10^8$	78.0 ±2.4
	1-2	$1.04 \pm 0.43 \times 10^9$	(7.1 ±0.7)*
22	0-1	$9.64 \pm 3.06 \times 10^8$	48.2 ±0.5
	1-2	$6.79 \pm 4.47 \times 10^8$	38.9 ±0.1
27	0-1	$6.30 \pm 2.14 \times 10^8$	11.29±0.46
	1-2	$4.02 \pm 1.36 \times 10^8$	(62 ±3) *
29	0-1	$1.60 \pm 0.41 \times 10^9$	42.2±1.3
	1-2	$1.82 \pm 0.70 \times 10^9$	46.8±1.4

* Extrapolated values

FIGURE LEGENDS

Figure 1. Location of stations taken on R/V KNORR cruise 69, leg 2. Cores were taken at the locations indicated by the closed circles and water profiles at stations indicated by the crosses. Station 18 was located in a small, shallow basin.

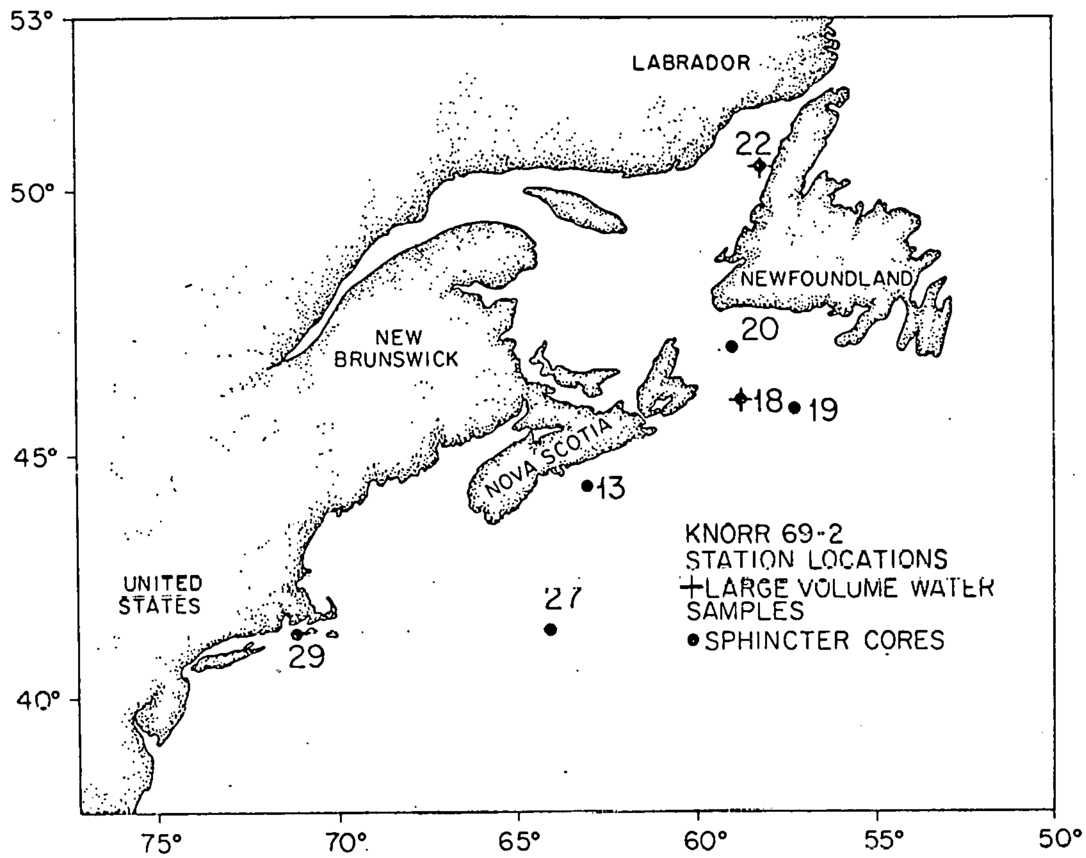
Figure 2a. Profiles, versus depth, of $^{239,240}Pu$ and of bacterial numbers in the water column at 2 stations from R/V KNORR cruise 69-2. Water station 14 was at the same location as core 22, and water station 8 was at the same location as core 18, as shown in Fig. 1. Horizontal bars represent one-sigma uncertainties, calculated from the counting statistics for $^{239,240}Pu$ or from the variability of counts of 10 or more replicate fields for bacterial numbers.

Figure 2b. A profile, versus depth, of $^{239,240}Pu$ and of bacterial numbers in the water column from a station in the N. Pacific. Horizontal bars represent one-sigma uncertainties, as described for Fig. 2a.

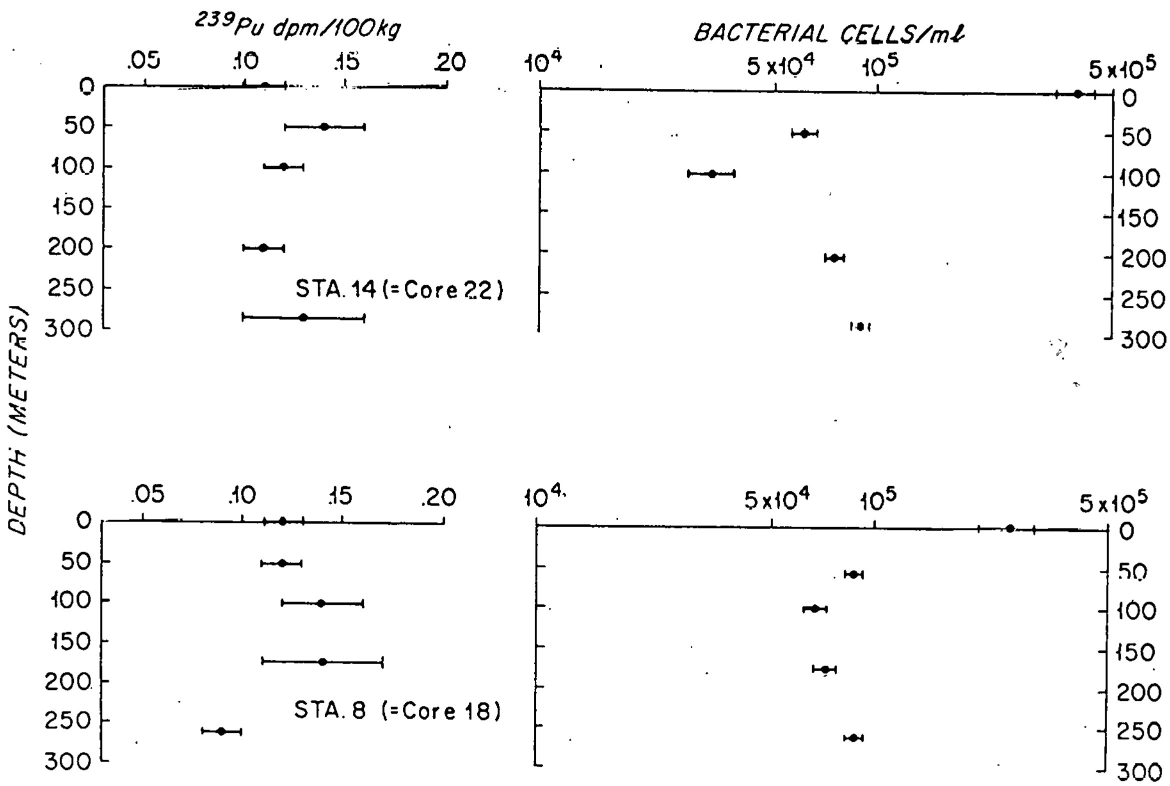
Figure 3. Profiles, versus depth, of $^{239,240}Pu$, and of bacterial numbers in four sediment cores whose locations are shown in Fig. 1. Vertical bars represent the sampling intervals, and horizontal bars represent one-sigma uncertainties, as described in the legend for Fig. 2. The open circles represent the wet/dry ratio for the sediments. The depth of overlying water and the calculated $^{239,240}Pu$ inventory are indicated for each sediment column.

Figure 4. Uptake of ^{237}Pu by bacterial isolate 37B in culture. Closed diamonds represent uptake by live cells, and open circles represent uptake by heat-killed cells. Vertical bars represent one-sigma uncertainties from the counting statistics.

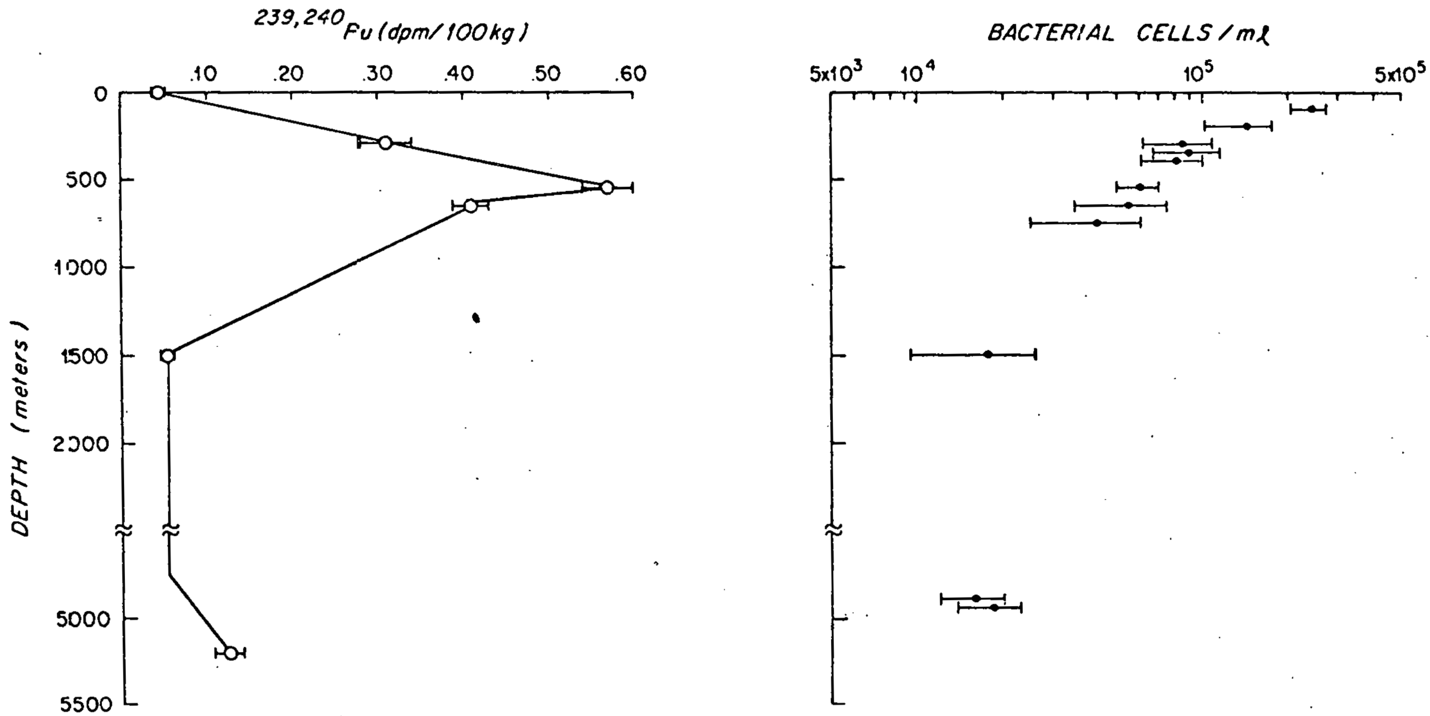
Figure 5. Uptake of ^{237}Pu by bacterial isolate 37B in culture. Closed diamonds represent uptake by live cells, and open circles represent uptake by heat-killed cells. Vertical bars represent one-sigma uncertainties from the counting statistics.



KNORR 69-2 SEPT. - OCT. 1977



RAMA 02, MAY 1980, STATION 178 27°00'N 163°00'W



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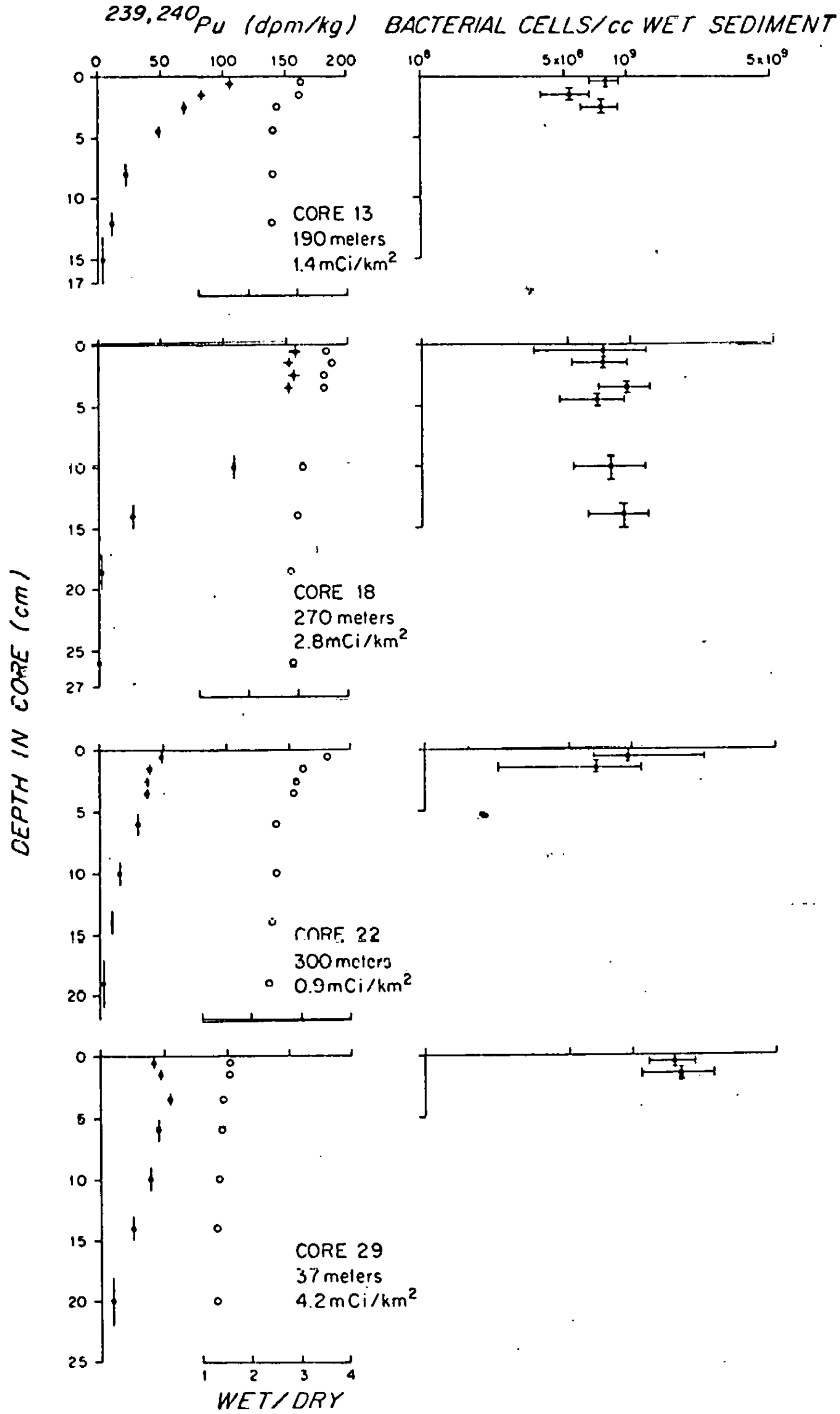
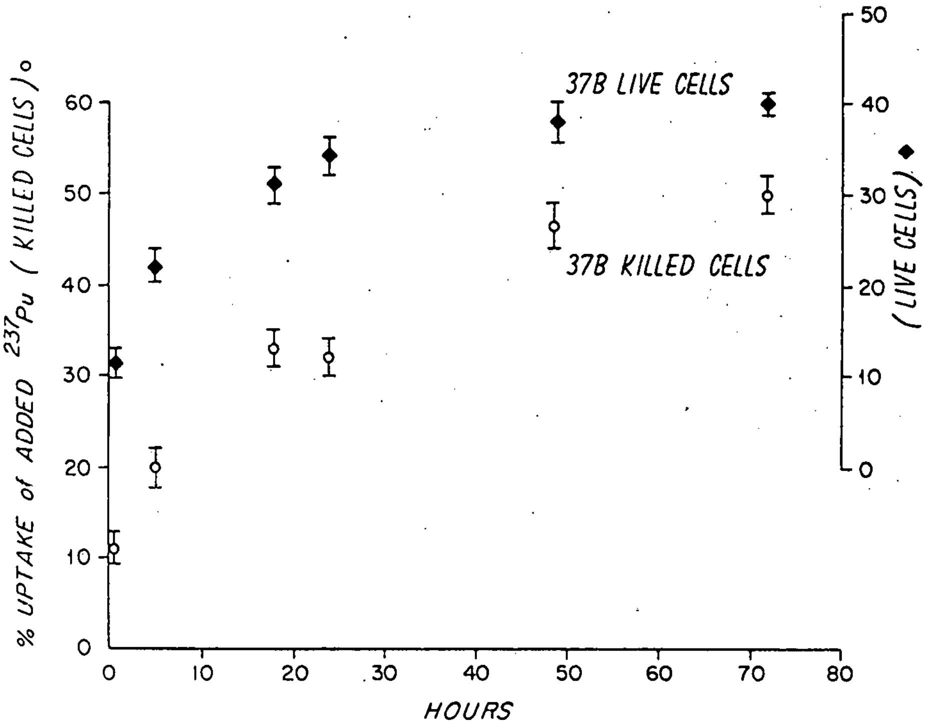
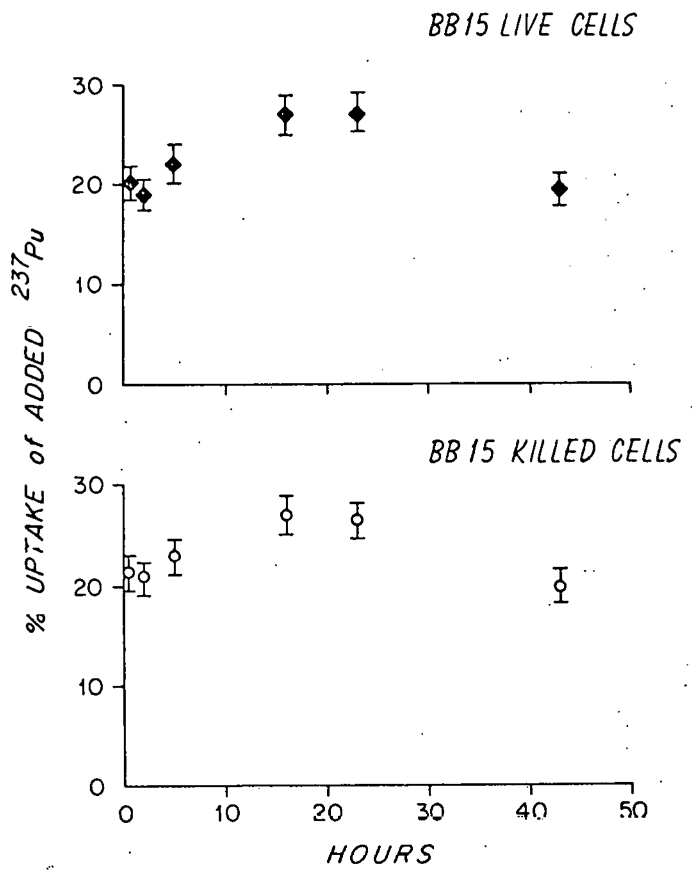



% UPTAKE of ADDED ^{237}Pu (KILLED CELLS) ○
(LIVE CELLS) ◆
37B LIVE CELLS
37B KILLED CELLS
HOURS


BB15 LIVE CELLS
BB15 KILLED CELLS
% UPTAKE of ADDED ^{237}Pu
HOURS

BACTERIA AND PLUTONIUM IN WATERS OF THE ALEUTIAN TRENCH[1]

Anne E. Carey

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts 02543

ABSTRACT

Data are presented showing $^{239,240}Pu$ concentrations and bacterial abundance, as determined by direct cell counts, in water stations in the Aleutian Trench. No correlations are seen between the data sets, further supporting the hypothesis that bacterial biomass is not a major factor in determining Pu distributions in marine water columns.

For Submission to Limnology and Oceanography

[1]This work has been supported by the Department of Energy, and its various precursors, under contract EY-76- , and via SANDIA Laboratories, under contract /1159, and by the GEOSECS program.

10/26/81

Introduction

In the Pacific Ocean, the delivery of plutonium has had two sources, worldwide atmospheric fallout (Hardy et al. 1973) and local, close-in fallout from the atmospheric testing of nuclear weapons (Joseph et al. 1971). The geochemistry of the artificial radionuclides thus introduced into the Pacific may be very different, reflecting these two sources. Distributions of $^{239,240}Pu$ in Pacific water columns display features unlike those of Pu distributions in other oceans studied by our laboratory (Bowen et al. 1980). Two layers of high Pu water are observed over much of the Pacific that has been studied; one a shallow subsurface layer between 300 and 750 m, depending upon latitude, and another somewhat less widely distributed and of lesser Pu concentration, just above the bottom. The inability of ancillary hydrographic data to explain the existence of particularly the shallow, high Pu water led us to look for biological indicators. Some of this work has been reported (Carey and Bowen submitted) and has shown no concordance of bacterial numbers in oceanic water columns with Pu distributions. The work presented here further extends our knowledge of the lack of the association of bacterial numbers with Pu distributions in the Pacific Ocean.

The work would not have been possible without the extensive work of those people associated with the GEOSECS program, the radiochemical laboratories at Woods Hole Oceanographic Institutions and at Lawrence Livermore Laboratories, and the officers and crew of R/V THOMAS WASHINGTON and R/V MELVILLE.

Methods

GEOSECS station 218, over the Aleutian Trench at 50° 26.8'N, 176° 35.0'W, was occupied by R/V MELVILLE on 4 October 1973. The large volume water samples from GEOSECS stations were collected in modified Gerard samplers (Roether 1971) as described by Bowen et al. (1980) and then stored in 60-liter linear polyethylene Deldrums. Radiochemical analyses were performed at WHOI according to methods which have been described (Wong et al. 1970; Livingston et al. 1975) or at Lawrence Livermore Laboratories according to published methods (Marsh et al. 1975; Wong et al. 1978; Noshkin et al. 1976). Plutonium data were obtained by alpha-spectrometry, a method which cannot distinguish ^{239}Pu from ^{240}Pu. Hence the data are presented as the sum of the two isotopes and indicated as $^{239,240}Pu$.

Laboratory intercomparison exercises have shown that the data obtained by these two laboratories using the various methods are comparable. In addition, duplicate analyses of these GEOSECS samples performed by either laboratory have given reproducible results.

Water samples from station 1 on cruise RAMA 15 on R/V THOMAS WASHINGTON were taken over the Aleutian Trench at 52° 54.3'N, 163° 1.8'W on 21-22 June 1981. Samples were collected with a 140-liter sampler (Bodman et al. 1961) and then pumped into 60-liter linear polyethylene Deldrums. Aliquots of 100 ml were saved for microbiological analysis. To each of these samples was added 2 ml of 50% glutaraldehyde (Eastman). The samples were then refrigerated for approximately 1 month until analyzed at WHOI.

Bacterial cells were enumerated by direct counting of acridine orange stained cells with epifluorescent microscopy, according to the method of Hobbie et al. (1977) as modified by Watson et al. (1977). Cells were counted using a Zeiss microscope with an epifluorescent illuminator consisting of a 100W halogen lamp, a BG12 excitation filter, an LP510 barrier filter an an FT510 beam splitter.

Results

The profile of $^{239,240}Pu$ in water samples from GEOSECS station 218 is shown in Fig. 11. Plutonium-239,240 concentrations show a shallow, broad maximum around 300 meters. This maximum of 0.25 ± 0.02 dpm/100 kg is six times greater than the surface concentration of 0.04 ± 0.01 dpm/100 kg. From this shallow maximum to about 2000 meters, there is a gradual decline in Pu concentration through the water colum to about 4500 meters, whereupon the $^{239,240}Pu$ concentrations increase to the bottom. In the deepest sample, about 100 meters above the bottom, the $^{239,240}Pu$ concentration of 0.13 ± 0.02 dpm/100 kg is three times the surface concentration and half the concentration of the shallow maximum.

The results of the bacterial cell counts are shown in Fig 1a. The surface sample had $6.8 \pm 2.5 \times 10^5$ cells/ml. Bacterial counts are maximum at 100 m, where $7.0 \pm 3.4 \times 10^6$ cells/ml were observed. From 100 to 500 meters, the bacterial numbers decline by about a factor of five. From there to 6532 m, the bacterial numbers are nearly constant, about 1.2×10^4 cells/ml.

In the three deepest samples (5000 meters and deeper) more morphologically distinctive cells, like vibrios and spirallae, were observed than in the shallower samples.

Discussion

The occurrence of two widespread layers of Pu-rich water in the Pacific, one a shallow, subsurface layer at 300-750 meters depth, and another just above the bottom, has been discussed in detail by Bowen et al. (1980). The occurrence of these Pu-rich waters was first discovered in samples collected in 1973 during the GEOSECS program. Subsequent sampling in 1978-1981 (Bowen et al. 1980; also unpublished results) has shown that the shallow layer of Pu-rich water has not sunk significantly since 1973. The high $^{239,240}Pu/^{137}Cs$ ratios in the water samples from the Pacific and the extensive occurrence of the two layers of high $^{239,240}Pu$ water (Bowen et al. 1980) are features unseen in any other ocean thus far studied. These observations suggest that there may be some very interesting and different geochemical processes at work on the Pu in the Pacific, which was delivered both as worldwide atmospheric fallout and as close-in fallout from the atmospheric testing of nuclear weapons in the 1950's and 1960's.

Bowen et al. (1980) found that the shallow layer of high Pu water has no coincidence with any of the hydrographic parameters to which one might look first to help explain the widespread, temporally and spatially stable, occurrence of this water mass. Pu contours show no relationships to maxima or minima of density, of O_2, or of salinity which might help explain this feature of Pu distribution in the North Pacific.

In the deep layer of high Pu water, in the Aleutian Trench (greater than 5000 meters) the $^{239,240}Pu$ concentration increases significantly over the mid-depth concentration and is three times the concentration of the surface $^{239,240}Pu$ concentration. This increase in $^{239,240}Pu$ concentration in the deep water may be associated with Pu resolubilization from sediments as a result of the biological productivity in the sediments. This concept has been discussed by Bowen et al. (1980). However, this deep, high Pu water has been seen in samples taken over much of the Pacific Ocean (Bowen et al. 1980), including areas in the central N. Pacific of low benthic productivity, collectively known as the Pacific marine desert. This high Pu water is thought to originate in the Aleutian Trench and spread rapidly southward out of the Trench and into the circulation of the North Pacific Bottom water (Bowen et al. 1980).

Previous work done in this laboratory (Fisher et al. 1980; Olson and Bowen 1981; Carey and Bowen, in press) addressed the question of Pu associations with biological phenomena. Pu-interactions with bacteria in the water column were thought to be possible explanations of the observations of Pu-rich waters in the Pacific Ocean. Results thus far have shown no convincing evidence of an association with bacterial numbers in ocean water columns with plutonium distributions. A recent cruise in the northeastern Pacific presented the oppoertunity to sample water over the Aleutian Trench in a location near to GEOSECS station 218, also located in the Aleutian Trench. Results presented by Bowen et al. (1980) are convincing in the stability of these high Pu water masses and in their widespread occurrence. Thus I feel it is appropriate to compare results of bacterial counts from water samples taken in 1981 to radiochemical data from GEOSECS samples obtained in 1973. Preliminary radiochemical results (D. M. Nelson, personal communication) confirm the validity of this comparison. Distributions of $^{239,240}Pu$ from RAMA 15, station 1, are nearly identical to those from GEOSECS station 218.

The results of the bacterial counts show that there is an increase in bacterial numbers from the surface to 100 m. This is as might be expected in waters as productive as those over the Aleutian Trench (Larrance 1971). From 100 m to the deepest sample, the decline in numbers of bacteria is similar to that reported from RAMA 02, station 178 (Carey and Bowen, submitted) and also similar to what would be expected in most oceanic water columns. There seems to be no correlation, either positive or negative, of the numbers of bacteria with the concentrations of Pu in the water column. The broad Pu maximum centered around 300 m seems to be independent of the bacterial distributions.

The increase in Pu concentration in the deep waters, from about 5000 m to the bottom, is not paralleled by an increase in bacterial numbers. However, there is a greater proportion of morphologically distinctive cells in the deep samples. This observation fits well with the observed high standing crop of benthic organisms (Jumars and Hessler 1976) and the high O_2-consumption data reported by Pamatmat (1973).

Conclusions

The microbiological and radiochemical analyses of water of the Aleutian Trench presented here corroborate previous results from waters in the central N. Pacific which exhibit similar distributions of bacterial numbers and Pu concentrations. These results further the conclusion that despite their major contribution to the biomass in ocean water columns (Watson 1978) bacteria are probably not primary vectors in the control of Pu distributions in oceanic waters.

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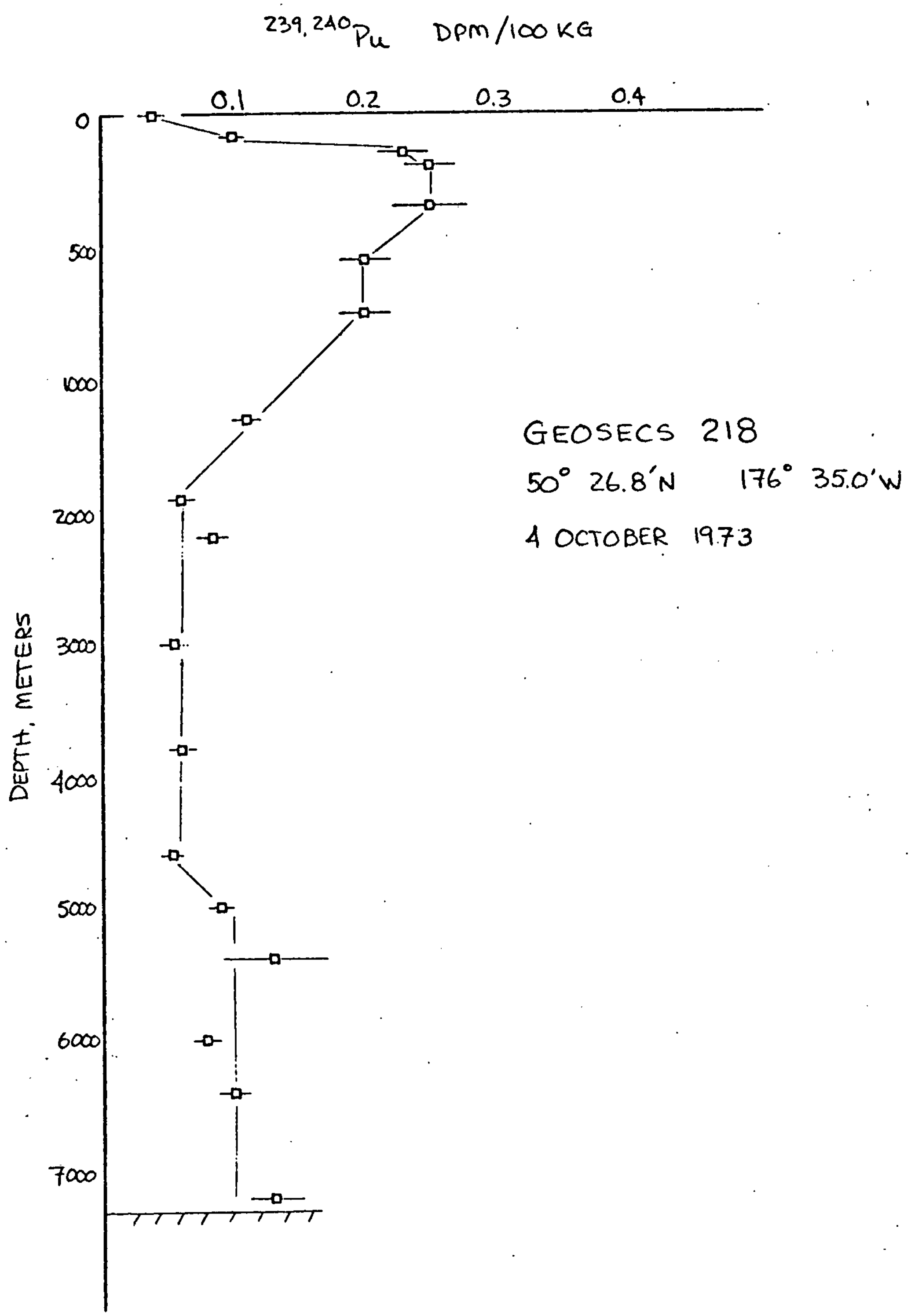
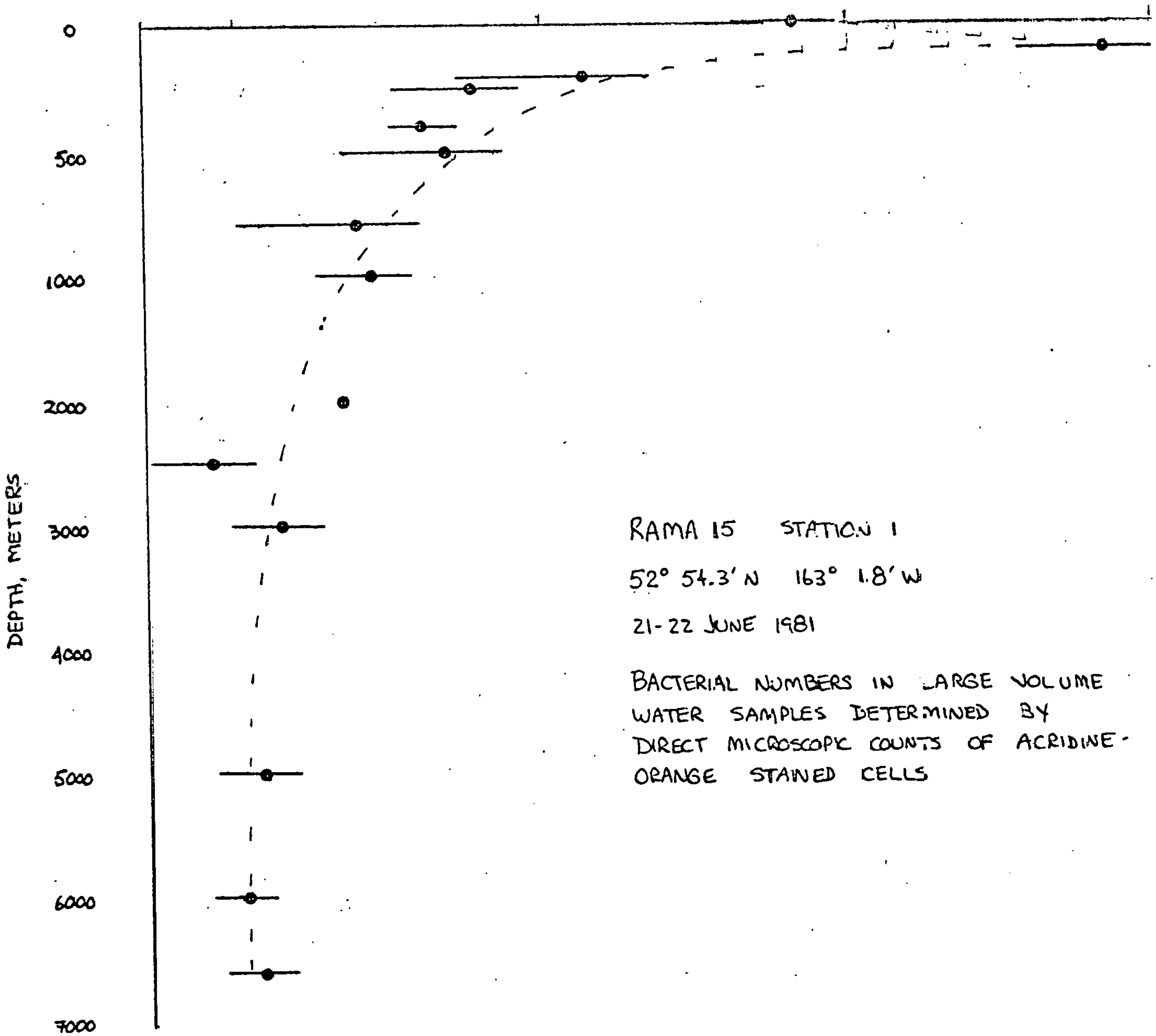
FIGURE LEGENDS

1a. Concentrations of $^{239,240}Pu$ in water samples from GEOSECS station 218, at 50° 26.8'N, 176° 35.0'W. The samples were taken on 4 October 1973. Horizontal bars represent 1-sigma uncertainties from the counting statistics. Sonic depth at this station was 7301 meters. Calculated $^{239,240}Pu$ inventory in the water column is 3.29 mCi/km^2.

1b. Bacterial numbers in water samples from RAMA 15, station 1, at 52° 54.3'N, 163° 1.8'W. The samples were taken on 21-22 June 1981. Horizontal bars represent 1-sigma uncertainties from counting ten or more replicate fields. Sonic depth at this station was meters.



$^{239,240}Pu$ DPM/100 KG
0.1
0.2
0.3
0.4
0
500
1000
2000
3000
4000
5000
6000
7000
DEPTH, METERS
GEOSECS 218
50° 26.8'N 176° 35.0'W
4 OCTOBER 1973


DEPTH, METERS
0
500
1000
2000
3000
4000
5000
6000
7000
RAMA 15 STATION 1
52° 54.3′ N 163° 1.8′ W
21-22 JUNE 1981
BACTERIAL NUMBERS IN LARGE VOLUME WATER SAMPLES DETERMINED BY DIRECT MICROSCOPIC COUNTS OF ACRIDINE-ORANGE STAINED CELLS

X. PHYSICAL OCEANOGRAPHIC STUDIES

Technical Program Coordinator: S. L. Kupferman

Introduction

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Pu Oxidation States in the Aleutian Trench and Central North Pacific

V. T. Bowen, Woods Hole Oceanographic Institution (presented by S. L. Kupferman) 363

Physical Oceanography Research Plan and General Overview

S. L. Kupferman, SNLA

At the Big Sky Workshop in January 1981 there was an initial assessment of processes relevant to a subseabed prediction model. On the basis of this information, a research plan was put together for the Physical Oceanography group by S. L. Kupferman and M. G. Marietta. Based on a preliminary assessment of the results of the Big Envelope meeting in September, 1981, we do not believe that the basic thrust of this research plan will be changed.

The start of a Sandia-funded field program (with the exception of the presently active radioisotope program) will probably be delayed at least until FY 1984 because of funding constraints. The modeling will proceed as outlined in the post-Big Sky research plan. We plan that models will be up, running and interfaced by August 1982; this will leave us sufficient time to conduct sensitivity studies in preparation for writing the status report in FY 1983.

We anticipate that the Big Envelope meeting report will be ready to go to the printers in FY 1982.

PRINCIPAL TASKS FOR PHYSICAL OCEANOGRAPHY

1) Understanding the Barrier Properties of The Water Column

2) Evaluation of the Consequences of Dilution and Dispersion of Radionuclides Inadvertently Released by Repository or Transportation Accidents

3) Assist in the Development and Implementation of a Program for Assessing the Oceanic HLW Disposal Plans of Other Nations

Method of Implementation - Numerical Modeling

MODELING PHILOSOPHY

1. Obtain best available models.

2. Upgrade by including additional physical processes judged to be important. Develop new models if necessary.

3. Verify by experiment that all physical processes are represented correctly.

PHILOSOPHY REQUIRES

1) STRONG IN-HOUSE MODELING PROGRAM SUPPORTED BY CONSULTANTS WHO HAVE DEVELOPED THE MODELS WE ARE USING

2) BEST AVAILABLE INFORMATION ABOUT RELEVANT OR POTENTIALLY RELEVANT PHYSICAL AND OTHER PROCESSES, UPDATED ON A CONTINUING BASIS.

3) BEST INFORMATION ABOUT RELEVENT EXPERIMENTAL AND FIELD DATA FOR USE IN VERIFICATION

INCLUDES HYDROGRAPHIC, CURRENT METER, FLOAT DATA

AND ALSO

NATURAL AND MAN-MADE RADIOISOTOPE AND OTHER TRACER DATA

SATISFY REQUIREMENTS BY MEANS OF BIG ENVELOPE MEETING ALONG WITH CONTINUING CONSULTANT INPUT

AND

SUPPORT OF TRACER MEASUREMENT PROGRAM AT WHOI - PU PROMISING TRACER

PERSONNEL

S. L. KUPFERMAN (SNL)	TPC
M. G. MARIETTA (SNL)	MODELING, DELEGATE TO SWG SYSTEMS ANALYSIS TASK GROUP
V. T. BOWEN (WHOI)	RADIOISOTOPE TRACER MEASUREMENTS AND DATA INTERPRETATION
A. R. ROBINSON (HU)	CHAIRMAN OF P. O. STEERING COMMITTEE, PRINCIPAL MODELING CONSULTANT, U. S. DELEGATE TO SWG P. O. TASK GROUP
E. S. HERTEL (PR)	COMPUTATIONAL PHYSICIST

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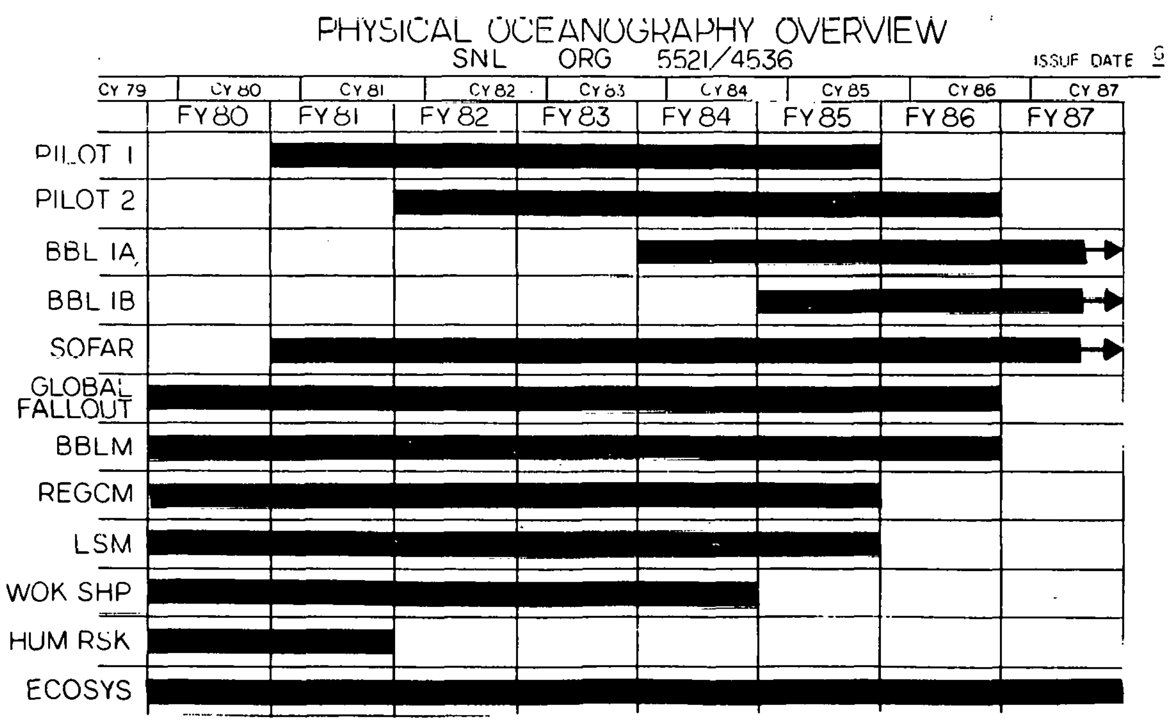


Big Envelope Meeting

A. R. Robinson, Harvard University

The presentation summarized in a preliminary form the findings of a workshop held in September 1981 in order to apply existing knowledge in physical oceanography and related ocean science to the task of the physical oceanography component of the Environmental Sciences section of the SDP. The presentation is well introduced and summarized by quoting from the first draft of the meeting report introduction:

"This report attempts to deal in a comprehensive way with the physical processes relevant to the time history of dissolved material emanating from a source somewhere on the deep bottom of the world's ocean. In addition, it deals with some of the related chemical, and to a lesser extent biological, processes which are important if the material is reactive and interactive. Some of these physical and related scientific processes are well known, some are poorly understood, and indeed, others may as yet remain undiscovered. The physical processes that are known and that may influence the dispersion of the material throughout the ocean are catalogued and comprehensively discussed in this report. Those processes that are poorly understood are noted along with research recommendations for acquiring adequate comprehension. Those chemical and biological processes that are believed to interact with the physics in determining the dispersion of the material are also noted and their contact points indicated. The format adopted to organize the presentation is to follow a passive tracer from its initial dispersion within the bottom boundary layer, through its transport by various processes, into the overlying deep water column, through its subsequent course of mixing and stirring as its overall size increases from mesoscale to planetary scale. Processes are described in general formulas, numerical ranges of quantitites are given and available uncertainties presented. Within the development of this comprehensive release description of Section II, when processes of a general nature, such as small scale vertical mixing, are indicated, a connection is made to Section III, which deals with fundamental processes and internactive processes not restricted to the physics of dissolved material. Section III also discusses various statistical and deterministic measures of concentration distribution. Section IV deals with geographical questions concerning both fundamental processes and the large scale consequences of release from some specific sites. This report is intended to act as a necessary and updateable physical framework for more complete considerations of the fate of released radionuclides and for site specific release scenarios. It serves as a quantitative vehicle for the identification of critical research requirements. these are presented both as they occur in context and then summarized, integrated, and discussed in Section IV.

"The meeting and the preliminary working group sessions upon which this report is based was called to evaluate and carry on some of the calculations needed to determine the relative importance of processes previously identified (Marietta and Robinson, 1980) as bearing most closely on the problem of describing and predicting the dispersion of radionuclides released from a source on the deep sea floor and to develop research priorities for measuring parameters or elucidating processes which have emerged as key, based on the work carried out at this meeting. A problem of this nature touches on almost all aspects of oceanographic science since it encompasses processes over the widest range of time and space scales. In order to arrive at a useful description and predictors of environmental impact, we have elected as a ased problem to consider the concentraction field of a dissolved substance releasted from a ddep ocean bottom source since the solution of the problem will be a fundamental component of any solution in which the released consituent displays more complex, reactive behavior. Thus, when the problem of the behavior of a bottom released dissolved constituent has been successfully considered, we can examine and compare the behavior of various classes of chemical elements, having differing chemical and biological cycles, in a rational and systematic manner. to this end, the attendees at the meeting comprised mainly physical oceanographers, expert in areas believed on the basis of preliminary efforts to be critical to the dissolved constituent prediction problem. Also present were a number of chemists, biologists, and geochemists with wide ranging interests, whose primary function was to indicate areas where nonphysical oceanographic processes could have critical influences on concentration fields of various classes of dissolved elements.

"With this quantitative framework of physical processes, including points of interaction with biological, chemical, and particulate processes, the SDP can (1) incorporate the best process parameterizations now available in numerical models for simulating test releases, (2) proceed in a logical manner to study more difficult parts of the physical oceanographyic problem for which existing applicable knowledge is not yet available, (3) identify important processes that must be studied numerically in order to estimate their relative importance to this problem, (4) analyze specific release scenarios by employing the included simple calculations, (5) incorporate explicitly and by state-of-the-art parameterization relevant processes in a hierarchy of circulations models for release simulations, and (6) pursue an orderly quantification of required biological and chemical interactions. This report will serve as a work plan which can be updated when necessary and provide guidance for scientists involved in deep ocean waste disposal for several years."

The presentation included reporting of important quantitative findings which are still under review by the participating experts, and therefore are not included in the published version in the annual report. Interested parties can contact Dr. S. L. Kupferman at SNL for further information.

BIG ENVELOPE MEETING

RECOMMENDATION OF BIG SKY PHYSICAL OCEANOGRAPHY WORKSHOP

HELD AT SCRIPPS INSTITUTION OF OCEANOGRAPHY, SEPTEMBER 9-12, 1981

HOST: A. YAYANOS

CONVENERS: A. R. ROBINSON AND S. L. KUPFERMAN

ADMINISTRATIVE AND LOGISTICAL ASSISTANT: K. JONES

PURPOSE

1. EVALUATE AND CARRY OUT SOME OF THE CALCULATIONS NEEDED TO DETERMINE THE RELATIVE IMPORTANCE OF PROCESSES IDENTIFIED AT THE BIG SKY WORKSHOP AS BEARING THE MOST CLOSELY ON THE SDP P. O. PREDICTION PROBLEM (I.E. FIND KEY PROCESSES).

2. DEVELOP A DETAILED RESEARCH STRATEGY FOR A) MEASURING KEY PARAMETERS, B) TESTING THE MODELS TO BE DEVELOPED.

3. IDENTIFY AND DETERMINE THE IMPORTANT INTERFACES BETWEEN P. O. AND OTHER TECHNICAL ELEMENTS OF THE PROGRAM, AND QUANTIFY THEIR IMPACT.

PRELIMINARY PLANNING

SELECTION OF SPECIAL SUBAREAS TO BE ADDRESSED

(JOHN EDMOND, STUART KUPFERMAN, PETER RHINES, ALLAN ROBINSON, NOVEMBER, 1980, CAMBRIDGE, MA.)

1) EXCHANGE PROCESSES BETWEEN BBL AND THE DEEP WATER FOR THE CASE OF A FLAT OR SLOPING BOTTOM OR FOR GENERAL TOPOGRAPHY.

2) CROSS ISOPYCNAL AND CROSS FRONTAL MIXING PROCESSES INCLUDING HIGH LATITUDE RESPONSE AND COASTAL BOUNDARIES.

3) SIMPLEST RELEVANT STATISTICAL MEASURES OF TRANSPORT DISTORTION, DILUTION AND EXCHANGE FROM LOCALIZED SOURCES AS FUNCTIONS OF TIME AND SPACE SCALES, INCLUDING A REVIEW OF SOLITON OBSERVATIONS.

4) INFERENCES ABOUT CIRCULATION AND GYRE PERMEABILITY FROM BOTH NATURAL AND MAN-RELATED CHEMICAL, RADIOCHEMICAL AND ISOTOPIC SOURCES.

TOPICAL SUBGROUPS

1) <u>Bottom Boundary Layer</u>: L. Armi (SIO, Chairman)
G. L. Weatherly (FSU), M. Wimbush (URI)

2) <u>Small Scale</u>: C. Garrett (DU, Chairman)
C. S. Cox (SIO), R. Schmitt (WHOI)

3) <u>Meso Scale</u>: G. Holloway (UW, Chairman)
R. Davis (SIO), A. R. Robinson (HU), T. Rossby (URI)

4) <u>Large Scale</u>: J. L. Reid (SIO, Chairman)
K. Bryan (GFDL/PU), K. Cochran (WHOI), J. M. Edmond (MIT), J. Sarmiento (PU), B. Taft (UW)

Unassigned: B. Hargrave (BI), N. Hogg (WHOI)

Overview Group: A. R. Robinson (HU), S. L. Kupferman (SNL), M. G. Marietta (SNL), E. Hertel (PR)

USES OF MEETING RESULTS

- INCORPORATE THE BEST PROCESS PARAMETERIZATIONS AVAILABLE IN NUMERICAL MODELS FOR SIMULATING TEST RELEASES
- PROCEED IN A LOGICAL MANNER TO STUDY MORE DIFFICULT PARTS OF THE PHYSICAL OCEANOGRAPHIC PROBLEM FOR WHICH EXISTING APPLICABLE KNOWLEDGE IS NOT YET AVAILABLE
- IDENTIFY IMPORTANT PROCESSES THAT MUST BE STUDIED NUMERICALLY IN ORDER TO ESTIMATE THEIR RELATIVE IMPORTANCE TO THIS PROBLEM
- ANALYZE SPECIFIC RELEASE SCENARIOS BY EMPLOYING THE INCLUDED SIMPLE CALCULATIONS
- PURSUE AN ORDERLY QUANTIFICATION OF REQUIRED BIOLOGICAL AND CHEMICAL INTERACTIONS

REPORT:

DISPERSAL FROM DEEP OCEAN SOURCES: PHYSICAL AND RELATED SCIENTIFIC PROCESSES.

"TIME HISTORY OF DISSOLVED MATERIAL RELEASED AT THE SEA BOTTOM"

A PROCESS ORIENTED GENERAL SCENARIO

- PROCESSES QUANTIFIED WITH ± ESTIMATES, "HOLES"
- SITES OF INTEREST (OR OF KNOWN PROPERTIES) DISCUSSED
- "HOOKS" FOR BIOLOGICAL AND CHEMICAL PROCESSES
- CRITICAL RESEARCH RECOMMENDATIONS GENERATED

FIRST CUT AT AN ENDURING, IMPROVABLE CENTRAL FRAMEWORK WHICH CAN BE USED FOR EXAMINING AND COMPARING THE BEHAVIOR OF VARIOUS CLASSES OF CHEMICAL ELEMENTS, HAVING DIFFERING CHEMICAL AND BIOLOGICAL CYCLES, IN A RATIONAL AND SYSTEMATIC MANNER

BIG ENVELOPE RESEARCH RECOMMENDATIONS

- SITE SPECIFIC CURRENT AND HYDRO STATISTICS - DEEP AND BBL (PROCESS IDENTIFICATION)
- BBL/INTERIOR EXCHANGE MECHANISM EXPTS.
- HIGH RESOLUTION MODEL SIMULATIONS FOR EDDY DISPERSION AND STREAKS
- COHERENT O(10 km's SEPARATION) RELEASE OF FLOAT CLUSTERS - MANY INDEPENDENT REALIZATIONS AT SITE
- TEMPERATURE MICROSTRUCTURE IN ABYSSAL OCEAN FOR DIRECT MEASUREMENT OF VERTICAL MIXING
- SYSTEMATIC MODELING OF DEEP CIRCULATION - TEST ALL TRACERS
- DIRECT DEEP CIRCULATION MEASUREMENTS THRU CHANNELS CONNECTING SOUTHERN OCEAN WITH BASINS AND BASINS WITH EACH OTHER
- MEASUREMENTS TO DEFINE FURTHER DEEP Pu IN NORTH PACIFIC AND RESEARCH ON BIO/CHEMICAL PROCESSES INFLUENCING CONCENTRATION
- DISCRETE EDDIES (LENSES) SURVEY OCCURENCE OF ANOMALOUS WATER PROPERTIES AND SEED FLOATS
- STUDY FEASIBILITY OF DYE RELEASES FOR MIXING/STREAKING
- BOUNDARY EFFECTS RESEARCH - SLOPES, SEAMOUNTS, CANYONS, RIDGES

Sandia Laboratories

Albuquerque, New Mexico
Livermore, California

date: October 23, 1981

to: D. M. Talbert, 4516

from: M. G. Marietta, 5521

subject: Annual Meeting Abstract

The environmental modeling program is concerned only with accident scenarios for the SDP although it applies directly to ongoing or future low-level disposal options that do not involve emplacement of the wastes in the sediments beneath the water column. The problem is to trace the radionuclide migration from a bottom source of relatively small initial dimension through the oceanic water column, including the inorganic and living/non-living organic material within it, to wherever the waste material comes into contact with man. We must know where the released waste material goes, when it gets there, and how much gets there in order to do a complete radiological assessment for doses to man. Along the way, we need to know how much of the material is taken up by selected marine species in order to do a radiological assessment for dose to biota. These two parts of the program objective for evaluating environmental feasibility must be studied on all space and time scales from source scales to the ultimate fate of the released radionuclides in the world ocean.

In order to accomplish a preliminary radiological assessment by the end of FY83, an ambitious modeling program was initiated. Our approach was to identify the best existing ocean models for each part of the dispersion problem, bring these models to SNLA with the best historical data that we could assemble, modify the models for waste disposal purposes, and then interface them in a scientifically reasonable, yet realistic, way. The modeling problem was divided into three parts corresponding to different regions (space scales) of the water column: the bottom boundary layer, a regional scale (an open block of ocean of about 1000 km), and the large scale (from regional up to full basin scale or even the world ocean). Between these parts, there are modeling problems concerned with the interfacing of the bbl model with various important sediment transport processes, the exchange processes between the bbl and the mesoscale or regional model, the embedding of the regional model in the larger scale model, and the interfacing of the various transport models with the ultimate radiological assessment.

Toward this end, last year we reported that (1) the one-dimensional bbl model from Florida State University had been acquired and modified for waste disposal studies; (2) the two-dimensional open-ocean regional-scale model from Harvard was operational at SNLA; i.e., test problems had been reproduced; and (3) the three-dimensional large-scale model from GFDL was also operational at SNLA.

During the past year, some one-dimensional bbl sensitivity and process studies have been completed, and a three-dimensional bbl model has been outlined. The processes studied with the one-dimensional model have been spatially varying topography, up/down-slope pumping, and the effects of a time-varying forcing velocity. Next year the three-dimensional model should be available for extensive process studies including exchange processes between the bbl and the overlying water. Also, an additional bbl activity has been to use the ecosystem box model to simulate carbon flux in the deep ocean. This represents a step toward eventually interfacing the bbl sediment, biological, and chemical processes with a bbl physical circulation model.

The large scale work was not vigorously pursued this past year due primarily to time and manpower constraints. World wind stress, temperature, salinty, and topograhic data was provided by GFDL so we can begin large scale simulations of the N. Atlantic, N. Pacific, and World Ocean circulation. Some program modificiation will be required for waste disposal purposes, but GFDL has also helped with these changes. We expect to have the capability of simulating releases at these large scales very soon. Of course, an extensive study of the model characteristics will be required before model results can be properly evaluated and used. How this work is accomplished will depend on available resources.

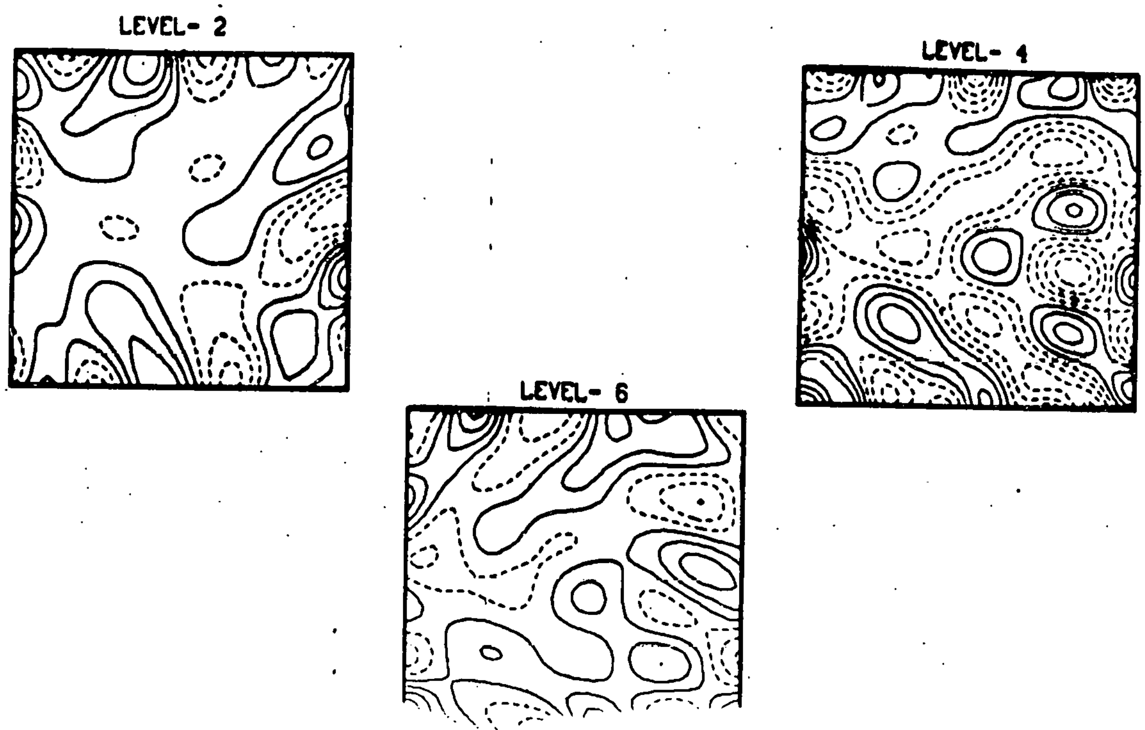
Most of the modeling effort during the last year was spent on the regional scale work. Using the two-dimensional open-ocean model, a careful resolution study was finished, an extensive study of the system for filtering small grid scale noise was completed, and a systematic extension of the model in physical parameter space, essentially from the MODE region to the Kuroshio Extension region, was begun. A companion two-dimensional dispersion program was written and a resolution study completed. Simulated releases of material in an eddy field driven by real ocean data (MODE region) and an evaluation of appropriate diagnostics for such releases was begun. A study using these models to look at particulate scavenging, biological repackaging, and particulate breakdown was started. This is the first step for interfacing the biological, chemical and particulate processes with the physical processes at this scale. A three-dimensional open-ocean model, which is an extension of the two-dimensional model, was acquired from Harvard, and this model is now operational at SNLA. The studies which have been completed with the two-dimensional model will now be extended with the three-dimensional model including the extension of the dispersion program to three-dimensions.

MGM:5521:njm:0162D

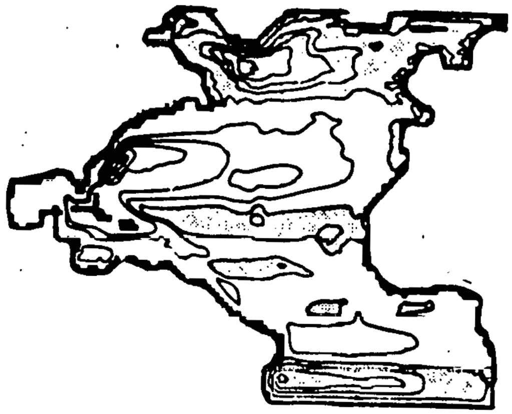
MODEL		TYPE	SOURCE	MODIFY	INTERFACE CHEM/BIOL	INTERFACE MODELS	POSSIBLE TRACER TEST
BBLM	1-D	FD	FSU	—	—	—	—
	3-D	FD(?)	SNLA	—	YES	BBL/REM EXCHANGE PROCESSES	^{222}Rn, ^{228}Ra, Cu, C, N
REM EGCM 2-D	CIRC	FE	HARVARD	YES	YES		
	DISP	FE	SNLA	—			
3-D	CIRC	FE	HARVARD	YES	YES	MODEL EMBEDDING	^{230}Th, ^{210}Pb, ^{210}Po, ^{3}He, ^{228}Ra
	DISP	FE	SNLA	—			
LSM	3-D	FD	GFDL	YES	YES		^{3}H, Pu, Mn

TIME- 15.17

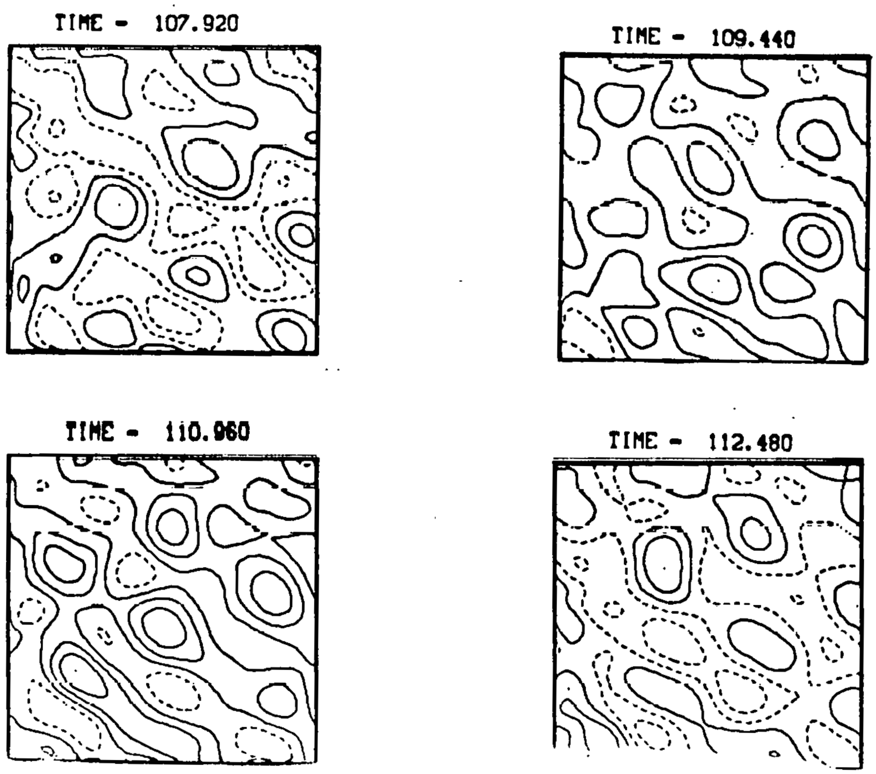
STREAMFUNCTION CONTOURS FOR A BAROCLINIC MODE SIMULATION WITH SIX LEVELS



VERTICALLY INTEGRATED STREAMFUNCTION FOR THE NORTH ALTANTIC



STREAMFUNCTION CONTOURS FROM A MODE REGION SIMULATION STARTING AT 18 PERIODS



Pu Oxidation States in the Aleutian Trench and Central North Pacific

V. T. Bowen
Woods Hole Institution of Oceanography

In last year's Progress Report we described the results of our first two cruises using in situ pumps, filters and chemisorption cartridges in the central N. Pacific water column. The most notable points were that:

a) In the upper part of the water column (1500m and less) particle-associated Pu ranged only 4% to 10% of the total, but at 3000m was 25 to 43% of the total; below 3000m the particulate fraction appeared to fall again to about 4-5% until, just over the bottom in the deep high-Pu layer, it was less than 2%.

b) Ratios of ^{241}Am to ^{239,240}Pu in the dissolved phase ranged 10 to 30%, whereas in the particulate phase they ranged mostly above 100% and as high as 300%.

c) Ratios of ^{55}Fe to ^{239,240}Pu in the particulates were much higher in 1980 than in 1979; in 1980 they ranged 250 to 400, except at the shallow Pu maximum, where the ratio was 30, and in the deep high Pu layer where it exceeded 2500.

Since reporting those data we have gathered a substantial amount of new data from the same set of samples. We have also, working in cooperation with Don Nelson (Argonne), obtained the first open-ocean water column measurements of Pu oxidation states. These data are set out in Tables IV-E-1 and IV-E-2

The oxidation state data especially are quite exciting:

1) In the upper part of the water column (300m to the surface) oxidized and reduced Pu are present in subequal amounts, the ratio probably

not significantly different from 1, considering the measurement uncertainty.

2) In the shallow Pu maximum and below it down to 750m, this ratio falls to the range 0.5 to 0.7 -- certainly significantly different from 1. Furthermore, in this layer, 5/6 to 7/8 of the oxidized Pu is apparently present as 5-valent.

3) It appears probable that below 1000m the oxidized"reduced ratio returns to about 1, until one reaches the deep high-Pu layer.

4) In the deep high-Pu layer, however, this ratio drops to 0.1 or less.

On the Aleutian Trench cruise of R.V. THOMAS WASHINGTON in 1981 (see above in Section II) oxidation-state tracers and acids were added to 1/2 the water barrels filled, and these samples brought back to Argonne for analysis. We have not yet seen the data, but telephoned reports from Nelson show the following differences:

5) Over the Trench the whole water column, including the shallow Pu maximum shows oxidized:reduced Pu ratios about 1, down to the depth of the Trench sill.

6) In the Trench, which is filled (as it was when sampled in 1973 on GEOSECS) with high-Pu water, the ratio of oxidized to reduced Pu falls to 0.1 or less, as it did in 1980 in the high-Pu-deep water.

7) The data also show that the Pu concentrations at the shallow Pu maximum, and in the high-Pu bottom water have not changed since 1973; the shape of the Pu concentration curve at the shallow Pu maximum does appear somewhat broadened, the maximum concentration of 0.25 dpm per 100 kg extending from about 250 to 800m, whereas in 1973 it was seen only at about 250 and 400m depths.

Analysis of fractions of these samples is still proceeding. It will be evident, from the data summary above, that the loss of information, because of the incomplete sampling on this cruise, was really serious.

Another point addressed by the 1980 data is the position of the eastern edge of the deep high-Pu layer in the N. Pacific. On Figure IV-E-1 the positions of the three relevant GEOSECS (1973) stations are set out: the unringed station at 150°W showed no evidence of the deep high Pu layer, whereas it was present at both the station about 160°W and that about 168°W. On the 1980 cruise, it was strongly present at the station (one occupation) at 163°W (double-ringed), while at the station at 158°45'W (double-ringed) the data suggest we were just at its edge: The station was occupied 7 times in the period 29 April to 17 May 1980; on 5 of these days the high-Pu deep layer was strongly present, on one it was absent, clearly, and on one Pu concentrations were definitely increasing toward the bottom, even though the highest concentration, about 0.09 dpm Pu, was less than the 0.10 we usually use as our criterion. It is even more interesting when one arranges the occupation by time: on 29 April no High-Pu deep layer, on 29/30 April the beginning of its development, and from 3 to 17 May the layer always present. This appears to us to tie down the general position of the eastern edge of this layer as well as could be, to suggest there has been no major movement of the edge from 1973 to 1970, but to hint, at least, that the edge undergoes appreciable excursions that are either seasonal or lunar. Further investigation of this should be undertaken.

TABLE IV-E-1

PARTICULATE VS TOTAL ACTINIDES AND IRON-55
IN N. PACIFIC WATER COLUMNS - 1980

	SAMPLES*		^{239}PLUTONIUM		SOLUBLE		PARTICLES	
Sta.	Depth m.	Volume l.	Whole Water dpm.100 kg^{-1}	Particles	Am/Pu	^{55}Fe/Pu	Am/Pu	^{55}Fe/Pu
105	Surface	210						
178	"	530	0.038±0.003	11.6	0.14±0.03	58±13	0.91±0.23	250±64
158A	"	526						
111	300	167						
142	550	338	0.508±0.018	4.3	0.17±0.01		3.05±0.31	30±18
161	550	777						
153	750	201						
177	3000	672	0.040±0.004	25.1	0.27±0.04	480±317	0.61±0.11	380±50
165	5600	650	0.097±0.019	4.4	0.18±0.04	^{55}Fe=0	1.63±0.32	370±110
162	5800	608	0.17±0.03	1.3	0.08±0.04	21±19	2.32±0.53	2545±516

*Samples collected in situ with battery powered pump, Microwynd Filter and MnO_2 chemisorptive cartridge

TABLE IV-E-2

PLUTONIUM OXIDATION STATES IN N. PACIFIC WATER COLUMN - 1980

SAMPLES*			^{239,240}Pu in disintegrations per minute per 100 kg				
Sta.	Depth m.	Latitude N.	TOTAL	REDUCED$^{\Delta}$ (III or IV)	OXIDIZED (V and/or VI)$^{+}$	OXIDIZED (V)^{X}	RATIO (III-IV)/(V-VI)
107	Surface	29°59.7'	0.044±0.005	0.020±0.004	0.024±0.005		0.83
			0.053±0.005	0.031±0.004	0.022±0.005		1.40
135	Surface	30°02.8'	0.042±0.005	0.020±0.002	0.022±0.002		0.91
			0.044±0.005	0.019±0.002	0.024±0.002		0.79
101	Surface	24°01.5'	0.056±0.006	0.028±0.007	0.027±0.007		1.04
116	300	30°01.2'	0.330±0.006	0.171±0.008	0.157±0.008		1.09
			0.320±0.020	0.157±0.016	0.160±0.016		0.98
101	550	24°01.5'	0.595±0.04	0.162±0.011	0.43 ±0.017		0.38
			0.675±0.04	0.235±0.010	0.44 ±0.014		0.53
120	550	30°03.0'	0.600±0.03	0.238±0.01	0.364±0.01		0.65
			0.645±0.04	0.238±0.01	0.407±0.016		0.58
161	550	29°57.3'	0.650±0.04	0.240±0.015	0.407±0.015	0.344±0.017	0.59
166	550	30°02.5'	0.535±0.04	0.206±0.012	0.329±0.017	0.251±0.013	0.63
125	750	30°04.4'	0.295±0.018	0.122±0.007	0.173±0.008		0.71
			0.293±0.020	0.120±0.009	0.173±0.012		0.70
150	3000	29°59.8'	0.073±0.007	0.033±0.003	0.040±0.003		0.83
			0.062±0.008	0.042±0.004	0.020±0.003		2.10
135	5600	30°02.8'	0.116±0.012	0.011±0.004	0.105±0.008		0.104
			0.120±0.013	0.011±0.002	0.109±0.007		0.101

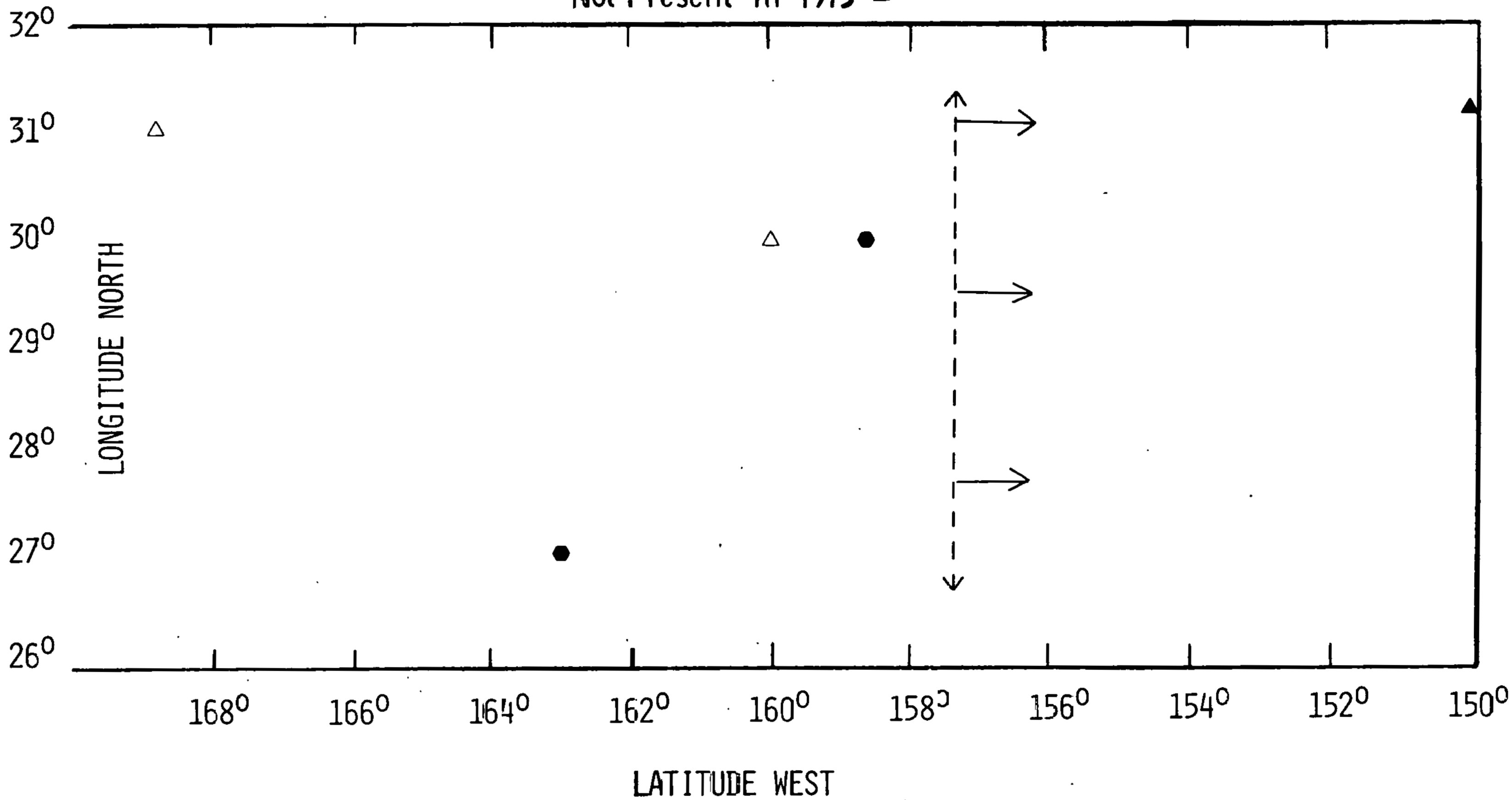
* Samples from 160-1. Bodman Bottles; Pu separations done on ship as soon as samples retrieved.

$^{\Delta}$ NdF_3 pptte in presence of $Cr_2O_7^{=}$ and excess $SO_4^{=}$.

$^{+}$ NdF_3 pptte after treating filtrate from above (Δ) with excess $FeSO_4$.

^{X} NdF_3 pptte from filtrate after SiO_2 adsorption (pH 7) of Pu III, IV, VI.

FIGURE IV-E-1
NORTH PACIFIC DEEP HIGH Pu LAYER
EASTERN EDGE: 1973-▲ ; 1980-●
Not Present In 1973-△



XI. INSTRUMENTATION DEVELOPMENT

Technical Program Coordinator: D. M. Talbert

Instrumentation Development Activities
D. M. Talbert, SNLA 371

Long Core Facility
A. H. Driscoll, University of Rhode Island 372

LCF: Modeling Summary
C. Karnes, SNLA 385

Instrumentation Development Activities

by

D. M. Talbert

There are currently six major instrumentation development activities in the SDP exclusive of the ISHTE project. Three of these activities were being actively pursued during FY 81; three existed in some state of suspension. These six development activities included the Long Coring Facility (LCF), the Penetrator Survey Instrument (PSI) and the In-Situ Vane Shear (IVS) as active programs and the Sandia Seabed Work Platform, the Giant Conical Net, and the Mobile Abyssopelagic Animal Assessment Acoustic Array as activities currently suspended due to funding limitations.

The LCF will be the only activity reported on in this section. The only PSI activity currently underway is discussed in the Emplacement Studies section. The IVS development is a three part activity: development of a stand alone unit, a unit for the ISHTE simulation laboratory work, and a unit for deployment as part of the full scale ISHTE. Only the ISHTE simulation unit currently exists and is discussed in the Thermal Response Studies section.

The LCF is a joint NSF - Sandia development activity. The SDP commitment through FY 81 to this activity is approximately $629,000. This funding has supported general system definition and development, preliminary configuration definition, and model development at URI and at Sandia. Anticipated funding for FY 82 is approximately $245,000 for the delivery of a phase one instrumentation package suitable for immediate use on the standard piston corers and for ultimate use on the long core.

A general overview of the project and a discussion of the modeling activities are given in this section.

INSTRUMENTATION DEVELOPMENT

- LONG CORING FACILITY (LCF)
- SANDIA SEABED WORK PLATFORM (SWP)
- GIANT CONICAL NET (GCN)
- PENETRATOR SURVEY INSTRUMENT (PSI)
- IN – SITU VANE SHEAR (IVS)
- MOBILE ABYSSOPELAGIC ANIMAL ASSESSMENT ACOUSTICAL ARRAY (MA5)

SUBSEABED ANNUAL WORKSHOP; OCTOBER 1981

DENVER, COLORADO

LONG CORE FACILITY, A.H. DRISCOLL

The stated objective of the Long Core Facility, (LCF), remains that of the design, development, and production of a highly reliable deep sea coring system capable of recovering 50 meter long cores of 11cm diameter from oceanic depths while utilizing a select number of support vessels. Previous modeling work performed by Sandia has confirmed the feasibility of this technique and the current work is concerned with the engineering design of the various sub-systems which compose the LCF. To date, the URI Design Group and LCF Working Group have determined that the 50 meter coring system can be produced utilizing existing technology.

Work during the FY 81 period has been concentrated on the refinement and design of an active piston control system, selection of a suitable barrel coupling design, and design of the core head instrumentation systems. During this work, active input was received from the computer modeling group at Sandia and the refinement of various design concepts subsequently effected. The status of each of the three major tasks pursued during FY 81 is as follows:

1. Active Piston Control

At present two approaches to this problem are being actively pursued by the design group at URI. The first, and primary system is the Hydrostatic Accumulator Piston (HAP) which was selected for development based on its ability to recover a usable sample even in the event of a piston control system failure. In this unlikely event a core would be obtained of no less a quality than that obtainable with conventional coring devices

The HAP system is based on the use of a parachute to provide a restraining force on the piston during coring. The motion of the piston would be controlled by a valve between the evacuated upper section of the HAP and the oil filled lower section. THE HAP will be capable of reducing its length during coring thereby maintaining a consistent piston position during the sequence. This ability will compensate for increases in internal wall friction which result in corer plugging and sample disturbance in conventional devices.

Development of this design is at a point where a reduced length model of the valving and body will be tested during FY 82, along with its associated control electronics.

The second alternative, the Free Activating Piston, (FAP) is under study. Conceptually this system would utilize an independent piston within the barrel string, but unlike the HAP there would be no connection to the deployment cable. Movement of the piston would be controlled by a two stage valve located between the piston and an evacuated chamber in the core head.

By controlling this valve the movement of the piston can be controlled during coring and would be capable of responding to the forces generated by sample drag in the core barrel.

2. Barrel Coupling Design

During FY 81 a finite element analysis of a slip over coupling and a wedge type coupling were performed by the Sandia modeling group. The results of these analysis were inconclusive as to the identification of a singularly superior design. Instead of further analysis a program of physical model testing was developed by the URI Design Group in order to identify an operational coupling design and to provide model confirmation for the Sandia group.

Preliminary model tests utilizing full size coupling sections are currently being prepared in order to evaluate both coupling designs. Based on the results of these tests a second series is planned for FY 82 where actual sections constructed of the HY 80-100 steel will be evaluated at Lehigh University using a 5,000,000 lb. Baldwin facility. Upon completion of these tests a final design of the coupling system will be produced.

3. Core Head Instrumentation

During FY 81 a suite of core head electronic systems was developed which would monitor both the mechanical performance of the corer and provide a sample quality monitoring function. The suite of instruments being developed include 1) Acoustic Release/Altimeter, 2) Rotation and Tilt Recorder, 3) Power and Control Unit, 4) Piston Motion Sensor, 5) Cable Angle Sensor, 6) Telemetry Package, and 7) Deck Unit.

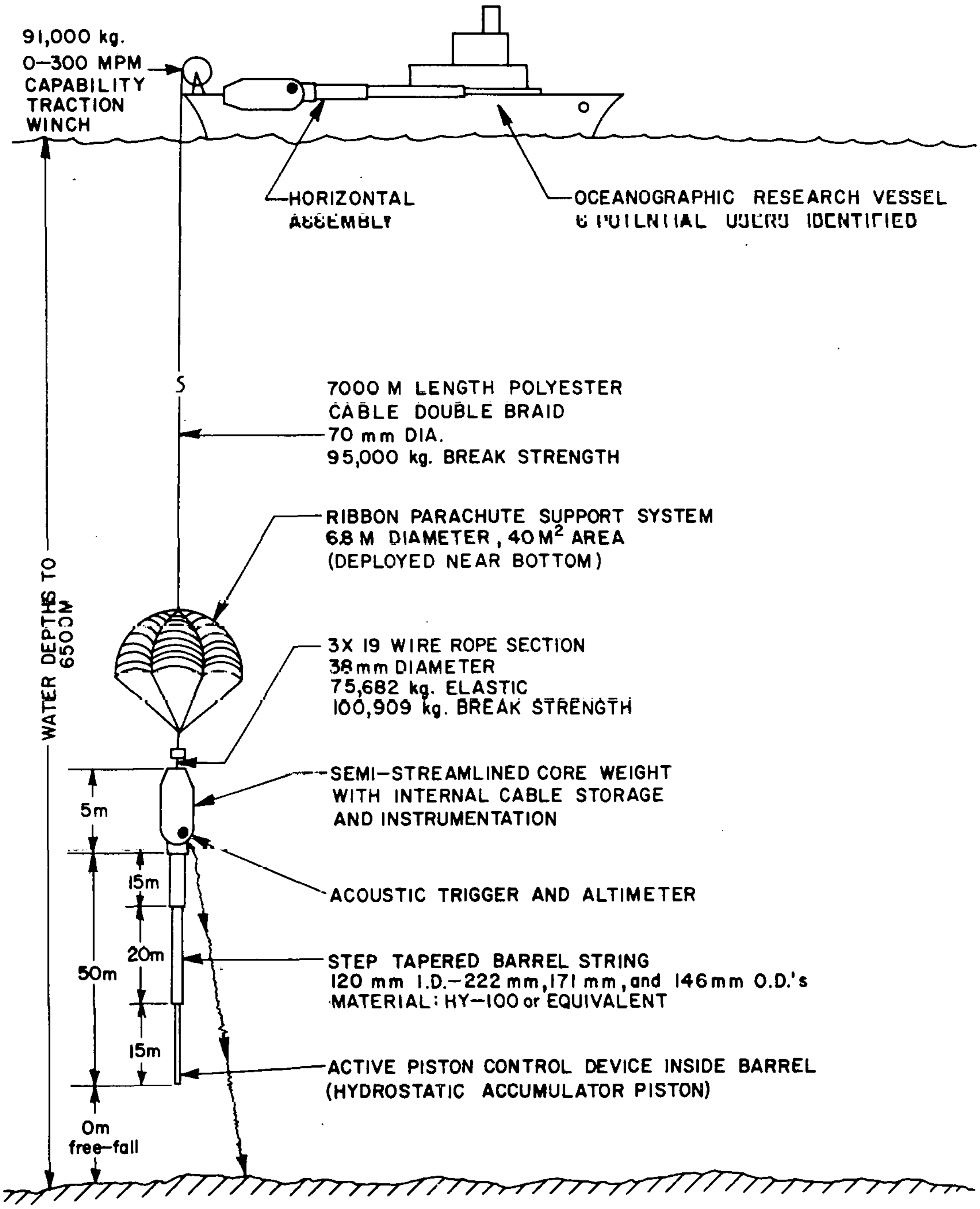
Each individual instrument has been designed to include three distinct sub-assemblies per unit. Under this design scenario the power supply and digital sub-assemblies are common to all instruments and the remaining sensor interface is the only unique sub-assembly. This approach has been taken to reduce design time and to provide as high a level of commonality between instruments as is possible.

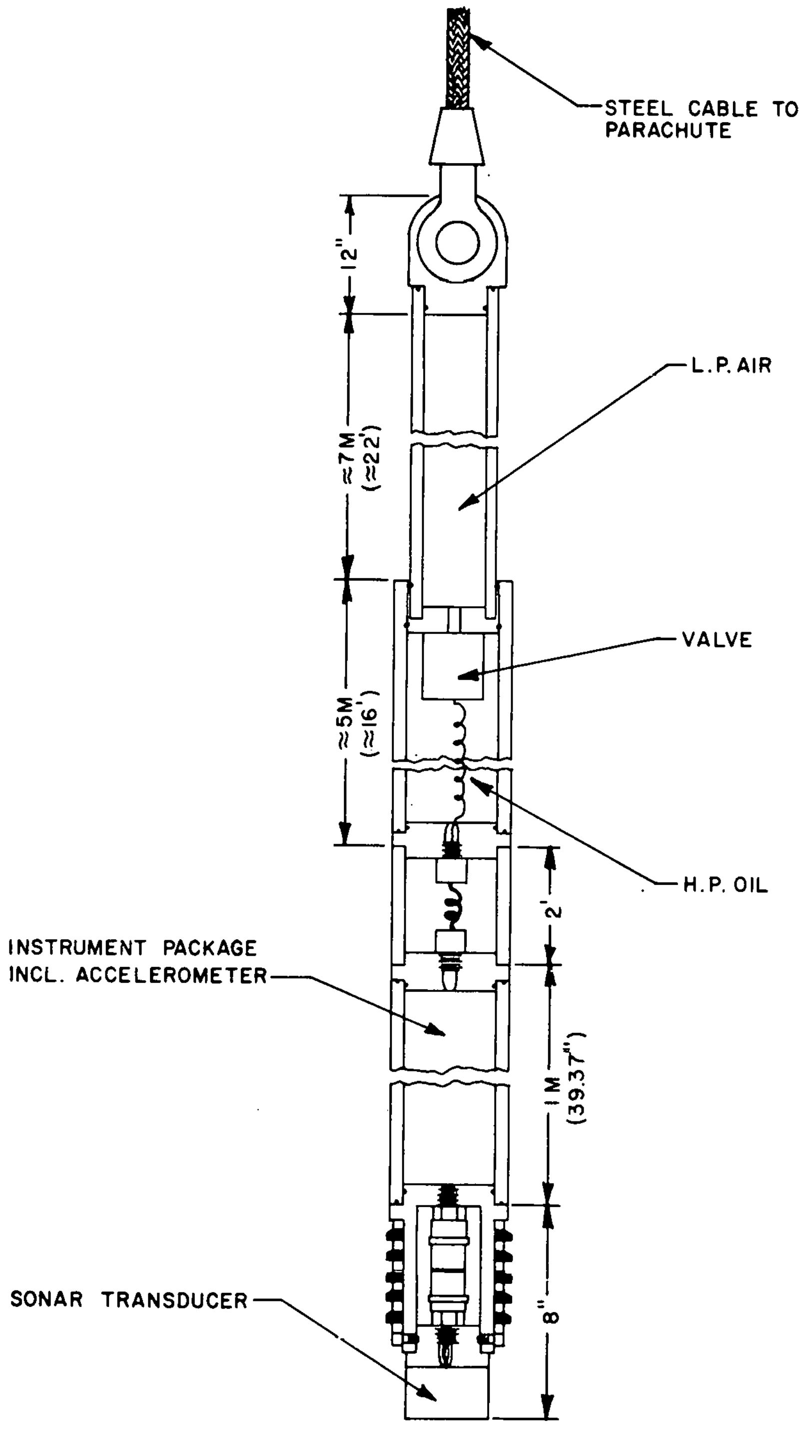
During FY 82 the construction of selected instrument systems will begin and field testing will be accomplished before the end of FY 82. Support for the design of the LCF is presently a duality shared by Sandia National Laboratory (SNL) and the National Science Foundation, (NSF). Under this structure SNL directly supports the development of the core head instrumentation systems and the control components required in the piston control system. The NSF portion of the project is concerned with the mechanical design of the device and its support equipment, i.e. the winch and cable system.

During FY 82, due to the reduction in available research funds, attempts to obtain support outside of the normal funding group will be made. These attempts will take the form of proposal submissions to both the Bedford Institute of Oceanography (Canada) and the RIjks Geologische Dienst. (Netherlands). This approach was deemed practical given the status of the LCF as a scientific facility rather than a single purpose device.

The attached figures display the system configuration as of October 1981 along with details of the various components under development.

LONG CORING FACILITY
GENERAL CONFIGURATION OF SYSTEM




STEEL CABLE TO PARACHUTE
L.P. AIR
VALVE
H.P. OIL
INSTRUMENT PACKAGE INCL. ACCELEROMETER
SONAR TRANSDUCER
12"
≈7M (≈22')
≈5M (≈16')
2'
1M (39.37")
8"

HYDROSTATIC ACCUMULATOR PISTON (HAP)

ALWAYS GET CORE - EVEN IF IT DOESN'T WORK
MINIMAL MAINTENANCE - REPLACE ENTIRE H.A.P. AT SEA
REQUIRES VALVE OPERATION AT 10,000 PSI
VALVE OPERATES IN A CLEAN ENVIRONMENT
HIGH RELIABILITY
REQUIRES MINIMAL R & D - OTHER THAN VALVE
REQUIRES PARACHUTE & SEPARATE CABLE
PHYSICAL SIZE REQUIRES H.A.P. TO EXTEND INTO CORE
WEIGHT AFTER PENETRATION
EASY ADAPTABILITY TO OTHER PISTON CORERS

HAP VALVE

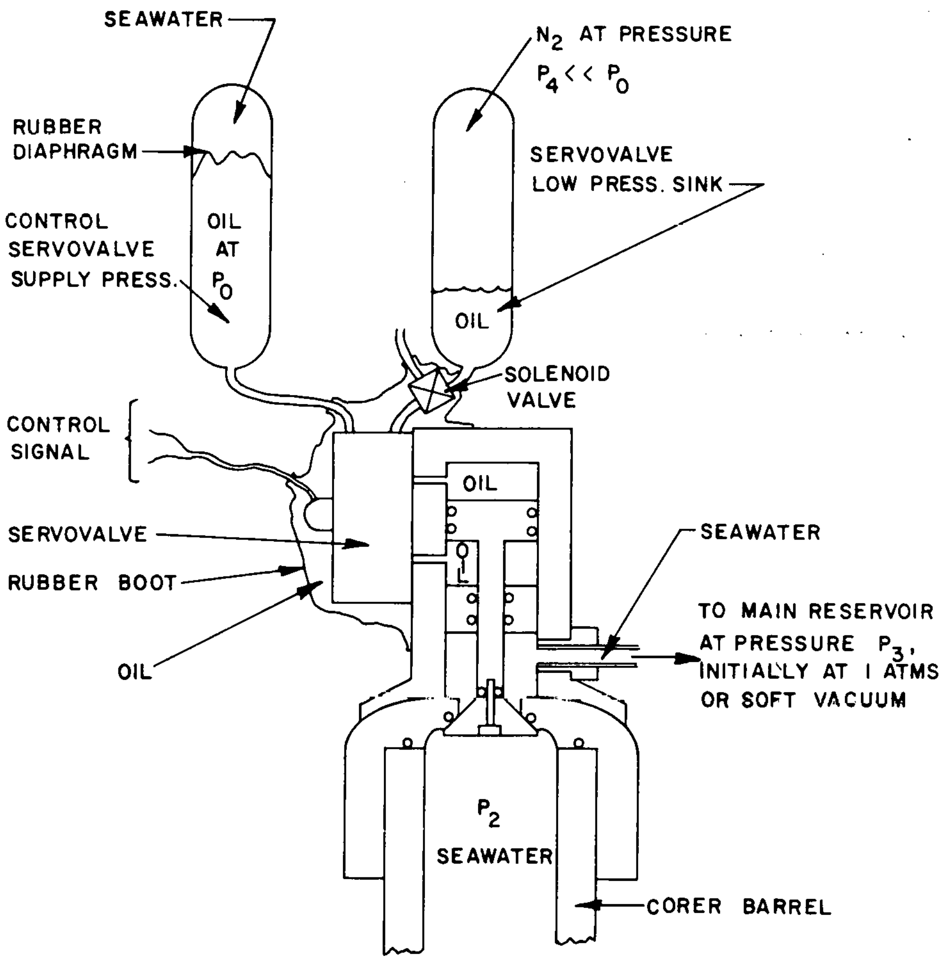
FUTURECRAFT SOLENOID VALVE

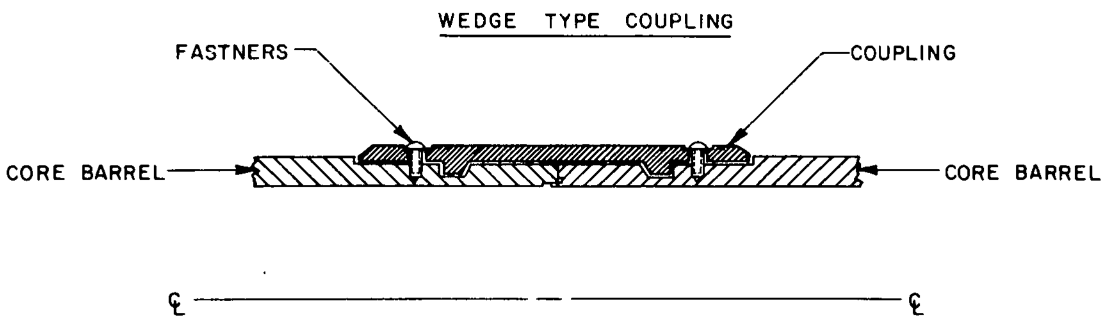
HIGH FLOW RATE - 200 GPM
OPERATE AT HIGH PRESSURE - 10,000 PSI
QUICK RESPONSE - 0.05 TO 0.10 SEC.
SMALL SIZE - LESS THAN 3 INCH DIAMETER

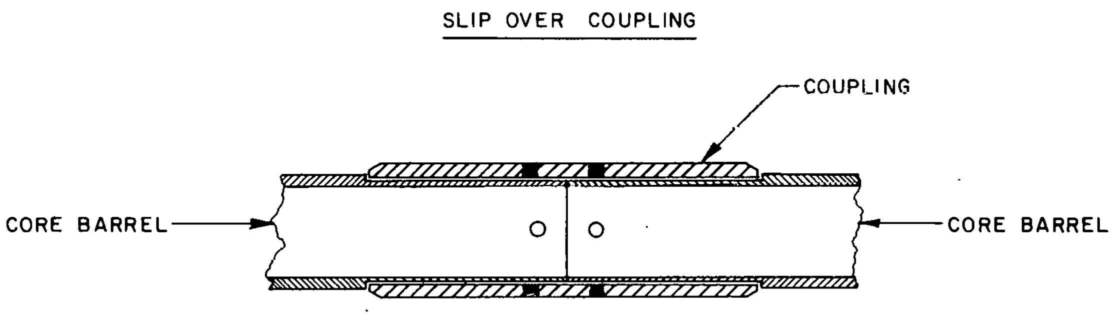
FREE PISTON

IF IT DOESN'T WORK - NOR CORE
NO PARACHUTE OR CABLE TO PISTON REQUIRED
TWO STAGE SERVOVALVE USED
VALVE OPERATION AT 10,000 PSI REQUIRED
VALVE MAY REQUIRE SOME DEVELOPMENT
REQUIRES CHAMBER (S) TO STORE BARREL WATER
ALSO NEEDS CHAMBERS FOR HYDRAULIC OIL & NITROGEN
REDUCES CORE WEIGHT AVAILABLE VOLUME
CONCEPT REQUIRES PIPING OR HOSES, FITTINGS, ETC.
POSSIBLE FOULING OF VALVE SECOND STAGE WITH DEBRIS
COULD BE A PROBLEM
MAINTENANCE REQUIRED - MORE THAN H.A.P.
REQUIRES MORE DEVELOPMENT THAN H.A.P.

PISTON CONTROL
FREE PISTON







CORE BARREL MATERIAL

HY - 80/100

CORROSION RESISTANCE

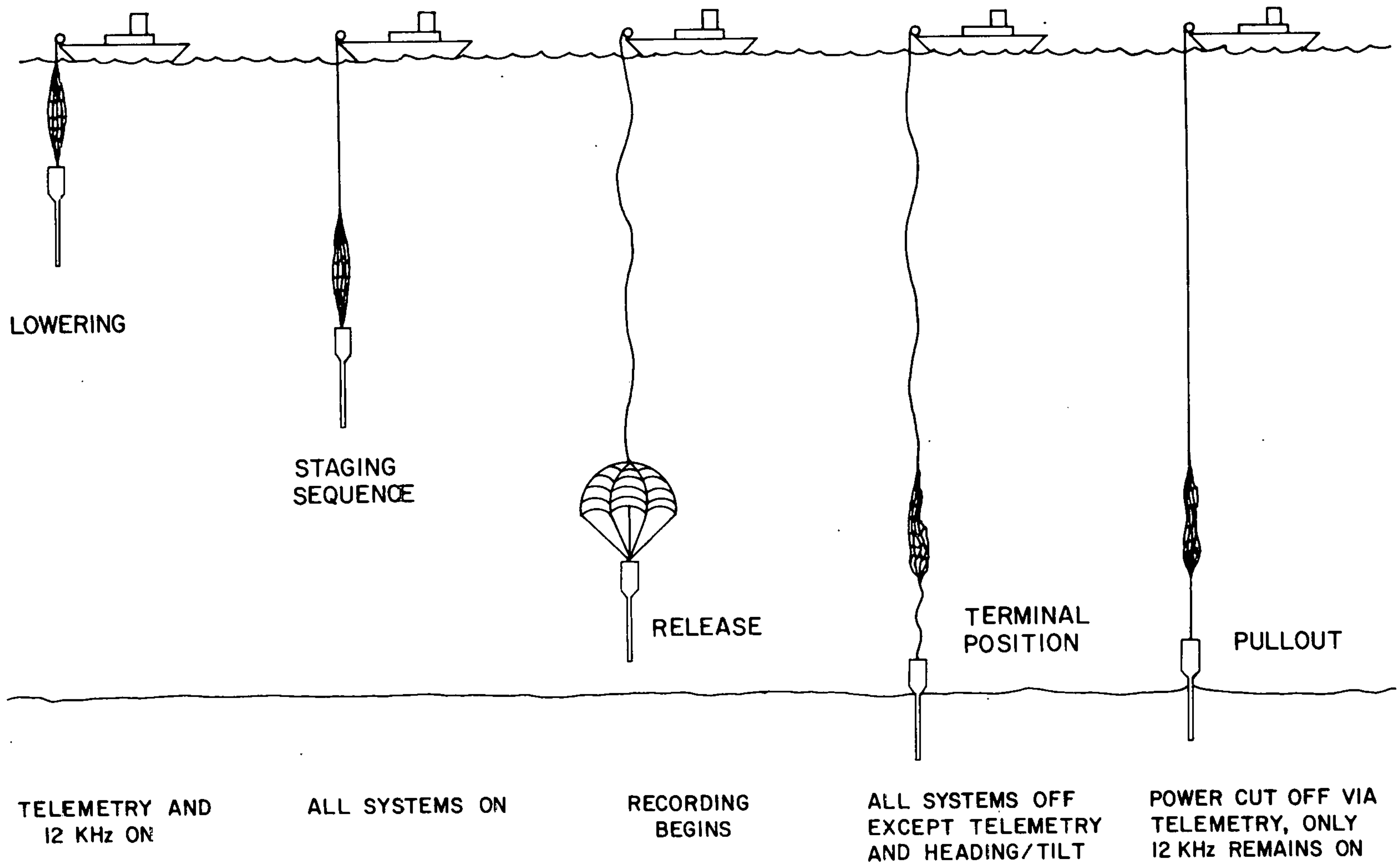
FATIGUE BEHAVIOR

MACHINABILITY

FRACTURE TOUGHNESS ON IMPACT AT COLD TEMPERATURES

HIGH YIELD STRESS

INSTRUMENT OPERATION SEQUENCE



RECORDING ALTIMETER/ACOUSTIC RELEASE

ACOUSTIC RELEASE FUNCTIONS:

- MEASURES DISTANCE FROM CORE WEIGHT TO SEDIMENT
- DETERMINES RELEASE ALTITUDE
- ACTIVATES MECHANICAL RELEASE MECHANISM
- SIGNALS OTHER INSTRUMENTS

RECORDING ALTIMETER FUNCTIONS:

- ACTIVATED AT TIME OF RELEASE
- RECORDS ALTITUDE VS TIME DURING PENETRATION
- RECORDS 10 SAMPLES PER SECOND

APPLICATION:

- CORER CONTROL
- DOCUMENT CORE SAMPLE

HEADING RECORDER/TILT ANGLE MONITOR

FUNCTION BEFORE RELEASE:

- PROVIDE TILT STATUS AND SPIN STATUS SIGNALS TO THE TELEMETRY SYSTEM
- ESTABLISH NORTH REFERENCE

FUNCTION DURING PENETRATION:

- RECORDS HEADING VS TIME
- RECORDING RATE OF 20 SAMPLES PER SECOND

FUNCTION AT PULLOUT:

- PROVIDE TILT ANGLES AND FINAL HEADING DATA TO THE TELEMETRY SYSTEM

APPLICATION:

- SAMPLE DOCUMENTATION
- CORER CONTROL

TELEMETRY SYSTEM:

TWO COMPONENT SYSTEM
1 - CORE HEAD TELEMETRY EQUIPMENT
2 - SHIPBOARD TELEMETRY EQUIPMENT

SIGNALS:

SHIP TO CORER	CORER TO SHIP
INSTRUMENT POWER ON	NO ALARM ** TILT ALARM ** SPIN ALARM **
	SONAR BOTTOM ACQUISITION RELEASE CONFIRMATION SLOW SERIAL DATA OR EQUIVALENT (AT PULLOUT)
INSTRUMENT POWER OFF	
AUX 1 *	AUX ! REPLY *
AUX 2 *	AUX 2 REPLY *

* TWO AUXILIARY COMMANDS ARE INCLUDED WITH REPLY SIGNALS FOR TEMPORARY EXPERIEMTNS "RIDING" THE CORER FROM TIME TO TIME

** ANY ONE OF THESE THREE STATUS SIGNALS ALSO SERVES AS A POWER ON INDICATION.

PISTON CONTROL SYSTEM FOR H.A.P.

CONTAINED WITHIN THE H.A.P.
SELF-POWERED DURING PENETRATION
CONTROLS CONTRACTION RATE OF H.A.P. BY MODULATION THE DUTY CYCLE OF THE CONTROL VALVE.
ACTIVATED BY PISTON LIFTING OFF MECHANICAL STOPS ABOVE THE CORE-CUTTER
SONAR MONITORS DISTANCE TO SAMPLE SURFACE.

APPLICATION:

CORER CONTROL
SAMPLE DOCUMENTATION

DECK UNIT

FUNCTIONS:

RETRIEVES AND RECORDS DATE FROM RECORDING INSTRUMENTS ON CORER

USED FOR QUICK FIRST EXAMINATION OF DATA, USING ANY SERIAL TERMINAL.

MAY BE USED TO LOAD THE RECORDED DATA INTO SOME OTHER COMPUTER OR ANALYSIS SYSTEM.

MAY BE USED TO PRESET OPERATIONAL PARAMETERS OF THE CORER INSTUMENTS.

PRIMARY FUNCTION IS TO RECORD DATA FROM CERTAIN OF THE CORER INSTRUMENTS WHICH THEMSELVES PERFORM IN - SITU DATA RECORDING. THIS DATA IS RECORDED ON DIGITAL CASSETTES, AND MAY BE DOWN LOADED TO OTHER INSTRUMENTS FOR ANALYSIS.

PROTABLE, BATTERY OPERATED.

REQUIRES NO CONNECTIONS, EXCEPT TO INSTRUMENT BEING READ.

MARKS DATA RECORDS WITH INSTRUMENT IDENTIFICATION, TIME DATE CODES.

SEALED UNIT, INTENDED FOR USE IN WET DECK CONDITIONS.

ITEMS	H P C	L C F
SYSTEM COST PER DAY AT SEA	30,000	10,000 (INCLUDING OPERATOR
COST PER 50M CORE IN 5000M	40,000	2,000
HOURS REQUIRED TO OBTAIN 50M SAMPLE AT (5000M) DEPTH	32	5
VESSEL ALTERTATIVES AT PRESENT	DYNAMICALLY POSITIONED DRILL SHIPS	6
SCHEDULING TIME FOR ACCESS TO SYSTEM	VARIABLE, BUT NORMALLY LONG LEAD TIME	1 YEAR
FLEXIBILITY OF VESSEL TO PERFORM ROUTINE SCIENCE	DEDICATED TO DRILLING OR HPC	FULLY VERSATILE ALL ASPECTS
CORES THAT CAN BE ACQUIRED PER DAY (24 HOURS)	1	2 TO 3 (100-150M)
SAMPLE DIAMETER	6.4 CM	11.4 CM
SAMPLE AREA	12.5 CM^2	45 CM^2
50M SAMPLE VOLUME	$1.71M^3$	$6.13M^3$
SYSTEM COMPONENTS AVAIL. FOR OTHER APPLICATIONS	NO-DRILL SHIP CAN BE USED FOR OTHER PURPOSES, I.E. LOGGING ETC.	YES-WINCY SYSTEM, BARREL SECTIONS, INSTRUMENTATION
CORE/DRILL STRING INSTRUMENTED TO MONITOR SAMPLE QUALITY	DOWN HOLE COMPASS HEAT FLOW IN FUTURE	COMPASS, ROTATION ALTITUDE, INCLINATION IN-SITU SAMPLE QUALITY MONITOR

SYSTEM COST IN DOWN PHASE PER DAY	N/A	6-$700.
ABILITY TO USE MODIFIED SYSTEM TO OTHER VESSELS (LESS THAN 50M)	DYNAMICALLY POSITIONED DRILL SHIP	MOST OF UNOLS FLEET
WATER DEPTH LIMITS	MIN 500M WITH 6900M MAX (MAX DRILL PIPE AVAIL. AT PRESENT)	UNLIMITED
WEATHER LIMITATIONS	SEA STATE 4-6 ALL DEPTHS	SEA STATE 4-6 ALL DEPTHS
USE AS TOOL FOR REGIONAL STUDIES	LIMITED BY COST	HIGHLY USEFUL MAJOR ADVANTAGE
MAXIMUM SEDIMENT SHEAR STRENGTH	1200 GM/CM^2 WITH PENETRATION TO 3000 GM/CM^2 WITH RETARDED STROKE, REGS, ADDITIONAL LOWERING TO ACHIEVE DEPTH	
MAXIMUM SECTION LENGTH	9.5M SECTION PER STROKE (SOFT SEDIMENT) SHORTER IN STIFF MATERIAL	50-60M SAMPLE RECOVERY SINGLE STROKE
MAXIMUM SAMPLE LENGTH ACHIEVEABLE	200M	50-60M

Modeling Studies For Long Coring Facility

C. H. Karnes, S. N. Burchett, E. A. Aronson - Sandia National Labs

The computer modeling studies for the Long Coring Facility has been in two areas during FY'81. The first is a refinement of the structural response affecting buckling and bending due to non-normal entry into standard and 50 percent stiffer sediments, and the second is the development of a model for the transient response of the hydraulic actuator piston control system.

The bending response is presented for the geometry presented in Fig. 1 identified as Corer F1 having a 13 mm wall thickness in the lower section 25 mm in the center and 63.5 mm in the upper section. Since the 50 m long corer is very long and slender and may not be released in exactly a vertical orientation, the calculations have been performed for orientations deviating from vertical by up to three degrees. Figs. 2 and 3 show the lateral deflection and bending stresses for the core barrel as a function of entry angle measured from vertical. It shows that the addition of a drag term due to the lateral motion of the weight stand has a negligible effect on the peak bending deflection.

The results represented by the circles and squares are for penetration into the sediment considered standard for the LCF design, that from LL44-GPC3 having a logarithmic function of sediment depth. A set of calculations was also done for a sediment which was 50 percent stiffer than the standard sediment to determine its response to a surprisingly stiff sediment. Fig. 3 shows that even a 1.5 degree entry angle into the standard sediment will cause a stress of 200 MPa which is the yield stress for mild steel. These calculations predict uniform bending stress neglecting the effects of stress concentrations in joints and couplings. It is concluded that entry angles must be controlled very carefully and even with a barrel wall thickness of 63.5 mm in the upper 15 m section, a medium-to-high strength steel must be used with careful attention paid to coupling stress concentrations.

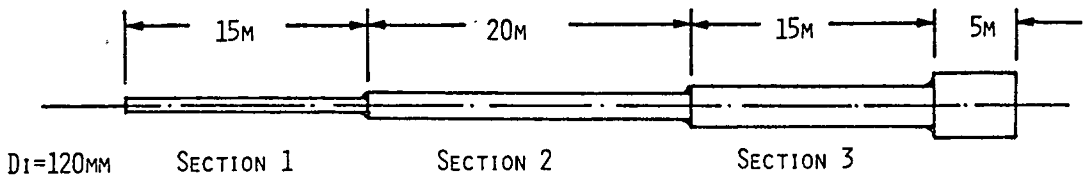
For the analysis of the piston control system, it is important to recall that the piston must be held stationary once the corer enters the sediment in order to prevent mechanical distortion of the core sample. One of two proposed piston control systems is the hydraulic actuator piston which is attached to a parachute similar to that used on LL44-GPC3.

The parachute used alone as a passive piston restraint would be pulled down several meters by the force required to hold the piston stationary. The hydraulic actuator shown schematically in Fig. 4 contains the piston (lower part of Unit 2) and a low pressure cavity (Unit 1). The ambient pressure, Pw, pressurizes the oil reservoir in Unit 2 and supplies the energy to contract the actuator as the control valve discharges the oil into the low pressure cavity. The control valve receives its signal from an accelerometer, integrator and microprocessor limit into Unit 2. This feedback control loop opens and closes the control valve in such a way to keep Unit 2, the coring piston, at zero velocity. A short-range acoustic device built into Unit 2 determines the velocity of Unit 2 as it approaches the sediment after corer trip and after the parachute lifts the hydraulic actuator piston off its electronic start switch. This supplies the electronic integrating circuit with an initial velocity so that the piston can be controlled to zero velocity.

A preliminary, transient analysis of the control system has been accomplished by obtaining a numerical solution to the set of coupled differential equations which describe the motion of Units 1 and 2. The motion of Unit 3, the core barrel is prescribed as a result of a previous solution with the piston being held fixed. The following effects are considered: parachute drag, buoyancy, mass changes of Units 1 and 2, pressure differences, friction between components and between the core sample and core barrel, the sediment shear strength versus depth, and the sediment bearing capacity.

Fig. 5 shows the results of the first series of calculations for the piston position versus time after the control system is turned on. The gain shown as a parameter is the factor relating the piston velocity (to be controlled to zero) to the signal which drives the control valve open. These results show that a gain of 100 is required to keep the piston stationary within the 10 cm goal.

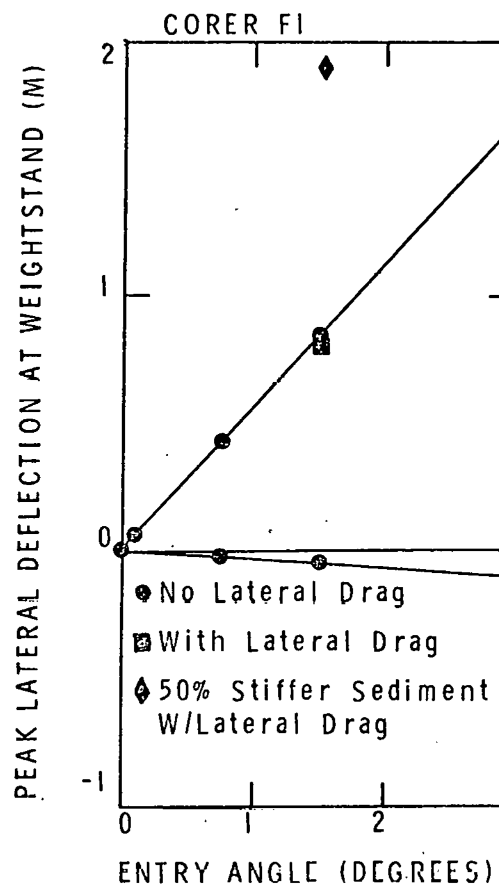
Future work on the mechanical response of the coring system will be to confirm the validity of the final mechanical design. Additional analyses of the hydraulic actuator piston control system will be performed to determine the sensitivity to other control parameters such as control valve response characteristics. An effort will also be initiated to analyze the response of the free piston control concept which also uses the ambient pressure as a power source.



CORER	WALL THICKNESS (MM) SECTION 1	SECTION 2	SECTION 3	M_B(KG)	MWS(KG)
F1	13	25	63.5	6770	7379
F2	13	38.5	63.5	7922	6653

FIG. 1 Stepped Tapered Barrel Geometry

FIG. 2 Peak Deflection Due To Non-Normal Entry



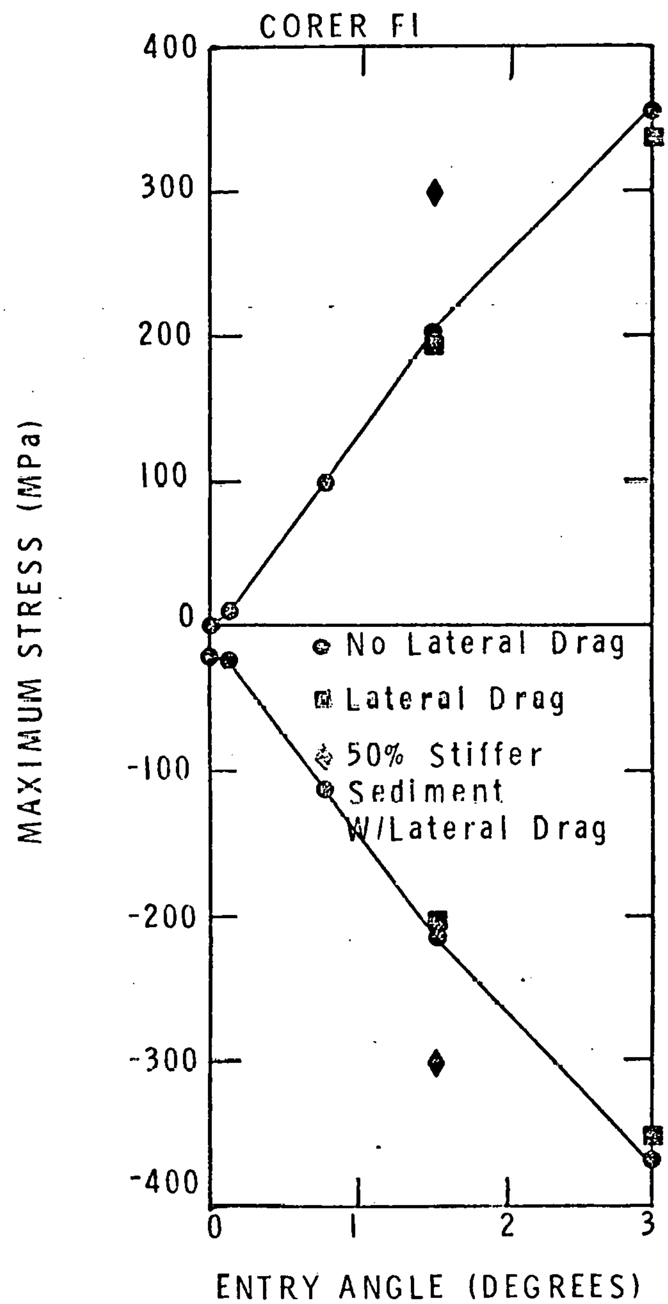


FIG. 3 Bending Stress Due To Non-Normal Entry

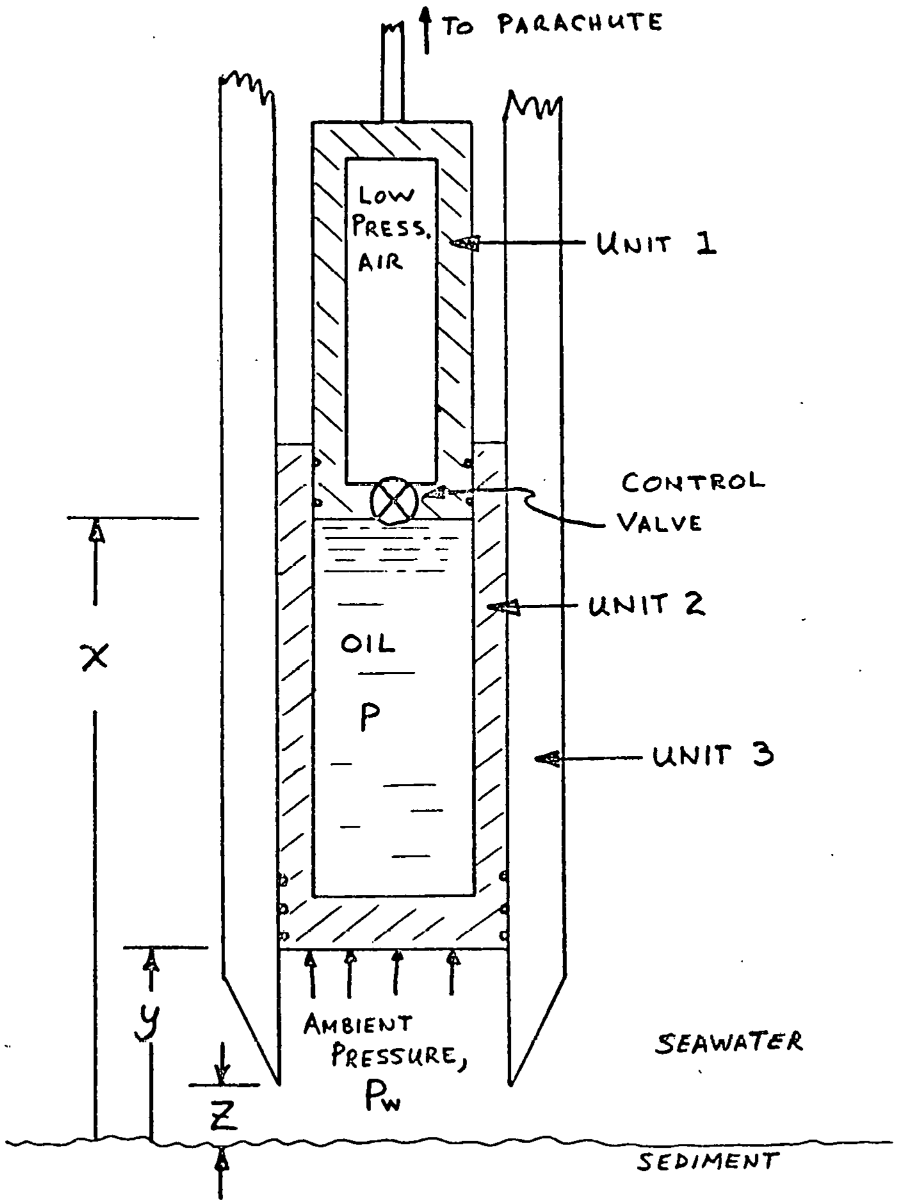


FIG. 4 Schematic Of Hydraulic Actuator Piston Control System

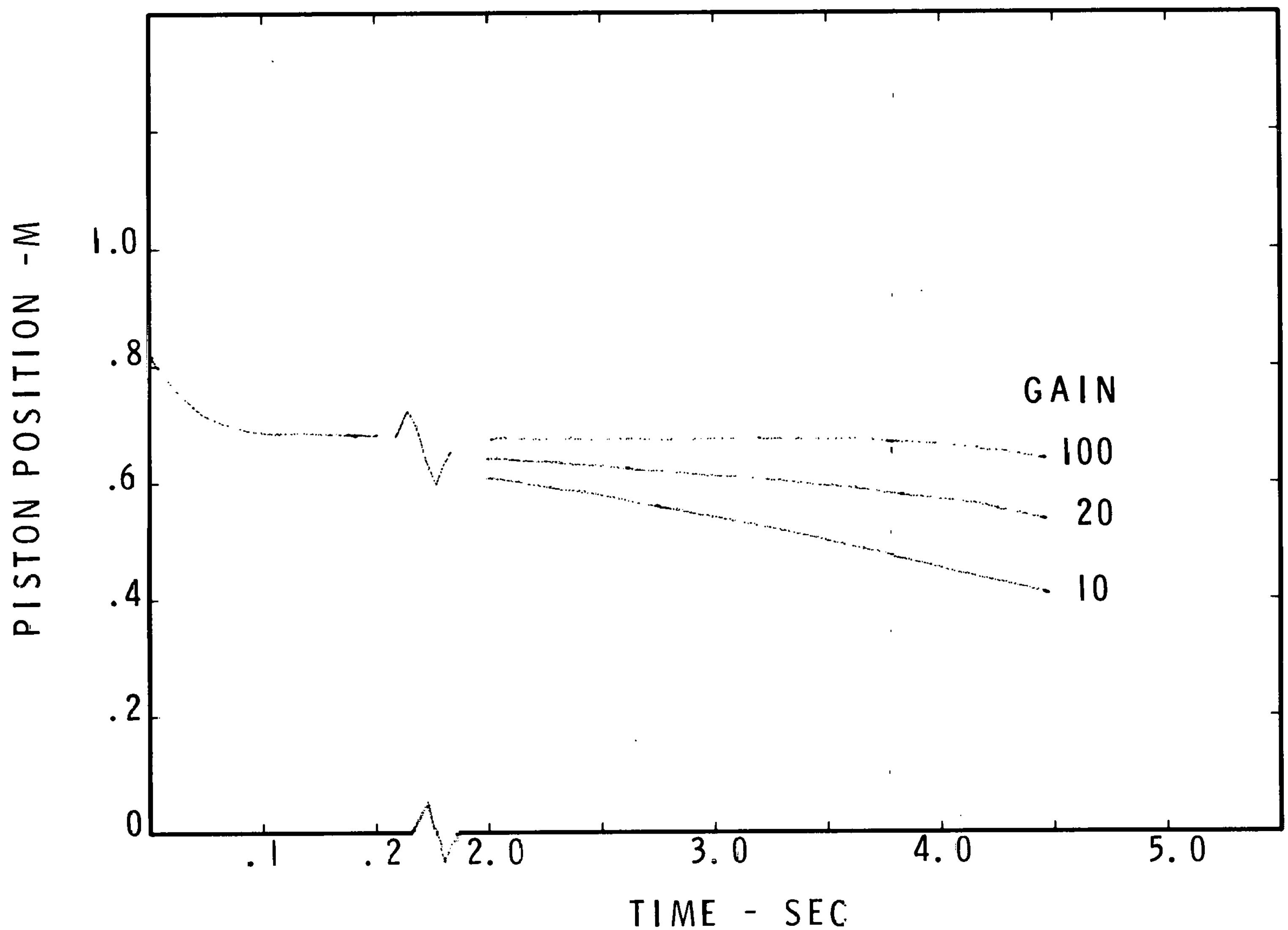


FIG. 5 Effects Of Gain On Piston Control Response

XII. TRANSPORTATION STUDIES

Technical Program Coordinator: D. R. Anderson

Conceptual Ship Design

C. G. Shirley, SNLA; M. Miller and C. Chryssostomidis, Massachusetts Institute of Technology 393

SUBSEABED NUCLEAR WASTE DISPOSAL CONCEPTUAL SHIP DESIGN

C. G. Shirley
Transportation System Development and Testing Division 4553
Sandia National Laboratories

M. Miller and C. Chryssostomidis
Nuclear Engineering and Ocean Engineering Departments
Massachussetts Institute of Technology

ABSTRACT

Concepts for transporting radioactive waste by ship from a specialized port facility to an ocean site for disposal in the subseabed have been investigated to develop a reference transportation system for risk analysis purposes. The investigation included ship design requirements, radioactive material storage methods, and methods of handling this material during loading at the port and in preparation for emplacement in the subseabed. In this phase of the work, emplacement of free-fall penetrators was assumed. The design concept has been developed from a review of existing and developing technologies for handling and storage of radioactive materials and from considerations of shipboard conditions. The concept incorporates transfer casks for loading the ship with assembled penetrometers, a water pool for storage aboard ship while in transit, and individual drop stations in the pool for the penetrometers. The concept is described at a level of detail which elucidates the main ideas; the direction of further analyses which would be required in order to carry concept development forward is also indicated.

For the purposes of this study, radioactive waste is considered to be either spent fuel (SF) from light water reactors (LWRs) or the high level waste (HLW) which derives from reprocessing that fuel. In both cases, it was assumed that the fuel was out-of-core for a minimum of ten years, and that it was encapsulated in a form suitable for final disposal in the subseabed.

Main conclusions and recommendations include:

- A water pool is the obvious choice for storage of the penetrometers aboard ship. In particular, the requirements for radiation shielding, criticality control, and decay heat removal can be easily met. Nevertheless, it would be worthwhile to investigate the possibility of adopting the convection vault dry storage method for this application.
- The transfer cask method for ship loading and the individual drop station method for disposal at sea have two main advantages:
  - a) a reduction in the number of waste canister and penetrator handling operations aboard ship both in dock and at sea, and
  - b) a simple penetrator release mechanism, consisting of a two-step valve operation.
- Further, work to be done in the area of penetrometer/disposal technique design, and loading operations at port:
  - a) Improvements in penetrator design including: incorporation of booster and electronic monitoring devices, analysis of possible damage on impact with the sea bed.
  - b) Detailed investigation of ball valve design, leakage rates, torque requirements, actuator devices, space requirements, manufacturing, installation and maintenance costs.
  - c) Design of cranes and control systems for the shore-ship cask transfer.
  - d) Development of technology concepts for alternate disposal techniques.
- Preliminary results support the feasibility of the ship design. However, areas of uncertainty exist, especially in the prediction of loads on the ship. It is recognized that the calculations performed need refinement in view of the unconventional nature of the ship to be designed. A further detailed static analysis (for the still water bending and torsional

moment) and a probabilistic analysis (for wave induced bending and torsional moments) should follow in the next phase of the Subseabed Program. Other important analyses to be performed include seakeeping analysis, floodable length and damaged stability, fatigue analysis, optimization studies for ship parameters and structural optimization and an economic evaluation of the system. Seakeeping analysis perhaps is the next major study that needs to be undertaken because it will determine the operating characteristics of the proposed vessel. The present concept is adequately developed, however, to support transportation system risk analyses.

SUBSEABED NUCLEAR WASTE DISPOSAL

CONCEPTUAL SHIP DESIGN

Sandia Laboratories

OBJECTIVES

- EXAMINE EXISTING SYSTEMS AND DEVELOP NEW CONCEPTS FOR SEA TRANSPORT AND SHIPBOARD HANDLING OF NUCLEAR WASTE
- ASSIST IN PLANNING TECHNOLOGY DEVELOPMENT

TASKS

- EXAMINE SHIP DESIGN FEATURES AND REQUIREMENTS
- REVIEW SHIPBOARD STORAGE OPTIONS
- EVALUATE SHIPBOARD HANDLING METHODS
- EXAMINE SAFETY FEATURES AND REQUIREMENTS

TRANSPORTATION SEQUENCE

- OVERLAND TRANSPORTATION TO PORT FACILITY
- SHORESIDE STORAGE AND PREPARATION
- TRANSFER TO SHIP
- SHIPBOARD STORAGE AND MONITORING IN TRANSIT
- OFF-LOADING FOR SUBSEABED EMPLACEMENT

SHORESIDE STORAGE AND PREPARATION

RECOMMEND WASTE CANISTER PREPARATION FOR DISPOSAL BE PERFORMED AT THE PORT FACILITY

- MINIMIZE SHIPBOARD HANDLING AND EQUIPMENT REQUIREMENTS
- INCLUDE PENETROMETER ASSEMBLY

TRANSFER TO SHIP

- TUNNEL TRANSFER - NOT RECOMMENDED

  DEGRADATION OF SHIP STRUCTURAL INTEGRITY

  DIFFICULTY IN SHIP BALLASTING, ALIGNMENT, AND MATING

- TRANSFER CASK - PREFERRED METHOD

  DEMONSTRATED TECHNOLOGY

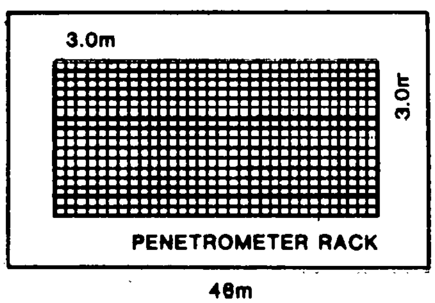
SHIPBOARD STORAGE OPTIONS

- DRY AIR-COOLED VAULT - REQUIRES FURTHER ANALYSIS
- WET POOL STORAGE - BASIS FOR CURRENT CONCEPT

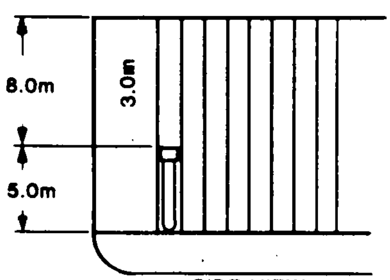
WET POOL STORAGE CONCEPT

- CAPACITY - 512 PENETROMETERS
- SHIELDING - 3.0 METERS OF WATER
- DECAY HEAT REMOVAL - 300 GPM FLOWRATE
- CRITICALITY CONTROL - WORST CASE Keff LESS THAN 0.95

STORAGE POOL



TOP VIEW

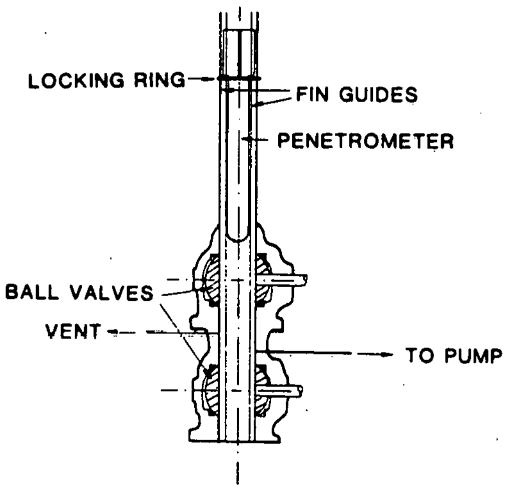


SIDE VIEW

OFF-LOADING FOR SUBSEABED DISPOSAL

- PENETROMETER EMPLACEMENT - FREE-FALL DROP
- PENETROMETER RELEASE CONCEPTS:

  CONVEYOR
  SLIDING RACK
  CAROUSEL
  FIXED RACK/CRANE
  FIXED RACK/INDIVIDUAL DROP STATIONS



PENETROMETER RELEASE MECHANISM

CONCEPTUAL SHIP DESIGN

- BREADTH - 30m
- LENGTH - 200m
- DRAFT - 11m
- SPEED - 16 knots
- DISPLACEMENT - 51200 tonnes
- HOLD STRUCTURAL FEATURES

  CLOSED CELLULAR WING TANKS

  LONGITUDINAL AND COLLISION BULKHEADS

CONCLUSIONS AND RECOMMENDATIONS

- PENETROMETER ASSEMBLY AT PORT FACILITY
- SHIP LOADING BY TRANSFER CASK
- WATER POOL STORAGE ABOARD SHIP
- INDIVIDUAL PENETROMETER DROP STATIONS
- NEXT IMPORTANT STEP IN SHIP DEVELOPMENT:

  SEAKEEPING AND DETAILED STRUCTURAL ANALYSES

Sandia Laboratories

XIII. SOCIAL ENVIRONMENT (LEGAL AND INSTITUTIONAL)

Technical Program Coordinators: D. R. Anderson
K. R. Hinga

Introduction - Overview and Program Plan
K. R. Hinga, Anachem, Inc. 403

Public Education and Participation
J. E. Kelly, University of New Hampshire 407

Management Systems
L. Susskind, Massachusetts Institute of Technology 417

Legal Comments
H. Herrmann
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Introduction - Overview and Program Plan

K. R. Hinga, Anachem, Inc.

A brief overview of the draft Program Plan for the Social Environment (Regulatory and Institutional Studies) was presented. The Table of Contents (Figure 1) shows the organization of the project.

The Reference Regulatory System (Table 1) was chosen to attempt to anticipate the problems and time necessary to implement an adequate regulatory regime. The London Dumping Convention was identified as the most likely vehicle for having the legality of the subseabed disposal concept formally established. The Education programs (Figure 2) have already started with scientists and decision makers, and in the next few years we will concentrate more efforts on interest groups and the general public.

REFERENCE REGULATORY SYSTEM

EDUCATION

REVIEWS

SEABED WORKING GROUP

RESEARCH AGENDA

- IDENTIFICATION OF THE SOCIAL ENVIRONMENT
- DETERMINATION OF MANAGEMENT REQUIREMENTS

LEGAL AND REGULATORY TOPICS

- CLARIFICATION OF LEGAL REGIME
- NEPA
- LICENSING

FACILITY SITING CONSULTATIONS

Table 1-Reference Regulatory System

OPERATION	TYPE OF REGULATION	DATE REGULATIONS NEEDED	REGULATORY BODY* U.S.	INTERNATIONAL
REPOSITORY AND EMPLACEMENT	REPOSITORY AND WASTE PACKAGE PERFORMANCE	1988	EPA	LDC
MONITORING	TYPE AND FREQUENCY	1998	NOAA	NEA
DOCK FACILITY AND SHIPS	WORKER SAFETY EXPOSURE LIMITS SHIP SAFETY	1998	OSHA NRC USCG	 IMCO
LAND TRANSPORTATION	SHIPPING REGULATIONS	1998	DOT NRC	
PACKAGING FACILITY	SAFETY AND QUALITY ASSURANCE	1998	NRC OSHA	
MANAGEMENT		1998	DOE	NEA

*EPA-Environmental Protection Agency
LDC-London Dumping Convention
NEA-Nuclear Energy Agency
OSHA-Occupational Safety and Health Agency
NRC-Nuclear Regulatory Commission
USCG-U.S. Coast Guard
IMCO-Intergovernmental Maritime Consultive Organization
DOT-Department of Transportation

Sector of the Public	Appropriate Modes of Communication
Scientists	Program Involvement
Physical	Peer-reviewed Publications
Engineering	Presentations
Social	Workshops
Government Decision-Makers	Briefings
Advisory Agencies	Congressional Hearings
Regulatory Agencies	Workshops
Congress	SDP-Publications
	Information Exchanges
Interest Groups	Briefings
Environmental Groups	Workshops
Industry Groups	SDP-Publications
	Public Meetings
	Mass Media
	Program Involvement
General Public	SDP-Publications
	Public Meetings
	Mass Media

Figure 2.

Abstract

Annual Report, FY 81

Public Education and Participation

As prescribed in Step 1 of the Public Education and Participation Process (attachment 1), industry, public interest groups, and decision-makers were briefed about the Subseabed Disposal Program. In regard to public interest groups, Drs. Hollister and Kelly were invited to present the technical and policy aspects of the Subseabed Program at a public forum in Hawaii sponsored by the Hawaii League of Women Voters, the Health Physics Society, and the East-West Center. The sponsors videotaped the forum for a film, entitled "Slowly Dying Embers: Radioactive Waste and the Pacific," which will be shown on television in Hawaii. In response to requests for information about the Subseabed Program, Congressional Staff, Representatives, and Senators (attachment 2) were briefed about the Subseabed Program as legislation related to the Program moved through Congress (attachment 3). Science oriented publications also were contacted about the Program (attachment 4).

Submitted by
Prof. John E. Kelly
Complex Systems Research Center
O'Kane House
Univ. of New Hampshire
Durham, NH 03824

Attachment 1

Public Education and Participation Process

STEP 1	BRIEFINGS WITH INDUSTRY, PUBLIC INTEREST GROUPS, AND DECISION-MAKERS (1981---)
STEP 2	WORKSHOPS WITH SUBGROUPS FROM STEP 1 (1982-84)
STEP 3	SCOPING SESSION WITH STEP 2 PARTICIPANTS AND OTHER INTERESTED PARTIES (1985-86)
STEP 4	PUBLIC PARTICIPATION UNDER THE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) (1986-88)

Attachment 2

Public Participation in the Subseabed Program FY 81

Participants:

Industry

Electric Power Research Institute (EPRI)
Gulf States Utilities
Potomac Electric Power Company (PEPCO)

Public Interest

Hawaii Health Physics Society
League of Women Voters:
League of Women Voters - Hawaii

Decision-Makers

Senate:

Asseltine, Jim
Staff-Environment and Public Works' Nuclear Regulation Subcommittee

Burgess, Barbara
Legislative Assistant (L.A.) to Sen. Laxalt (R-NV) (Appropriations Committee)

Chakoff, Elliot
Staff-Energy Committee (Sen. McClure R-ID)

Cooper, Ben
Staff-Energy Committee (Sen. Johnston D-LA)

Crow, Steve
Staff-Appropriations' Energy and Water Subcommittee (Sen. Hatfield R-OR)

Freihoffer, Dan
L.A. to Sen. Humphrey (R-NH) (Energy Committee)

Gilman, Paul
Staff-Energy Committee
(Sen. Domenici R-NM)

Gleason, Jack
L.A. to Sen. Weicker (R-CT)
(Appropriations, Energy Committees)

Granger, Dick
L.A. to Sen. Hatfield (R-OR)
(Appropriations, Energy)

Gwaltney, David
Staff-Appropriations' Energy and
Water Subcommittee

Jordan, Jim
L.A. to Sen. Stennis (D-MS)
(Appropriations)

Lane, Carol
Staff-Sen. Schmitt (R-NM)
(Appropriations, Commerce)

Maginnis, Tom
L.A. to Sen. Hatfield
(Appropriations, Energy)

McCluskey, Bill
Staff-Commerce's Ocean Policy Study
(Sen. Packwood R-OR)

Moore, Curtis
Staff-Environment and Public Works'
Toxic Substances Subcommittee

Peterson, Andy
L.A. to Sen. Rudman (R-NH)
(Appropriations)

Tsongas, Sen. Paul (D-MA)
Energy Committee
Foreign Relations Committee

Tyson, Mitch
L.A. to Sen. Tsongas (D-MA)
(Energy, Foreign Relations)

Vance, Ann
L.A. to Sen. Wallop (R-WY)
(Energy)

Walsh, Tom
L.A. to Sen. Bumpers (D-AR)
(Energy, Appropriations)

Wicklund, Bob
L.A. to Sen. Weicker (R-CT)
(Energy, Appropriations)

House:

Dravo, Andrea
Staff-Interior Committee
(Rep. Udall D-AZ)

Dugan, Jack
Subcommittee Staff Director
Science and Technology's Energy Research and
Production Subcommittee
(Rep. Bouquard D-TN)

Durkin, Patrick
L.A. to Rep. Gregg (R-NH)
(Science and Technology)

Eustaquio, George
Administrative Assistant (A.A.) to Rep. Won Pat (D-Guam)
(Interior)

Freiwale, Joyce
Staff-Science & Technology's Energy Research Subcommittee
(Rep. Lujan R-NM)

Godown, Lee
L.A. to Rep. Ottinger (D-NY)
(Science and Technology)

Greer, Mel
Staff-Appropriations

Gregg, Rep. Judd (R-NH)
Science and Technology Committee

Hobson, Priscilla
L.A. to Rep. Lowery (R-CA)
(Science and Technology)

Ketcham, Rob
Special Energy Assistant
Science and Technology Committee
(Rep. Fuqua D-Fla.)

Krebs, Martha
Subcommittee Staff Director
Science and Technology's Energy Dev. and Applications

Lundine, Rep. Stanley (D-NY)
Science and Technology Committee

Malow, Dick
Staff-Appropriations' HUD-Independent Agencies Subcommittee

Markey, Rep. Edward (D-MA)
Energy Committee
Interior Committee

Moss, Tom
Science and Technology's Science Subcommittee

Potter, Frank
Staff Director
Energy and Commerce Committee

Richardson, Mary Ann
L.A. to Rep. Lundine (D-NY)
(Science and Technology)

Schaeffer, Eric
L.A. to Rep. Schneider (R-RI)
(Science and Technology)

Schneider, Rep. Claudine (R-RI)

Star, Roger
L.A. to Rep. Gore (D-TN)
(Science and Technology, Energy and Commerce)

Stein, Ralph
DOE Fellow
Science and Technology's Energy Research Subcommittee

Wallace, Lee
Minority Staff Director
Energy Research Subcommittee

Ward, Mike
Counsel
Energy and Commerce's Energy Conservation Subcommittee

Won Pat, Rep. Antonio (D-Guam)
Interior Committee

Office of Technology Assessment

Barnard, Bill

Attachment 3

DEPARTMENT OF ENERGY AUTHORIZATION

HOUSE ACTION

SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION

In March the Subcommittee asked DoE to reduce its Civilian Waste Management budget of $206.241 million by $15 million (7%). DoE responded by reducing Subseabed by $3 million, from $6.5 million (Reagan Request) to $3.5 million (46%).

COMMITTEE ON SCIENCE AND TECHNOLOGY

Congressman Judd Gregg attached Report Language to the full Committee bill in May: "Radioactive waste management is a long-term scientific and institutional problem... an international as well as national problem... The Subseabed Disposal Program is an efficient, well-managed international research and development project... (and) should be continued as an international option as well as a national alternative...It should be funded at sufficient levels to determine whether subseabed disposal is scientifically and technically feasible."

But the $3.5 million funding level for Subseabed was maintained by the full Committee.

RECONCILIATION CONFERENCE

The Reconciliation Conference is a new step in the authorization process in which all authorization bills are considered as one rather than as separate bills.

The Reconciliation Conference eliminated detailed budget items, such as Subseabed $3.5 million item, in July. DoE was authorized to spend $194.124 for Civilian Waste Management on programs of its choice. However, nuclear waste legislation now moving through Congress will determine which programs DoE will support.

SENATE ACTION

COMMITTEE ON ENERGY AND NATURAL RESOURCES

The Committee authorized DoE to spend a bulk sum on all research activities.

97TH CONGRESS
1ST SESSION

S. 1662

To establish a limited program for Federal storage of spent fuel from civilian nuclear powerplants, to set forth a Federal policy, initiate a program, and establish a national schedule for the disposal of nuclear waste from civilian activities, and for other purposes.

IN THE SENATE OF THE UNITED STATES

SEPTEMBER 24 (legislative day, SEPTEMBER 9), 1981

Mr. MCCLURE (for himself, Mr. STAFFORD, Mr. DOMENICI, Mr. SIMPSON, and Mr. SYMMS) introduced the following bill; which was read twice and referred jointly to the Committee on Energy and Natural Resources and the Committee on Environment and Public Works, with the proviso that if either committee reports the bill, the other committee shall be obligated to report the bill in thirty calendar days (not including days on which the Senate is in recess for more than three days) or be discharged from further consideration thereof

---

A BILL

To establish a limited program for Federal storage of spent fuel from civilian nuclear powerplants, to set forth a Federal policy, initiate a program, and establish a national schedule for the disposal of nuclear waste from civilian activities, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

NUCLEAR WASTE LEGISLATION

SENATE ACTION

THE PROPOSED NUCLEAR WASTE POLICY ACT OF 1981 (SENATE BILL #1662) CONTAINED NO PROVISION FOR CONTINUING RESEARCH AND DEVELOPMENT OF ALTERNATIVE WASTE DISPOSAL TECHNOLOGIES, SUCH AS SUBSEABED DISPOSAL.

SENATOR WALLOP (R-WYOMING) PROPOSED, AND SENATOR TSONGAS (D-MA) SECONDED, THE FOLLOWING AMENDMENT WHICH THE ENERGY COMMITTEE ACCEPTED BY UNANIMOUS CONSENT ON 21 OCTOBER 1981. THE COMMITTEE THEN PASSED S-1662 AND SENT IT TO THE FULL SENATE WHERE IT IS EXPECTED TO PASS.

The Secretary shall continue and accelerate a program of research, development, and investigation of alternative means and technologies for the permanent disposal of high-level radioactive wastes from civilian activities, atomic energy defense activities of the Secretary and Federal research and development activities. Such program shall include examination of various waste disposal options.

HOUSE ACTION

THERE ARE SIX NUCLEAR WASTE BILLS IN VARIOUS STAGES OF DEVELOPMENT IN THE HOUSE. SOME OF THESE PROVIDE FOR CONTINUATION OF ALTERNATIVE TECHNOLOGIES. IT IS UNCERTAIN WHICH, IF ANY, OF THESE BILLS WILL SUCCEED IN THE HOUSE AND THEN GO TO THE HOUSE/SENATE CONFERENCE.

Attachment 4

SCIENCE ORIENTED PUBLICATIONS CONTACTED

AAPG EXPLORER

BIOSCIENCE *

DISCOVER

EOS *

GEOTIMES

NATURAL HISTORY +

NUCLEAR NEWS

OCEAN SCIENCE NEWS

OCEANS *

OMNI

SCIENCE DIGEST

SCIENCE NEWS

SCIENCE 81

SCIENTIFIC AMERICAN

SCIQUEST

SEA FRONTIERS +

SMITHSONIAN +

OVERVIEW ARTICLES

SCIENCE
ENVIRONMENTAL SCIENCE AND TECHNOLOGY

* article

+ Contact by Nancy Penrose

Management Systems

L. Susskind, Massachusetts Institute of Technology

Our task is to design a management system capable of delivering high level waste to carefully selected and monitored subseabed sites at the least possible cost, in a fashion that respects all appropriate national and international legal guidelines. The design of the management system must not only fit our regulatory context but also minimize political conflict as well.

To do this, we have specified a "most likely case" that presumes reprocessing, presumes retrievability, presumes (at least at the outset) an East Coast port, and presumes a US-initiated effort. We have analyzed the likely sources of institutional and interest group opposition given our initial design assumptions. We are now beginning the task of specifying the ways in which changes in the "base case" might respond to (and minimize) opposition. We have also identified the basic management science and social science research needed to build a minimally acceptable understanding of the systems and conflicts involved.

We have identified ten components of a subseabed management system:

(1) land transportation
(2) storage and reprocessing
(3) port transfer
(4) sea transport, emplacement, and retreival
(5) monitoring
(6) security
(7) safety and accident prevention
(8) emergency response
(9) development and administration
(10) coordination and control

Based on a detailed review of existing studies and discussions with a range of consultants (especially at a workshop in Cambridge, Massachusetts in July, 1981), we have identified the key issues involved in the design of each of the ten management system components.

SUBSEABED DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE: MANAGEMENT SYSTEM DESIGN AND SOCIAL IMPACT ASSESSMENT

Massachusetts Institute of Technology
Prof. Lawrence Susskind, Principal Investigator

October 1981

I. COMPONENTS OF A MANAGEMENT SYSTEM

II. IDENTIFICATION OF KEY MANAGEMENT ISSUES

III. SOURCES AND TYPES OF CONFLICTS

I. COMPONENTS OF A MANAGEMENT SYSTEM

A. Land Transportation Component
B. Storage and Reprocessing Component
C. Port Transfer Component
D. Sea Transport, Emplacement and Retrieval Component
E. The Monitoring Component
F. The Security Component
G. Safety and Accident Prevention Component
H. Emergency Response Component
I. Development and Administration Component
J. Coordination and Control Component

II. IDENTIFICATION OF KEY MANAGEMENT ISSUES

A. Land Transportation Component

1. Selection of routes
2. Specification of modes of transportation
3. Loading and off-loading procedures
4. Frequency and volume of shipments

B. Storage and Reprocessing Component

1. Distribution of solidification, repackaging, storage and reprocessing activities (at reactor / AFR)
2. Selection of storage and reprocessing sites
3. Design of storage and reprocessing facilities
4. Control of access to storage and reprocessing facilities

C. Port Transfer Component

1. Selection of port sites
2. Design of port facilities
3. Control of access to port facilities
4. Storage at ports

D. Sea Transport, Emplacement and Retrieval Component

1. Specification of ocean routes
2. Specification and design of carrier and emplacement units
3. Emplacement site selection
4. Specification and design of retrieval system
5. Storage of retrieved material

E. The Monitoring Component

1. Elements of monitoring system
   a. For transportation systems
   b. For storage and retrieval systems
   c. For port handling
   d. For emplacement and retrieval
   e. For emergency response
2. Scope of monitoring (environmental, economic and social impacts)
3. Storage, retrieval, and analysis of monitoring information
4. Standards for response

II. IDENTIFICATION OF KEY MANAGEMENT ISSUES

F. Security Component

1. Elements of the security system
   a. During transport
   b. During storage and reprocessing
   c. During port handling
   d. During emplacement and retrieval
2. Scope of security provided
3. Responsibility for security
4. Standards for response to security violations

G. Safety and Accident Prevention Component

1. Assignment of risk and liability
2. Safety standards
   a. For employees
   b. For general public
   c. For natural environments
3. Accident prevention procedures
4. Public education and awareness of safety procedures

H. Emergency Response Component

1. Standards for emergency response
2. Responsibility for emergency response
3. Procedures and plans

I. Development and Administration Component

1. Financing, engineering and construction of all system components
2. Day to day supervision of all employees and contractors
3. Regulatory reviews and compliance
4. Maximization of cost-effectiveness
5. Imposition of fallback arrangements

J. Coordination and Control Component

1. Ownership
2. Coordination of international responsibilities and agreements
3. Coordination of intergovernmental responsibilities and agreements
4. Coordination of interagency responsibilities and agreements.
5. Accountability for systems breakdown or failure
6. Responsibility for public participation
7. Research and development

III. SOURCES AND TYPES OF CONFLICTS

A. Conflicts Over International Control of System Components

B. Conflicts Over Intergovernmental Control of System Components

C. Conflicts Over Financial Responsibility

D. Conflicts Over Liability and Appropriate Levels of Risk

E. Conflicts Over Public Perceptions of Risks Versus Benefits

F. Conflicts Over Governmental Versus Private Responsibility

G. Conflicts Over Performance Standards

Legal Comments

H. Herrmann (Presented by K. R. Hinga)

Two sections of the Law of the Sea test have language that could be construed in such a way as to present problems for the establishment of a subseabed disposal operation. The first is a provision that requires that "activities in the area shall be carried out with reasonable regard for other activities in the marine environment." The text clearly defines as a reasonable activity exploration by drilling, which would conflict with a subseabed repository. Changes in the text are offered that would mitigate this problem. The second is the difficulty with the ambiguous definition of "dumping" and a lack of a definition of "marine environment."

ADD TO ARTICLES 89 AND 137 (1):

"LONG TERM OR PERMANENT USE OF ANY PART OF THE AREA, OTHERWISE CONSISTENT WITH THE TERMS OF THIS CONVENTION, SHALL NOT, IN AND OF ITSELF CONSTITUTE A CLAIM OR EXERCISE OF SOVEREIGNTY OR SOVEREIGN RIGHTS OVER, OR AN APPROPRIATION OF, ANY SUCH PART OF THE AREA OR THE HIGH SEAS."

'5. (A) "DUMPING" MEANS: (I) ANY DELIBERATE DISPOSAL OF WASTES OR OTHER MATTER FROM VESSELS, AIRCRAFT, PLATFORMS OR OTHER MANMADE STRUCTURES AT SEA ONTO THE SEABED OR INTO THE WATER COLUMN ABOVE.'

ARTICLE (1) (4) " 'MARINE ENVIRONMENT' (INCLUDING ESTUARIES) MEANS THE SEA-BED SURFACE AND THE WATER COLUMN ABOVE."

ARTICLE 1, SECTION 1 (5) (A) "DUMPING" MEANS:
(1) ANY DELIBERATE DISPOSAL OF WASTES INCLUDING INCENERATION, OR OTHER MATTER FROM VESSELS, AIRCRAFT, PLATFORMS OR OTHER MANMADE STRUCTURES AT SEA.

. . . . SOLID MINERALS IN THE OCEAN FLOOR AT DEPTHS OF MORE THAN THREE METERS.

PART XI, SECTION 3
ARTICLE 147 (1)

"ACTIVITIES IN THE AREA SHALL BE CARRIED OUT WITH REASONABLE REGARD FOR OTHER ACTIVITIES IN THE MARINE ENVIRONMENT."

INSERT AS ARTICLE 147, SECTION (4):

NOTHING CONTAINED IN THIS ARTICLE SHALL BE CONSTRUED TO FORECLOSE THE POTENTIAL BENEFITS TO MANKIND FROM THE AS YET THEORETICAL, OR TOTALLY UNFORESEEN, ACTIVITIES IN, OR USES OF, THE AREA AND THE MARINE ENVIRONMENT, WHICH TECHNOLOGICAL CHANGE AND PROGRESS IN THE NEAR AND DISTANT FUTURE MAY MAKE POSSIBLE. THERE SHALL BE NO PRESUMPTION IN FAVOR OF THE ACTIVITIES OR USES SET FORTH IN THIS CONVENTION OVER FUTURE ACTIVITIES OR USES NOT SPECIFICALLY MENTIONED, IRRESPECTIVE OF THE NATURE, SCOPE, AND DURATION OF SUCH AS YET NON-DESIGNATED ACTIVITIES OR USES, PROVIDED THAT THE LATTER ARE SITED SO AS TO MINIMIZE INTERFERENCE WITH OTHER ACTIVITIES OR USES AND ARE OTHERWISE IN COMPLIANCE WITH THE PROVISIONS OF THIS CONVENTION.

XIV. INTERNATIONAL SEABED DISPOSAL

Technical Program Coordinator: D. R. Anderson

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D. R. Anderson, SNLA 427

International Trends
D. R. Anderson, SNLA; C. D. Hollister, Woods Hole Oceanographic Institution 433

Seabed Working Group Status Report

D. R. Anderson, SNLA

During the last year, the International Seabed Working Group (SWG) added an ad-hoc Task Group to look at the social scientific problems of the SWG within each country. The UK, US, and NEA have studies now under way, and a status report will be given at the next Annual Meeting, in March in La Jolla, California. Several new countries have joined (Figure 1) over the past year; Switzerland and Belgium are observers (observer status is the first step in joining the SWG). As you are all painfully aware, the US funding has been decreasing over the last two years; I hope it will stabilize at a level of approximately $5,000,000 expense--the level at which we are now. The non-US funding for the international program is approximately $1,000,000 greater than the US funding, and the differential is expected to increase (Figure 2). As an example, the UK currently splits their funds for HLW disposal equally between mined and subseabed disposal. From my limited vantage point, it is obvious that very soon the other SWG participating countries will dominate the program, and thus I have asked the US International SWG participants to help develop a Five-Year Plan. In this way we can influence the long-term development of the international program before we lose our scientific leadership. The next three viewgraphs show the outline of the Five-Year Plan. Any comments, additions, or changes will be appreciated.

NUCLEAR ENERGY AGENCY–RADIOACTIVE WASTE MANAGEMENT COMMITTEE

SEABED WORKING GROUP

CANADA	G. VILKS
JAPAN	R. ICHIKAWA
FRANCE	A. BARBREAU
NETH.	B. P. HAGEMAN
UK	F. S. FEATES
US	D. GLENN BOYER (CHM)
CEC	C. N. MURRAY
FRG	HOSCHUTZSKY

NEA SECRETARIAT
B. RUEGGER

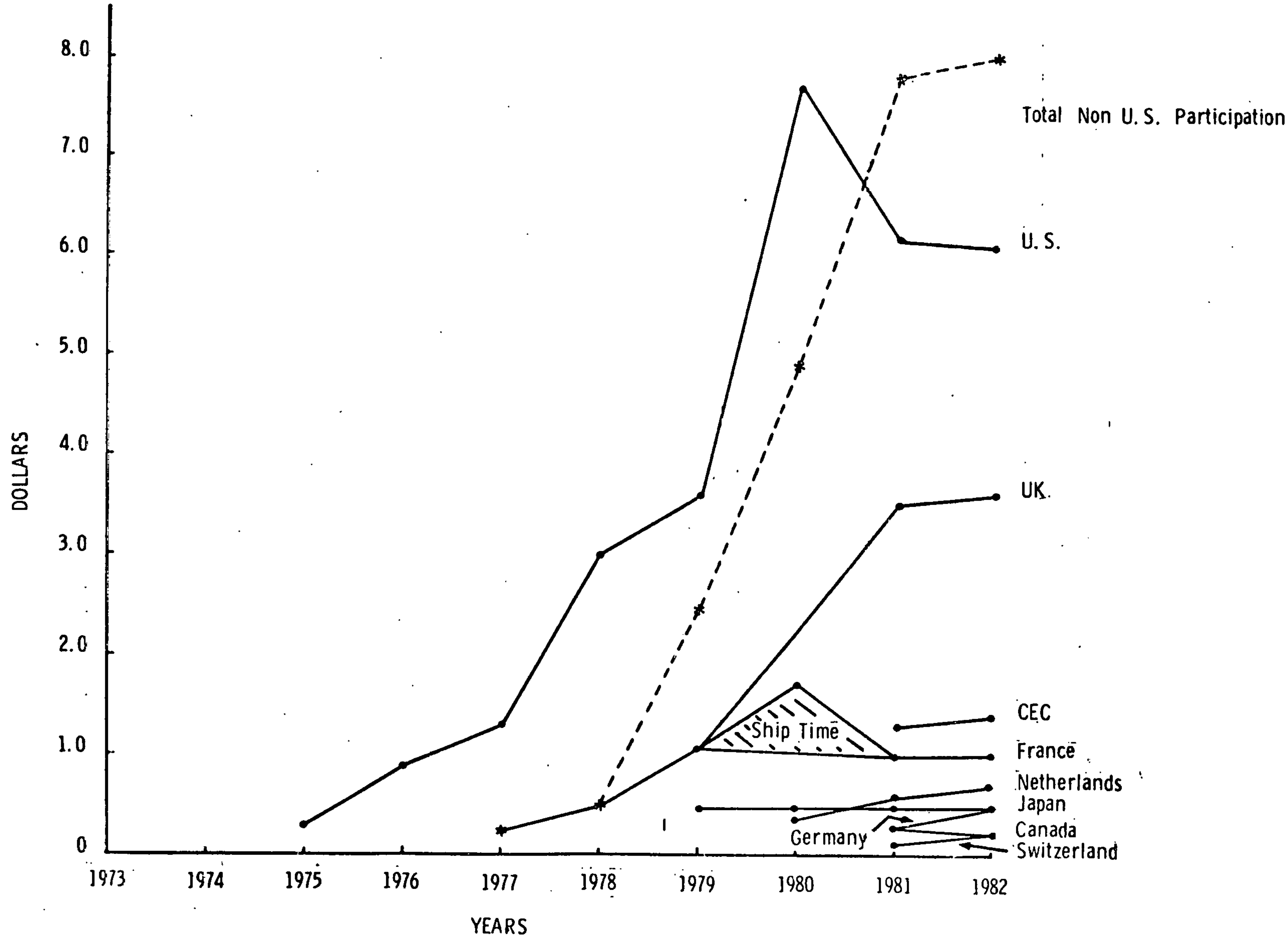
TASK GROUP COORDINATOR
D. R. ANDERSON (US)

TASK GROUP	CANADA	JAPAN	FRANCE	NETHERLANDS	UK	US	CEC	FRG
PHYSICAL OCEAN	–	HORIBE	MADELAIN	–	H. HILL	ROBINSON*	–	KAUTSKY
WASTE FORM & CANISTER	–	–	POTTIER	–	MARSH	MAGNANI*	LANZA	
BIOLOGY	HARGRAVE	ICHIKAWA	BELOT	CADEE	PENTREATH*	YAYANOS	SCHULTE	FELDT
SEDIMENT & ROCK	CRANSTON	–	RANCON*	KUIJPERS	FRANCIS	HEATH	AVOGADRO	
SITE CRITERIA	BUCKLEY	HOTTA	WANNESSON	SCHUETTENHELM	SEARLE*	LAINE	–	
SYSTEM ANALYSIS	VILKS	H. ISHIKAWA	DE MARSILY*	VAN WEERS	M. HILL	MARIETTA	MURRAY	
EMPLACEMENT ENGR.	–	–	BOULANGER	NIEUWENHUIS	ST. JOHN	TALBERT*	MURRY	

*LEAD CORRESPONDENT

OBSERVERS

BELGIUM
SWITZERLAND



Subseabed Disposal Program
Comparison Of International Funding Levels

Task Group	Activity	1982	1983	1984	1985	1986	*
System Analysis Task Group	Complete preliminary radionuclide risk and transport prediction		X				
	Complete detailed radionuclide risk and transport prediction					X	
	Complete initial phase of sensitivity studies for each Task Group:						
	SSTG			X			
	SRTG		X				
	WFCTG		X				
	POTG		X				
	BTG			X			
	ESTG				X		
	Make successful-emplacement and accident scenario predictions					X	
	Submit summary document					X	
Site Selection Task Group	Compile and analyze data		X				
	Develop site criteris		X				
	Perform G&G survey		X				
	Carry out near-bottom activities (acoustic and deep sediment sampling)				X		
	Complete sensitivity studies			X			
	Recommend reference site					X	
	Submit summary document					X	
Physical Oceanography Task Group	Develop standard bench-marking problems for model testing	X					
	Estimate model input parameters	X					
	Acquire preliminary parameters			X			
	Acquire parameters						X
	Complete sensitivity studies		X				
	Make preliminary predictions		X				
	Verify models, using field data		X				
	Make long-term predictions for safety assessment						X
	Submit summary document					X	

*To be covered in the next Five-Year Plan.

Task Group	Task	1982	1983	1984	1985	1986	*
Biological Oceanography Task Group	Develop models		X				
	Estimate model input parameters		X				
	Acquire preliminary parameters		X				
	Acquire parameters						X
	Complete sensitivity studies			X			
	Make preliminary predictions			X			
	Verify models using field data						X
	Make long-term predictions for safety assessment						X
	Submit summary document					X	
Sediment and Rock Task Group	**Thermal**						
	Develop models	X					
	Acquire laboratory model input parameters		X				
	Make verification tests					X	
	Near field chemistry						
	Develop models	X					
	Acquire laboratory model input parameters				X		
	Make verification tests					X	
	Far field chemistry (ion transport)						
	Develop radionuclide transport models	X					
	Acquire laboratory model input parameters: K_d and permeability			X			
	Make experimental design				X		
	Make verification tests				X		
	Perform LCF experiments				X		
	Mechanical (shallow)						
	Develop models	X					
	Acquire laboratory model input parameters			X			
	Make verification tests				X		
	Mechanical (deep)						
	Develop models						
	Generic		X				
	Refined					X(post-LCF)	
	Acquire laboratory model input parameters					X	
	Make verification tests						X
	Complete sensitivity studies for above-listed five areas		X				
	Submit summary document					X	

*To be covered in the next Five-Year Plan.

		1982	1983	1984	1985	1986	*
Waste Form and Canister Task Group	Complete sensitivity studies		X				
	Develop leach tests		X				
	Perform glass + sediment leach tests			X			
	Perform glass + sediment + corrosion product leach tests:						
	Corrosion-resistant canister				X		
	Controlled-corrosion canister				X		
	Preform glass-in-damaged-canister leach tests				X		
	Perform scoping experiments (corrosion)		X				
	Select reference canister type		X				
	Perform welds and closing-pressure equalization tests			X			
	Develop a void-free package					X	
	Complete preliminary engineering design of waste package					X	
	Submit summary document					X	
Engineering Studies Task Group	Complete sensitivity studies				X		
	Develop preliminary emplacement models	X					
	Develop preliminary mechanical parameter data base			X			
	Complete preferred-option preconceptual design					X	
	Complete conceptual design						X
	Field "proof of concept" mechanical test						X
	Design port and dock facilities and sea transport system						X
	Design and develop retrieval system						X
	Design and develop monitoring system						X
	Submit summary document					X	
Legal and Institutional ad hoc Task Group	Draft additional chapter for LDC		X				
	Assess the extent of national commitment to the international seabed disposal program				X		
	Incorporate LDC chapter						X
	Submit summary document					X	

*To be covered in the next Five-Year Plan.

International Trends

D. R. Anderson, SNLA
C. D. Hollister, Woods Hole Oceanographic Institution

During the last year we have briefed many of the US organizations which are involved in setting international policy. In addition, Dr. Hollister has made a concerted effort to become involved with several of the international scientific organizations which have influence over waste disposal in the oceans. They are listed in the attached viewgraph.

Through membership in these organizations and Dr. Anderson's involvement in the SWG, the following trends can be seen to be developing:

(1) The European community is becoming more interested in the SWG and its rapid development.

(2) The European community is placing more of its HLW disposal funds into the assessment of the subseabed option.

(3) The SWG is actively developing a strategy for adapting the international treaties to allow the safe, environmentally sound disposal of HLW into geologic formations beneath the oceans.

(4) There are only two treaties which have an effect on possible subseabed implementation: the London Dumping Convention and the Law of the Sea (if the latter is ratified).

Table 1

INTERNATIONAL EFFORT

ORGANIZATIONS WHICH ARE INVOLVED WITH SUBSEABED

1975	IAEA	(International Atomic Energy Agency, Vienna)
1975	IMCO	(Intergovernmental Maritime Consulting Organization, London)
1976	NEA	(Nuclear Energy Agency, Paris)
1979	ICSU	(International Council of Scientific Unions, Paris)
1980	East-West Center, Hawaii	
1981	NATO	(North Atlantic Treaty Organization, Bruxelles)

ORGANIZATIONS WHICH SHOULD BE INVOLVED WITH SUBSEABED

IIASA	(International Institute for Applied Systems Analysis, Vienna)
UNEP	(United Nations Environmental Program, Nairobi)

XV. SUMMARY REMARKS

D. R. Anderson, Program Manager

Summary Remarks

D. R. Anderson, Program Manager

SITE - Les Shephard

An acceptable site has been found in the Pacific and by the end of 1983, all the archival data for the Atlantic will have been reviewed and several cruises will have gone to the sites receiving the highest marks as assessment will have been made as to the acceptability.

The main problem in this area is the possibility of a natural convection cell in the sedimentary layers due to heat moving outward from the mantle of the earth.

THERMAL - Mark Percival

In this section, the models have been developed, the important properties have been measured, the model has been exercised. The results indicate that the heat flows through the sediments by a conduction process and there is no appreciable pore water movement due to the heat source in the sediments.

The main problem remaining to be answered is the verification of the model through both large laboratory tests and the ISHTE field test. (1984 fielding date)

SEDIMENT MECHANICAL BREACHMENT - Joel Lipkin

In this section, the one-dimensional models have been developed and are operational, the properties to feed those models have been estimated; and the model has been exercised. The results indicate that 1) the buoyancy effect (burp) is not a problem; 2) the can sinks a bit into the sediments, and the sediment which is warm but at a distance from the canister will rise slightly, but in neither case is the movement greater than 1 m.

The main problems identified at this time are the funding and the time needed for the long term property tests that are needed to acquire necessary properties.

EMPLACEMENT - Dan Talbert

In this section the one-dimensional models have been developed and are in operation, the material properties to feed those models have been estimated, and the model has been exercised. The results to date indicate that 1) the hole does indeed close; 2) a free-fall penetrometer with a terminal velocity of about 30 m per second will penetrate approximately 30 m into the red clay sediments of the Pacific. The beginning development phases of a boosted penetrator which is planned to penetrate up to 100 m are underway.

The main problem identified in this area is the presence of sand layers which are almost impossible to penetrate.

SYSTEMS - Bob Klett

In this section the systems models are up for the canister, the near field thermal and the far field chemical sections. The properties have been estimated and the models exercised. The results are as follows:

1) a canister is not needed if the waste package has been correctly emplaced in the sediments. For example, 1/10 to 1/2 m of additional depth into the sediment is equivalent to a thousand-year waste package.

2) In the thermal section, the important parameter is the thermal conduction. The pore water does not move appreciable distances in the sediment during the thermal period.

3) In the far field section, the positively charged ions with long half-lives and high K_Ds do not get out of the sediment. The positively charged ions with low K_Ds and short or intermediate half-lives do not get out of the sediment. The negatively charged radionuclides with reasonably high K_Ds do not get out of the sediments. The iodine with its essentially infinite half-life and low K_D will get out, however, the sediments can be used as a slow relief valve to keep the concentration at a very low level during dilution and isotopical dispersion. As far as the heat and ion transport is concerned, the old theory of placing the canister in thin sediment half-way between the sediment water interface and the basement rock is not important. The canister can be placed directly on the basement rock and the same protective results will be obtained unless the basement rock outcrops in the near vicinity.

The risk and safety analysis has been made on certain sections of the pathways back to man. The risk has been found to be small.

The main problem in this section is the need for more time and data to complete both the systems and the safety analyses.

THE NEAR FIELD - Larry Brush

In this section, the models have been developed, the properties have been estimated, the models have been exercised. The results show that a canister can be built that can last for a reasonable lifetime of hundreds of years.

One of the main problems in this area is that there is no way that we can test a thousand year can and prove it is reliable. We can, however, do some accelerated testing to give us indications that certain known failure mechanisms are not important -- such as hydrogen embrittlement, depassivation of the TICODE 12, and speciation of the radionuclides after the canister and waste form have been breached.

There is no waste form work underway in the subseabed program.

FAR FIELD - Larry Brush

In this section, the models have been developed, the main properties have been measured, the model has been exercised, and the main accomplishments are as follows:

1) None of the positively charged ions get out of the sediment if the waste package is placed correctly at depths of 30 to 50 m.

2) The negatively charged ions may not get out depending on their sorption coeficients (certain reducing sediment strongly sorb Tc). The sediments can be used as a slow release valve for the release of I_2, which has an essentially infinite half-life.

The main problem in this area remains the proof that speciation of the radionuclides to form neutral or negatively charged non-sorbing ions does not occur.

BIOLOGY - Leo Gomez

In this section, the models have been developed, the properties have been estimated, the model is now being exercised. The results to date are mainly from the field experiments which are underway to help quantify the radiation sensitivity of deep water organisms.
The radiation sensitivity of one-deep sea bacteria is the same as its shallow water analogs.

The main problem in this area is the development of the tools necessary to acquire the critical properties for the models.

PHYSICAL OCEANOGRAPHY - Stu Kupferman

Approximately one-half of the Phase I models have been developed, the properties for those operating models have been estimated. All of the remaining Phase I models will be completed by the end of FY 1982. The results to date show that waters (which may contain radionuclides) in the mid-ocean areas of interest both in the Atlantic and the Pacific outcrop at the poles in times of 100 to 300 years.

The problem in this area is the acquisition of the necessary properties.

INSTRUMENTATION - Dan Talbert

The large coring facility is moving forward slowly. No insurmountable technical problems have been identified. It still seems that we can acquire a 50 m undisturbed core using this technology.

The main problem is limited funding.

TRANSPORTATION - Clint Shirley

Land transportation networks have been set up which we can use as need arises. A preliminary design of a ship for the handling of free fall penetrometers has been completed.

Conclusions to date are:

1) This section of the program does not need detailed work until other phases of the program have moved farther forward.

2) The emphasis during the next year should be placed on the information needed for safety assessments and for the development of a conceptual design.

SOCIAL ENVIRONMENT - Ken Hinga

The concensus from this section is that we must do additional social scientific research. we are currently in the same phase of development that the physical sciences were several years ago in that the research plan is incomplete, thus there is some hesitancy in what should be done next.

We do know, however, that we must inform and educate the decision-makers and scientists. The conclusion is that if the concept continues to be found technically feasible, we can accomplish the needed social scientific changes. If it is found to be unfeasible, we can also stop the program very easily.

INTERNATIONAL PROGRAM - D. R. Anderson

There is increased interest both by participating countries and by new countries as well in the subseabed program, in that in the last two years four new countries have joined the Seabed Working Group. In addition, although the funding for the Subseabed Disposal Program has decreased in the United States, in all the other participating countries the funding has either increased or held constant over the past years.

Conclusions from not only the international program but the contacts that have been made in the international community indicate the following:

1) Given the interest and funding levels inside and outside the United States, we can expect to lose the leadership of this program within the next couple of years.

2) Outside forces will drive the U. S. program rather than forces inside the United States.

3) The social scientific problems in the Atlantic are drastically different than those in the Pacific and both need to be addressed.

APPENDIX: PARTICIPANTS

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