Biological Studies of the United States Subseabed Disposal Program

MASTER

$c\rho$

L. S. Gomez, R. R. Hessler, D. W. Jackson, M. G. Marietta,
K. L. Smith, Jr., D. M. Talbert, A. A. Yayanos

Sandia National Laboratories

SF 2900-Q(3-80)

BIOLOGICAL STUDIES OF THE U.S. SUBSEABED DISPOSAL PROGRAM

SUBSEABED BIOLOGY TEAM: (L.S. Gomez[1], R.R.
Hessler[2], D.W. Jackson[3], M.G. Marietta[1], K.L. Smith, Jr.[2],
D.M. Talbert, A.A. Yayanos[2].)

[1]Sandia Laboratories
Albuquerque, N.M.   87185

[2]University of California
Scripps Institution of Oceanography
La Jolla, CA   92093

[3]Falcon Research and Development
2350 Alamo Avenue S.E.
Albuquerque, N.M.   87106

ABSTRACT

    The Subseabed Disposal Program (SDP) of the U.S. is assessing
the feasibility of emplacing high level radioactive wastes (HLW)
within deep-sea sediments and is developing the means for assessing
the feasibility of the disposal practices of other nations.   This
paper discusses the role and status of biological research in the
SDP.   Studies of the disposal methods and of the conceived barriers
(canister, waste form and sediment) suggest that biological knowledge
will be principally needed to address the impact of accidental
releases of radionuclides.   Current experimental work is focusing
on the deep-sea ecosystem to determine: (1) the structure of
benthic communities, including their microbial component; (2) the
faunal composition of deep midwater nekton; (3) the biology of
deep-sea amphipods; (4) benthic community metabolism; (5) the rates
of bacterial processes; (6) the metabolism of deep-sea animals, and
(7) the radiation sensitivity of deep-sea organisms.   A multi-
compartment model is being developed to assess quantitatively,
the impact (on the environment and on man) of releases of radio-
nuclides into the sea.

BIOLOGICAL STUDIES OF THE U. S. SUBSEABED PROGRAM

INTRODUCTION

On a world-wide scale the nuclear fuel cycle is producing an ever increasing amount of waste. A recent review (McElroy and Burns, 1979) describes concisely the several options being investigated in the U.S. for the disposal of high level radioactive wastes (HLW). The deep sea is among the loci being considered as potentially suitable. Anderson (1979) has written a current report on the U.S. Subseabed Disposal Program (SDP), which has two overall objectives: (1) to determine the feasibility of emplacing HLW within selected deep-sea sediments; and (2) to develop a capability for assessing the feasibility of the practices of other nations disposing radioactive wastes into the marine environment. The research and development goals at the operational level of the SDP are to achieve or analyze site selection, multibarrier description, emplacement processes, transportation considerations, societal-political aspects, risk, economics, and environmental impact. The biological aspects of the research, the subject of this paper, are relevant to most of these goals.

The disposal of appropriately packaged and solidified HLW in the seabed differs from many of the other geological options being evaluated in that the marine environment could be affected. In addition, other geologic disposal methods might also require transportation by ship if one nation were to use the land disposal site or reprocessing facility of another nation. A ship carrying HLW destined for disposal on land or into the seabed could accidently be lost at sea. Another kind of accident could occur if there were a failure to emplace packaged HLW into the sediments. Once the waste is successfully buried, the canister and waste form should contain the radionuclides for hundreds of years. During this period the ecosystem should be minimally affected. After the canister and waste form corrode and disintegrate, however, then radionuclides will interact with sediments. These interactions should result in virtually all of the radionuclides being sorbed onto the sediments (Duursma and Gross, 1971; Heath, et al., 1979). But we do not yet know if all radionuclides and their chemical forms will be sorbed, and processes yet to be fully evaluated may result in some release to the benthic boundary layer where interaction with deep-sea life would occur. Clearly, the evaluation of accidental releases makes biological research necessary. Finally, biological research may allow for the design of sensitive monitoring programs (Schaefer, (1960).

Radioactivity of man-made origin has been entering the marine environment by several mechanisms for decades. The continuing study of the pathways of these radionuclides provides much of the necessary information needed for assessing the impact of a deep-sea disposal plan. Low level wastes have been disposed by the U.S. (Ocean Dumping, 1970) and are being disposed by a consortium of nations (European Nuclear Energy Agency, 1969) onto the sea floor. Some of the low level disposal sites in the deep sea have been studied (e.g., Noshkin, et al., (1978). Nevertheless, the bulk of our knowledge of the pathways to man and of the impact of radioactivity in the marine environment is derived mainly from shallow water situations such as the Bikini tests affecting the Pacific Ocean (e.g., Japan Society for the Promotion of Science, 1956), the Windscale effluents into the Irish Sea (e.g., Preston, 1975), and the Hanford discharges into the Pacific Ocean via the Columbia River (e.g., Pearcy, et al., 1977). The point is that the radioecological data base is most deficient in the deep sea. Indeed, biological knowledge in general about the deep sea is lagging behind that of shallow waters. In part this situation is due to the virtually virgin nature of many deep-sea resources. Research to achieve management of these resources has thus been unnecessary. The burgeoning world population will result in closer scrutiny of the food resources of the deep sea; the need for minerals is already causing examination of the deep-sea floor; waste disposal (some radioactive) into the marine environment is already a reality-even if not yet for HLW. There is a desire to use a given resource of the deep sea without affecting others, and consequently research in deep-sea biology is beginning to be stimulated world wide.

On account of this dearth of basic biological knowledge of the deep sea, much of the research in the SDP to date has had mainly to do with deep-sea ecology. The radioecology of the deep sea will be more directly addressed this coming year because of the successes in basic deep-sea ecology over the past few years. What follows is a description of the highlights of the biological aspects of the ongoing U.S. SDP program and an indication of the directions it will be taking over the next year.

Workshops internal to the Subseabed Disposal Program, as well as international workshops help to identify the important problems of HLW in the deep sea. A Biology Task Group is one of seven Task Groups of the Seabed Working Group of the NEA-Radioactive Waste Management Committee. The Seabed Working Group meetings provide an international forum on all aspects of HLW in the deep sea by identifying cooperative research efforts, providing information exchange and evaluating progress.

Finally, it should be noted that the SDP has a schedule
aiming to provide a demonstration of the capability to emplace
canisters by approximately 1990-95. A more immediate milestone is
to show the technical and environmental feasibility of the SDP
concept by the end of 1983.

Development of an Ecosystem Model

There are a large number of biological and physical events
whose interactions may transport radionuclides released inadver-
tently into the environment. Food for marine organisms is synthe-
sized by phytoplankton in surface waters. This is the beginning
of the nourishment of marine organisms ranging in size from
bacteria to the largest of animals, blue whales. Feeding and
excretion transfer material through the fabric of the seas.
Migrations of the animals themselves are also important. Certain
marine mammals and birds exhibit annual horizontal migrations
of thousands of miles. Salmon, shad and other fishes have
dramatic anadromous migrations. Many commercial fishes reproduce
with pelagic eggs transported horizontally for tens of miles
(Russell, 1976). Vertical migrations in the water column are no
less profound, ranging from a diel pattern (Longhurst, 1976) over
hundreds of meters to the ontogenetic migration of rattails
(Merrett, 1973) that can extend over a few thousand meters.
Some benthic invertebrates have pelagic eggs or larvae that
may disperse horizontally. These and other biological interactions
are influenced by an assortment of physical processes such as
currents, eddies, upwellings, and thermal structure.

A mathematical model which describes the migration of radio-
nuclides by the various transport mechanisms (physical as well
as biological) of the sea is being developed in order to quantify
the impact due to any accidental release of waste material. This
model is directed towards answering two questions: what is the
effect upon the marine environment, and what is the effect upon man?
The goal is to estimate the levels of radioactivity in marine
organisms and the dose to man.

The model is made up of the following modules: near-field
transport in sediments with heat effects; far-field isothermal
transport in the sediments; physical and biological transport;
human dosimetry; affected human populations; and finally, human
health effects. The resultant human health effects studies will
answer the question concerning the effect on man. The concentra-
tions of radioactivity predicted in the physical and biological
transport module will provide part of the answer for the question
concerning ecosystem effects. Knowledge of how a given concen-
tration of radioactivity will affect particular organisms will

be gained through an investigation of the radiosensitivity of deep-sea organisms. Predictions of effects on the ecosystem inferred from the studies on individuals should be confirmed experimentally.

The oceanic ecosystem has been compartmentalized in a manner begun by Wishner (1977) by grouping organisms according to their function. The species within a compartment are assumed to behave similarly both in their relationships with the environment and in the way that they pass along radionuclides. Group bounds on the standing crop and metabolic rates may then be assigned to each compartment by observing the constituents of the group. Further, the module for the water column and biological transport has been separated into sub-models, reflecting the different mixing layers of the water column. The benthic boundary layer part of the model extends from the lower limit of biological activity in the sediments and extends into the bottom 20-50 meters of the water column. Above the boundary layer is a multi-layered model.

The mass transports between biological compartments and physical compartments are most complex. Besides predator-prey relationships, the radionuclides may be transported by excretion, mortality, adsorption, migration (feeding, breeding, and ontogenetic), and molting. In addition, both organic and inorganic sediments and/or particulate materials may be consumed. Radionuclides may also be taken up directly from the water column or from the interstitial water of the sediments. There are various physical transports to be considered, such as association-disassociation in the sediments and water column for both organic and inorganic matter, erosion-sedimentation, vertical and horizontal water dispersion, bioturbation, horizontal migration of benthic megafauna, vertical migration of mid-water animals, and dispersion of host particulate matter. Each of these radionuclide transports between compartments is being examined.

Modelers and experimenters of the SDP meet bimonthly to develop the proper mathematical expressions for the biological transports in the model. While a deep-sea data base is being obtained, it is being supplemented with shallow water data in order to exercise the model. In addition, some algorithms for computing the transfer rates have been adopted.

Biology of Near-Field and Far-Field Regions

In the SDP concept, HLW would be buried in sediments 30 to 100 meters beneath the sediment water interface. The near-field region is that immediately surrounding the canister; the far-field region

extends to a spherical surface whose radius comes up to the zone of
active animals in the sediments. The biological questions in these
regions are mainly microbiological. These, along with chemical and
physical processes (see Krumbein, 1978; Gieskes, 1975), are in-
volved in the diagenetic events in sediments. The need for a
greater understanding of the microbiological processes is widely
recognized. Are there metabolically active or potentially meta-
bolically active microbes at these sediment depths? Can micro-
biological activities affect (adversely or favorably) the canister,
the waste form, or the sediment-radionuclide interactions at
30 to 100 meter sediment depths? We would not expect organisms
to survive in the near-field region or in the adjoining parts
of the far-field regions because of thermal and radiation effects.

About three years ago a core about 24.5 m long was taken
(Hollister, 1977) with a giant piston corer and was sampled
for microbes (Yayanos and Van Boxtel, 1977). The samples were
preserved by several methods (freezing, freeze drying, and chemical
fixation). Organic carbon content ranged from 0.06% to 0.15%
(w/w). ATP (adenosine triphosphate--a component of living but not
of dead cells) was present at depths shallower than ten meters
and in a single sample at about a 24 m depth. This could have
been due to a contaminant. The use of ATP is a tenuous method
for determining the presence of cells. In using it to detect
low cellular concentrations, for example, contamination from
gear and the experimenter can be a difficulty. These problems
could be minimized. Yet the chief source of uncertainty
would remain, due to the length of time it takes to retrieve
and dismantle a large corer to allow sampling. ATP content of
cells would most likely change during such delays. We plan to
analyze some of the other samples (frozen and freeze dried)
using microscopy this coming year. In order to achieve an analysis
of many microscopic fields of view we will use computer-assisted
image analysis. The variety of methods of sample preparation to
be investigated includes fluorescent labelling for microbes.

Cultivation of microbes is one of the most sensitive ways
to detect their presence. Because of the well-known uncertainty
involved the above indirect methods of microbial detection
are also being explored. We have endeavored, however, to find
cultivation conditions for deep-sea microbes. Rather than tackle
the cultivation problem for the microbes of deep sediments first
--even though these might be of most interest during the first
few hundred years of emplacement--we have chosen to solve culti-
vation difficulties using microbes whose existence is quite
apparent--those that participate in putrefaction. Our success
has been encouraging (Dietz and Yayanos, 1978; Yayanos, Dietz
and Van Boxtel, 1979) with the isolation of genuine deep-sea
microorganisms. We have many isolates but have only studied

one in detail. This isolate (designated CNPT-3, and originating
in the central North Pacific Ocean) grows rapidly (a generation
time of about 9 hours at deep-sea pressures and temperatures).
We are studying its growth requirements to find out which of
the many cultivation variables are significant. CNPT-3 dies when
decompressed at increased temperatures (above 15°C). We thus
imagine that cultivation of microbes from core samples will
necessitate that sediments be kept cold during retrieval.
Decompression during recovery of samples from the deep sea does
not seem to harm them. Microbes sustain decompressions (growth
is often stopped or inhibited), but warming is intolerable (they
die at about 15 to 20°C). Once the cold sample is on board ship,
we attempt the cultivations both at low temperatures and at
high pressures. The brief decompression of cultures to achieve
the transfer of inocula has no detectable adverse effects. Culti-
vation at atmospheric pressure has been avoided to eliminate
or reduce the chance of contamination of cultures with shallow
water microbes which continuously enter the deep sea. We hope
to use this procedure in the near future to isolate deep-sediment
bacteria.

Spores of thermophilic (that is, preferring high temperatures)
bacteria have been found in sediments (Bartholemew and Paik, 1966).
The ability of these spores to germinate in the presence of heat
from HLW needs to be determined. Evidence to date with the
bacterium CNPT-3 and a few other isolates suggests that the deep-
sea microbial population will stop functioning above 15°C at
580 bars. Thus, in the 100°C regions of the waste,
only spores of thermophilic bacteria could have an effect.

Benthic Boundary Layer Studies

If and when the emplaced canister and waste form disintegrate,
radionuclides may interact with sediments so that some substantial
fraction or possibly all could be sorbed (Duursma and Gross, 1971;
Heath, et al., 1979). An accident, however, might place radio-
nuclides into the upper portion of the overlying sediment where
microorganisms and macrobiota live. We will need to understand
the composition, structure, function and dynamic processes of
this benthic community and how it interacts with radionuclides.
These kinds of data would help determine if recoverability, which is
possible, would be necessary.

Community Structure

A box corer technique for retrieving a reasonably undisturbed
portion (0.25m²) of sediment and its community is described by
Hessler and Jumars (1974). Analyses of the contents of such
cores inform us of the composition and three dimensional distribu-
tion of the organisms living in the sediments. Hessler and Jumars
(1974, 1977) reported the analyses of twelve box cores from the

central North Pacific Ocean -- a mid-plate, mid-gyre region (Hollister, 1977) of the kind where HWL might be emplaced. Only a few of the many results from this type of study will be noted here.

The analyses show the area to be oligotrophic (that is, with an apparently small food supply). There were only 84 to 160 individual macrofauna per m^2 of sediment. The species present form a diverse set, but any given species is rare. Many of the possible taxa are not represented in the samples, and of the 108 species, 67 were found only once. Polychaetes and tanaidaceans together accounted for 75% of the individuals, with the polychaetes representing 55%. A substantial number of polychaetes had sedi-ment in their guts. Although foraminifera and nematodes were not sampled adequately, there was evidence of a substantial population of these meiofauna (animals which pass through a 1 mm mesh size screen). Subsequent work by Jumars (1978) shows, among other things, that sediment-ingesting polychaetes stay mainly in the upper 1 cm of the sediment, but occasionally a few individuals will extend ten to twenty centimeters into the sediment. Bernstein, et al. (1976) and Bernstein and Meador (1979) have observed that there is an order of magnitude more foraminifera than macrobiota, and that foraminifera have a patchy distribution. Because of their abundance in the samples, the foraminiferan species composition and distributional patterns reveal a patch structure, and a persistence of this structure over more than one generation. Details such as this one of community structure may allow for the detection of changes in deep-sea community disturbed by an abnormal level of radionuclides. Burnett (1979) found that nematodes do not penetrate much beyond 5 to 10 mm into the sediment and that they too are abundant, as suggested by Hessler and Jumars (1974). The determination of the food web of all of the infauna, of their elemental composition, and of their metabolic rate should greatly augment our capability to predict important radionuclide transport pathways. Of course the locomotor and feeding activities of the infauna move both sediments and pore water -- a process referred to as bioturbation.

The above discussion has dealt with those organisms whose existence is intimately tied to the sediments. The visible effects of their activities can be seen in the pictures in Heezen and Hollister (1971). Photography with baited cameras (Isaacs, 1969; Hessler, et al., 1972) has revealed the presence of large, mobile, apparently epibenthic animals. Liparids, rattails, shrimp, amphipods, and other animals have been photographed at abyssal depths in the vicinity of bait. There appears to be some interest in the study of rattails (macrourids) as evidenced by the

study of McLellan (1977) on their feeding and the study of Merrett
(1978) on the distribution of their larval and juvenile stages.
A sufficient data base for understanding the role of rattails in
mobilizing radionuclides to upper portions of the water column
would include a knowledge of the size of the population, its age
structure, fecundity, their migratory behavior, their elemental
composition, and their radiosensitivity.

We have chosen to pursue at this time the study of one
component of this mobile epibenthic group of animals--amphipods.
It is practically an axiom of deep-sea biology that these animals
will always come to bait on the sea floor (Hessler, et al.,
1979). Since they can be caught, many aspects of their population
structure can be learned. The age structure of a catch, for
example, is mirrored by a plot of the frequency of a given size
class versus the size class of the animals. This is a consequence
of their growth by steps necessitated by molting. An abnormal
event in the population can lead to a distinctive cohort. If
this could be followed by sampling a population over time, then
good approximation of age would result.

Studies are also in progress to determine the size of the
populations using tag-recapture data. The methodology for
tagging amphipods has been developed. We are now dealing with
the fielding of tag-recapture experiments at 5700 m depths and
have learned that labeled animals can be recovered.

Among the several species of amphipods (Hessler and Ingram,
1979), Eurythenes gryllus appears to be the most ubiquitous and
to have the greatest range in its distribution having been
trapped at least 500 m above the sea floor. Its mobility and
ingestion of sediments suggests that E. gryllus could diperse
radionuclides.

Another method for dispersion of matter vertically may exist
because of the feeding habits of amphipods and because many
lipids are less dense than water. Amphipods are scavengers and
do not necessarily consume their entire food source. It is
likely that lipid particles are often released and float to the
sea surface. This may not be a major pathway in a normal ocean.
A poor epi-seabed disposal practice may result in an abundance
of dead animals on the sea floor. The resultant attraction of
mobile scavengers may result in the movement of lipid-containing
particles (and any bound radionuclides) rapidly and directly to
the sea surface (Yayanos and Nevenzel, 1978).

Community and Organismal Processes

One way to gauge the function of the deep-sea benthic community is to determine its metabolism in a fashion which disturbs it as little as possible. A free vehicle grab respirometer (FVGR) has been designed and constructed (Smith, et al., 1979) to achieve the capability of measuring metabolism in situ. The instrument is deployed with ballast. On the sea floor, it will respond to commands from the ship. It can gently place 4 boxes (grabs) over the sediments, trapping water and undisturbed sediment. Electrodes detect the utilization of oxygen by the entrapped organisms. Syringes can sample or inject substances into the entrapped water. On command, the grabs are closed retaining the sediment and water on which measurements were made. A final command releases the ballast and the FVGR is recovered. The water samples in the syringes are analyzed chemically. The sediments from the grabs are analyzed for biomass and faunal composition.

Measurements with this instrument (Smith, 1978) revealed that benthic community respiration diminished by three orders of magnitude with depth along the Gay Head Bermuda transect of the Atlantic Ocean. Two stations vertically spaced by 2600 m in the Pacific Ocean, however, showed little difference in community respiration. This similarity may be due to the enriching effects of the California Current system.

The FVGR is a useful tool for doing in situ experiments with radionuclides. Already a tracer experiment using a neutron-activatable isotope has been fielded.

We are also studying methods for capturing and retrieving deep-sea animals in a live condition (Yayanos, 1979). If these animals can be maintained in the laboratory, their behavior, nutrition, and physiology can be studied in detail. To date, we have been successful in capturing amphipods at a 5900 m depth and keeping them at 590 atm and $2^{0}C$ for nearly 17 days. If maintenance of these animals can be extended indefinitely, they should be valuable for studies of radiosensitivity.

Abyssopelagic Fauna

The depths considered for the disposal of radioactive wastes (about 5,00 m) are known as the abyssal depths of the sea. The extensive amount of water defined by about ten to a few hundred meters above this sea floor and below the $4^{0}C$ isotherm is known as the abyssopelagic zone. This is a poorly understood volume of the oceans because of the difficulty in sampling mobile

animals which may live there. In an effort to determine what
lives there, new methods of sampling and catching organisms are
being developed. Fisheries that are commercially important at
the present time are above this zone. Radionuclides released
from a hypothetical deep-sea disposal site would have to penetrate
this zone in order to reach man's sea food. One of the mechanisms
by which this could happen is by the possible trophic relationships
among the animals in this zone which could link the benthic
ecosystem to the shallow water one.

A free vehicle midwater net system consisting of gill nets,
baited traps, and baited hooks has recently been developed. The
gill nets are 30.5 m by 3.3 m with a 7.6 cm mesh. The system
of nets, hooks and traps has been deployed extensively. Examples
of species taken with it are the fish Coryphaenoides armatus
(up to 685 m off of the sea floor); the fish Nomoctes alvifrons
(730 m above the sea floor; and the amphipod Eurythenes gryllus
(400 m above the sea floor)(Smith et al., 1979). These are
widely regarded as benthic animals. We do not yet know to what
extent these animals penetrate the abyssopelagic realm or for
what reason they would leave the sea floor and enter the presumably
relatively food-poor deep midwater regions of the sea. This
evidence for life in this zone reinforces the notion that there
exists a mechanism for actively transporting matter from the
sea floor towards the sea surface. Whether the transport goes
all the way to the upper few hundred meters of the sea remains
to be shown.

Now that we have evidence that there are, indeed, large
mobile organisms living in the abyssopelagic region, we are
developing another type of net to capture them. This net has a
100 m diameter and 200 m depth. It is deployed in a folded con-
figuration with ballast. Upon reaching the sea floor, the ballast
is released, and the net rises slowly towards the sea surface,
sampling a 100 m diameter column of the ocean for nearly the full
depth of the ocean. The slow ascent, large diameter, and vertical
motion should all combine to obviate the net avoidance problem
experienced with towed nets.

Radiosensitivity of Deep-Sea Organisms and Ecosystems

As far as we know, the radiosensitivity of deep-sea organisms
has not yet been determined. But there is a body of research per-
taining to the radiosensitivity of shallow water organisms and
ecosystems (Templeton, et al., 1970); Blaylock and Trabalka, 1978).
There are many problems in dealing with radiosensitivity:
determining the dose to the biota; defining and measuring a
meaningful biological endpoint--this is difficult in experiments

both with single organisms as well as with ecosystems; assessing
genetic effect; dealing with low-level doses; and assessing
many other biological, radiation and synergistic aspects.

In an effort to gain data on the radiosensitivity of deep-
sea organisms we intend to: (1) determine the radiation sensi-
tivity of a few bacteria, since these can be cultivated at deep-
sea conditions in the laboratory; (2) determine aspects of the
radiation sensitivity of deep-sea amphipods, since these can be
recovered in a living state and maintained in the laboratory for
at least a few weeks; (3) identify situations peculiar to the
deep sea that might exhibit an enhanced radiosensitivity. For
example the pelagic eggs of rattail fish may be radiosensitive
because of the vertical ontogenetic migration they undergo.
This stresses them with decompressions of several hundred at-
mospheres, and possibly with temperature changes if the eggs pene-
trate the thermocline. The adult rattails may be radiosensitive
if their swimbladder tissues contain oxygen, which is known to
greatly enhance radiosensitivity.

This kind of information on radiosensitivity in the deep sea
will allow an estimate of the appropriateness of using the data
on shallow water organisms in assessing the impact of accidents
on individual organisms in the deep sea. A determination of the
effects on a deep-sea community may ultimately require an in-situ
experiment.

References

(1) Anderson, D.R., 1979.   "Nuclear Waste Disposal in Subseabed
      Geologic Formations: the Seabed Disposal Program," SAND78-2211,
      National Technical Information Service, Springfield, Virginia.

(2) Bartholemew, J.W. and Paik, G., 1966.   "Isolation and Identi-
      fication of Obligate Thermophilic Spore-Forming Bacilli from
      Ocean Basin Cores" Journal of Bacteriology, 92, 635-638.

(3) Bernstein, B.B., Smith, R., Jumars, P.A., 1978.   "Spatial
      Dispersion of Benthic Foraminifera in the Abyssal Central North
      Pacific," Limnology and Oceanography, 23, 401-416.

(4) Bernstein, B.B. and Meador, J.P., 1979.   "Temporal Persistence
      of Biological Patch Structure in an Abyssal Benthic Community,"
      Marine Biology, 51, 179-183.

(5) Blaylock, B.G. and Trabalka, J.R., 1978.   "Evaluating the
      Effects of Ionizing Radiation on Aquatic Organisms," Advances in
      Radiation Biology, 7, 103-152.

(6) Burnett, B.R., 1979.   "Benthic Biological Studies: Microbiota
      and Meiofauna" in Seabed Disposal Program Annual Report, 1978.
      National Technical Information Service, Springfield, Virginia.

(7) Dietz, A.S. and Yayanos, A.A., 1978.   "Silica gel method for
      isolating and studying bacteria under hydrostatic pressure,"
      Applied and Environmental Microbiology, 36, 966-68.

(8) Duursma, E.K. and Gross, M.G., 1971.   "Marine Sediments and
      Radioactivity," U.S. National Academy Sciences, Washington,
      D. C.

(9) European Nuclear Energy Agency, 1968.   "Radioactive Waste
      Disposal Operation into the Atlantic, 1967" ENEA/OECD, Paris,
      74 pp.

(10) Gieskes, J.M., 1975.   "Chemistry of Interstitial Waters of
      Marine Sediments' Annual Review of Earth and Planetary Sciences,
      3, 433-453.

(11) Heath, R., Epstein, G.P., Leinen, M. and Prince, R.A., 1979.
      "Geotechnical and Sedimentological Assessment of Deep Sea
      Sediments," in SAND78-1359, National Technical Information
      Service, Washington, D.C., 33-55.

(12) Heezen, B.C. and Hollister, C.D., 1971.   "The Face of the Deep,"
      Oxford University Press, New York, 659 pp.

(13) Hessler, R.R., and Jumars, P.A., 1974.   "Abyssal Community
      Analysis from Replicate Box Cores in the Central North
      Pacific," Deep-Sea Research, 21, 185-209.

(14)   Hessler, R.R., and Jumars, P.A., 1977. "Abyssal Communities
       and Radioactive Waste Disposal," Oceanus, 20, 41-46.

(15)   Hessler, R.R., Isaacs, J.D. and Mills, E.L., 1972. "Giant
       Amphipod from the Abyssal Pacific Ocean," Science, 175, 636-637.

(16)   Hessler, R.R., Ingram, C.L., Yayanos, A.A., and Burnett, B.R.,
       1978. "Scavenging Amphipods from the Floor of the Phillippine
       Trench" Deep-Sea Research, 25, 1029-1047.

(17)   Hessler, R.R. and Ingram, C.L., 1979. "Benthic Biological
       Studies" In Seabed Disposal Program Annual Report, 1978, National
       Technical Information Service, Springfield, Virginia.

(18)   Hollister, C.D., 1977. "Annual Report for Sandia Seabed
       Program" in Report SAND77-1270, National Technical Information
       Service, Springfield, Virginia (1977) 25-38.

(19)   Isaacs, J.D., 1969. "The Nature of Oceanic Life," Scientific
       American, 221, 146-162.

(20)   Japan Society for the Promotion of Science, 1956. "Research
       in the Effects and Influences of the Nuclear Bomb Test
       Explosions" Vol. I and II., Ueno, Tokyo, 1824 pp.

(21)   Jumars, P.A., 1978. "Spatial Autocorrelation with RUM (Remote
       Underwater Manipulator): Vertical and Horizontal Structure
       of a Bathyal Benthic Community," Deep-Sea Research, 25, 589-604.

(22)   Krumbein, W.E. (Editor), 1978. "Environmental Biogeochemistry
       and Geomicrobiology" Vol. 1, 2, 3, Ann Arbor Science,
       Ann Arbor, Michigan.

(23)   Longhurst, A.R., 1976. "Vertical Migration" in The Ecology of
       the Seas (Cushing and Walsh, Editors) W.B. Saunders Co.,
       Philadelphia, 116-140.

(24)   McElroy, J.L. and Burns, R.E., 1979. "Nuclear Waste Management
       Status and Recent Accomplishments," Report NP-1087, Electric
       Power Research Institute, Palo Alto, California.

(25)   McLellan, T., 1977. "Feeding Strategies of the Macrourids,"
       Deep-Sea Research, 24, 1019-1036.

(26)   Merrett, N.R., 1978. "On the Identity and Pelagic Occurrence
       of Larval and Juvenile Stages of Rattail Fishes (Family
       Macrouridae) from 60°N, 20°W and 53°N, 20°W," Deep-Sea
       Research, 25, 147-160.

(27) Noshkin, V.E., Wong, K.M., Jokela, T.A., Eagle, R.J. and
     Brunk, J.L., 1978. "Radionuclides in the Marine Environment
     Near the Farallon Islands," Report UCRL-52381, University of
     California, Livermore, California, 17 pp.

(28) "Ocean Dumping," 1970, Council on Environmental Quality,
     Superintendent of Documents, U.S. Government Printing Office,
     Washington, D. C.

(29) Pearcy, W.G., Krygier, E.E. and Cutshall, N.H.,1977. "Bio-
     logical Transport of Zinc-65 into the Deep Sea" Limnology and
     Oceanography, 22, 846-855.

(30) Preston, A., 1975. "The Radiological Consequences of Release
     from Nuclear Facilities to the Aquatic Environment" in Impacts
     of Nuclear Releases into the Aquatic Environment, IAEA,
     Vienna, 3-23.

(31) Russell, F.S., 1976. "The Eggs and Planktonic Stages of
     British Marine Fishes" Academic Press, N.Y., 524 pp.

(32) Schaefer, M.D. 1960. "New Research Required in Support of
     Radioactive Waste Disposal" in Disposal of Radioactive Wastes,
     IAEA, Vienna.

(33) Smith, K.L., White, G.A., and Laver, M.B., 1979. "Oxygen
     Uptake and Nutrient Exchange of Sediments Measured In Situ Using
     a Free Vehicle Grab Respirometer," Deep-Sea Research, 26,
     337-346.

(34) Smith, K.L., Jr., 1978. "Benthic Community Respiration in the
     N.W. Atlantic Ocean: In Situ Measurements from 40 to 5200
     Meters," Marine Biology, 47, 337-347.

(35) Smith, K.L. Jr., White, G.A., Laver, M.B., McConnaughey, R.R.,
     and Meador, J.P., 1979. "Free Vehicle Capture of Abyssopelagic
     Animals," Deep-Sea Research, 26, 57-64.

(36) Templeton, W.L., Nakatani, R.E., Held, E.E., 1971. "Radiation
     Effects" in Radioactivity in the Marine Environment, National
     Academy of Sciences, Washington, D.C.

(37) Wishner, K., 1977. "An Ocean Ecosystem Model" in SAND77-1270,
     National Technical Information Service, Springfield, Virginia,
     356-364.

(38) Yayanos, A.A. and Van Boxtel, R.: "Progress Report: Deter-
     mination of the Microbial Content of Ocean Sediments" in
     ibid. 281-288.

(39) Yayanos, A.A., Dietz, A.S. and Van Boxtel, R., 1979.
      "Isolation of a Deep-Sea Barophilic Bacterium and Some of Its
      Growth Characteristics," Science, 205, 808-810.

(40) Yayanos, A.A. and Nevenzel, J.C., 1978. "Rising-Particle
      Hypothesis: Rapid Ascent of Matter from the Deep Ocean,"
      Naturwissenschaften, 65.

(41) Yayanos, A.A., 1978. "Recovery and Maintenance of Live Amphipods
      at a Pressure of 580 Bars from an Ocean Depth of 5700 Meters,"
      Science, 200, 1056-1059.