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The Disposal of High Level Nuclear Waste in the Oceans

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Mathematical Geophysics
In this session, the following topics were presented:
- Application of asympotic ray theory to siesmic body waves in anisotropic media (Hron, Univ. of Alberta)
- Resonance absorption of gravitational radiation in the Earth's crust (Jensen, McGill)
- Current trends in Canadian seismic risk analysis and their uncertainties (Weichert, EPB, Ottawa)
- Deformation of porous clastic solids (Withers, Univ. of Alberta)
- A variational approach to shear heating (Spanos, Univ. of Alberta)
- A variational approach to long period Earth oscillations (Smylie, York)
- The thermal regime of downwarped lithosphere and the effect of varying the subduction angle (Jones, Univ. of Alberta)
- Gravity zoning of Newfoundland (Miller, Memorial).

The contributions and attendance of graduate students in geophyics (in particular the Univ. of Alberta group) was a welcomed innovation of this session.

Modern Trends in Geodesy
Variations in gravity due to seasonal ground-water movements in two coastal areas of Eastern Canada were reported by Beaumont. Nyland stressed the importance of repeated geodetic survey for geophysical ends and reported on a geodetic survey used to monitor tectonic measurements in the Peruvian Andes. Gagnon presented an analysis of step by step adjustment procedures for large horizontal geodetic networks. The use of long baseline interferometers as a means of testing the theory of relativity and for geodetic and astronomic measurements was described in two presentations (Cannon). Bower showed the response of an aquifer to an earthquake. John indicated how geoid determination is obtained from astrogeodetic, gravimetric and Doppler satellite data. Lachapelle showed how the determination of deviations from the vertical can be obtained using geodetic data of heterogeneous type and Leclerc explicated the problem of the definition of the vertical coordinate in geodesy.

General Geophysics
This very tight session included such topics as geomagnetic field, seismic methods and seismicity, terrestrial heat flow and gravity.

Concerning the magnetic field, the presentation of an analytical representation of the geomagnetic field in Canada at year 1975 (Newitt) was followed by an example of subsurface mapping of the Appalachians of Southern Quebec using aerial magnetostatic field data (Seguin). Applications and advantages of a SQUID gradiometer to airborne geomagnetic measurements were discussed by Vrba.

Keith discussed the behaviour of seismic body waves in anisotropic media synthetic seismograms. Using surface waves data, a model of the upper mantle of southern British Columbia was constructed (Wickens). Kunz (New Mexico Univ.) generalized the calculations of Goss-Hänchen shift to apply to a shock-wave type of moving interface. Leblanc reported on 1974 microseismic data from the La Malbaie-Baie St-Paul area and Hearthy on the slowness and azimuth measurements from a temporary array of the same region. Induced seismicity was predicted in the recent Manic 3 dam site. Anglin discussed the nature of the microseismic events.

Hamza (Univ. São Paulo, Brazil) pointed out the relation between heat flow and heat generation through lower continental and oceanic crust; he established a unified interpretation of the dependence on tectonic age. A gravity study of the Manicouagan large circular structure in Eastern Quebec suggests a meteorite impact origin rather than the eroded remains of a resurgent caldron (Sweeney). Finally, Schloessin commented on permanent deformation of the lithosphere by solid Earth tides.

This meeting turned out to be a very interesting one. Many informal exchanges and discussions during, between and after the sessions were the highlights of the congress. The large variety of topics and the high quality of the presentations definitely contributed to this success; the response of the audience was instantaneous.

Abstracts of most of the contributions to this meeting may be found in Physics in Canada (v. 32, no. 3) or Bulletin of the American Physical Society (v. 21, no. 5, May issue).

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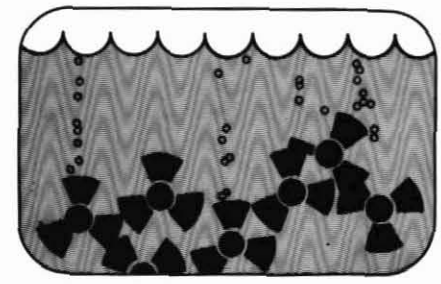

The Disposal of High Level Nuclear Waste in the Oceans

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Preamble
A workshop to consider the feasibility of using the sea-bed as a disposal site for highly radioactive nuclear waste was held at Woods Hole, Massachusetts, February 16 to 20, 1976. It was sponsored by the United States Energy Research and Development Agency (ERDA) and Nuclear Energy Agency (NEA) which functions within the Organization for Economic Co-operation and Development (OECD). Canada is a full member of NEA.

The meeting was attended by 37 scientists and observers from Australia, Canada, France, Federal Republic of Germany, Japan, United Kingdom, and United States. All the basic disciplines involved with ocean studies were represented, including engineering and waste management.

In his welcoming remarks Dr. F. Frosch, Associate Director of the Woods Hole Oceanographic Institution emphasized that with diminishing deposits of hydrocarbons as a source of energy, nuclear power will be used until other schemes are developed. However, there are problems with toxicity and the storing of radioactive waste that are not very appealing, not at least to the public. The multiple barrier concept, whereby the waste is sealed off from man by rock or sediment is geologically satisfactory. On the other hand, ocean water alone, regardless of depth, is a poor barrier. However, some countries have fewer

options than others with respect to suitable disposal sites on land and they may strongly advocate the use of the sea-floor for disposal.

The meeting was called to informally discuss: 1) current knowledge on disposal technology; 2) what we need to know and to what certainty; 3) potential criteria for disposal decisions; and 4) programmes needed.

Highlights of Meeting

A number of concepts developed from research strictly concerned with radioactive waste disposal in the marine environment were presented by members from United States, United Kingdom, and Japan. The two Canadian delegates, P. Hamel from AECB and I, jointly presented a short statement on the existing Canadian policy for the handling of radioactive waste and on a number of factors that will preclude at this time the disposal of radioactive waste in the Arctic Ocean or the Canadian Arctic Archipelago.

The conceptual design for utilization of the sea-bed as a disposal site for radioactive waste was discussed by the delegates from two points of view: 1) the placing of vitrified and encapsulated waste on the sea-floor, and 2) the burying of solid waste below the sea-floor within the sediments or bedrock. The first approach assumes a total lack of barriers between the source of radioactive emissions and man. The release rates of radionuclides into the water in this case would depend on the leaching rates of the glass containing the radioactive materials. This method is based on the assumption that dilution of harmful emissions would have taken place before any radioactive nuclides could reach man. The second approach depends on the efficiency of a set of barriers between man and the radioactive waste including the walls of the containers, the rock or sediment, and finally the ocean water. Both approaches were discussed by members in attendance.

1. Basic Disposal Criteria for a Barrier System

Predictability. As a basic criterion it will be necessary to predict what is going to happen geologically on the sea-floor at the disposal site for the future one to ten million years. The predictability of future events is greater where good lateral coherence of features can be established in addition to a continuous record of the sediment column. According to this criterion, a large part of the oceans are unsuitable for the disposal of high level radioactive wastes. For example, abyssal plains are unsuitable because sediments are normally delivered *via* unpredictable turbidity currents. Areas of active submarine volcanism and mid-oceanic ridges are also unsuitable because of their tectonic instability.

Possible Exploitation. Areas subject to future exploitation for resources, such as, continental margins, manganese nodule areas, fishing sites, etc., are unsuitable.

Chemical and Physical Characteristics of Sediment and Rock. Calcareous and silicous oozes are less suitable than red clays mainly because the latter are less porous. The migration of interstitial water through basalts is unpredictable because of fissures and lack of lateral homogeneity.

Considering the established criteria, the most suitable sites are the mid-plate/mid-gyre localities of abyssal hills. Here the sedimentation is mainly pelagic, slow, and continuous. The sea-floor in these areas is stable and the biological activity is low because of the low organic productivity of mid-gyre water.

These areas are scientifically not very exciting and as a result have been neglected. During the discussions it became evident that the studies of radioactive waste disposal feasibility in the oceans, require a slightly different approach. The main purpose of this research is not to satisfy scientific curiosity or explain systems on a global scale. The problems are more localized and require more definite answers.

Biological Criteria. At all costs the possibilty must be avoided of radionuclides reaching man and a destruction of the biological environment (the physical environment cannot be destroyed). From a biologist's point of view, the floor of the deep ocean is not a dead end in the transfer of organic matter; it is, rather, a site of intermediate processes. Organic nutrients are regenerated; therefore, matter in the organic cycle will find its way back to the surface waters and man. From the biological-ecological point of view these are the criteria that define a suitable disposal site: 1) Minimal biological activity, 2) No commercial fisheries, 3) Longest possible chain of biological transport back to man.

The centres of mid-latitude gyres are areas of low primary productivity and are deep-water environments. Here, the standing crop of benthos is lowest, the turnover rates of fauna are lower, and species are more sessile; therefore, the biological advection here is low as anywhere else. By contrast, the standing crops of benthos in deep trenches are higher, despite the great depths involved.

Not enough is known about the degree of sensitivity of deep ocean fauna to external disturbance. The high diversities of deep sea fauna indicate stable conditions to which the fauna have adapted; therefore, any interference may destroy the deep-sea communities. Very little is also known about the deep sea bacteria, except that their activities are much slower at great depths. Respiration rates also are slower; for example, deep water fishes use less oxygen than their shallow water relatives. Pathways of organic matter in the water column and sediments must be defined more precisely. From the biological point of view, there are no barriers to the radioactive waste on the sea-floor.

The peculiar environment imposed by great depths makes it necessary to carry out *in situ* measurements for reliable values of biological transport rates. The discussions centred around the difficulty involved in making reliable recordings with instruments and cameras on the deep sea-floor or in the water column. Owing to the precarious balance of the deep sea food chain, existing instruments themselves will introduce a factor of disturbance sufficiently large to affect the processes under observation.

2. Considerations in U.S.A.

It is predicted that by the year 2000, one-third of all energy in the U. S. will have nuclear fusion and fission as source. As a result, about 10,000 m^3 of solidified high level waste will be accumulated with a level of activity of about 10^5 MCi. These large amounts of radioactive waste cannot be dispersed into the environment without degrading the

quality of that environment. The disposal of the waste in the sea-bed is promising, but there are many unknowns.

Since 1973, Sandia Laboratories, Albuquerque, New Mexico, have led a feasibility study for the disposal of high level solidified nuclear waste below the sea-floor. Various characteristics of the bedrock, deep sea sediments, and water circulation were investigated as well as container design and transport and emplacement of containers below the sea-bed. Technical and engineering capabilities are presently ahead of the understanding of natural systems and site selection criteria.

The sea-bed disposal program conducted by Sandia and participants from about 25 other institutions and universities is concentrated in two localities: the central North Pacific and the Bermuda Rise. The objective is to identify barriers to the migration of radionuclides in solidified waste, walls of containers, basement rock, sediment, the benthic boundary layer, and the water. Various emplacement schemes have been considered. In unconsolidated sediment, the containers can be emplaced with a free-falling or a winch-controlled penetrometer. In consolidated sediments a hole could be drilled and, depending on its depth, accommodate up to 400 canisters. The holes would be sealed with grout.

3. Considerations in U. K.

For the past 30 years, low level waste has been disposed on the floor of the sea. With the Ministry of Agriculture, Fisheries and Food, MAFF, as the lead agency, tests for leaching, adsorption, migration, biology, etc., of radionuclides in the sea have been carried out. At present, high level radioactive wastes are stored on land in liquid form in specially designed structures. In the future, the waste will be vitrified in steel containers and probably stored in a suitable geologic structure. In the U. K., this may be difficult due to the high density of population and possible lack of suitable geologic features. The feasibility of using the sea-bed should be investigated and concepts developed on a quantitative basis. Expertise in the U. K. and elsewhere exists to carry out the necessary research. A large amount of good data is needed for the establishment of mathematical models and the validification of the existing ones.

Members of the British Nuclear Fuels Ltd., are working with problems related to solidification and encasement of high level radioactive waste. It was proposed that waste containers can be safely dumped on the sea-bed within a few years of waste discharge from nuclear reactors. The containers would be in contact with the sea water, which will remove the heat from fission product decay. This approach eliminates the problem of excessive temperatures within the buried containers because of the low thermal conductivities of the sediment. However, the radioactive waste is exposed to sea water after the failure of the container and the effects of local concentrations of high level radioactivity on the sea-floor must be studied before this approach can be seriously considered. To minimize the possibility of container failure, materials that have a known longevity in sea water should be used. Archeological artifacts found on the sea-floor have been studied for this purpose.

A model was developed by the National Radiological Protection Board, England, that gives an assessment of total impact of radioactivity to man by the year 2000, assuming that all waste is dumped on the sea-floor. A number of simplifying assumptions were made, some of which are given below.

By the year 2000, the total generation of electricity will have reached 12,000 GWY and as a result there will be 400,000 T of waste from reprocessed fuel, yielding about 10^9 Ci actinidites and 10^{10} Ci fission products. This is the input to the oceanographic model. The waste will be stored in vitrified form in encased cylinders 0.53 m in diameter, three m high and with 0.5m^3 as total volume of glass per cylinder. By the year 2000, 60,000 of these cylinders will accumulate. It is assumed that the containment of glass failed upon landing on the sea-floor, spreading waste in fist-sized lumps of glass. It is also assumed that the borosilicate glass leaches at 10^{-5} gm/cm^2/day. The major transport process of the released nuclides in the water is assumed to be diffusion.

Owing to the wide range of half lives of the nuclides, two models were considered; the short term local diffusion model and the long term model of the world oceans. The short term model predicts maximum concentration of radionuclides with intermediate half lives, e.g., 137 Cs, 30 years, at times of 100 years or less depending on the assumed diffusion coefficients.

An attempt was also made to follow the pathways of the various radionuclides through the food cycles of the oceans and to predict how the nuclides may reach man through ingestion or exposure. An important factor is the dosage and the ratio of estimated intake of each nuclide over the maximum permissible annual intake as recommended by the International Commission of Radiological Protection is used. The ratios are in the range of 10^{-2} to 3×10^{-6} and it is concluded that according to these models, no overriding reason has been found that would preclude the disposal of high level radioactive waste on the sea-floor. This view is controversial and triggered questions, such as: What is the probability of not having homogeneous oceans where diffusion is not following the proposed model? The critical features are the ones that do not follow averages.

4. Considerations in Japan

Owing to the lack of favourable geological formations on land, Japan is conducting an intensive feasibility program for the disposal of high level radioactive waste on the sea-bed. The criteria for a favourable disposal site are similar to those discussed in previous presentations with one important difference: the Japanese are testing the feasibility of impregating liquid waste in concrete contained in drums.

A discussion followed pointing out the high leaching rates of concrete, making it a poor barrier for radionuclides in the seawater. It was suggested that bitumen and epoxy resins behave better in this regard.

Summary and Recommendations

Despite the fact that to date the disposal of high level radioactive waste in the marine environment has not been officially approved by any country, various agencies have carried out extensive feasibility studies for a possible use of sea-bed as disposal site. The initial work indicates that there are places in the oceans that have been stable for a long period and it is therefore possible to predict future stability for the required time intervals. The sea floor of the mid-plate/mid-gyre areas is

geologically stable and is relatively distant in terms of man's activities. The biological transport is low, the sediments are normally red clays of sufficient lateral continuity or homogeneity to ensure high predictability in terms of sedimentary processes.

Some work has been done on the engineering aspects of the problem. The manufacture of waste containers has been studied in conjuction with the vitrification processes of the liquid waste. The longevity of materials in sea water at great depths and the presence of radioactive emissions in a high temperature environment is important for the concept of the barrier system and requires a great deal of additional work.

It is necessary to make a requirement that no radioactive emissions resulting from the sea-bed disposal may reach any part of the ocean biota and man. To meet this requirement, potential barriers are identified, tested and accepted on the basis of satisfactory safety margins.

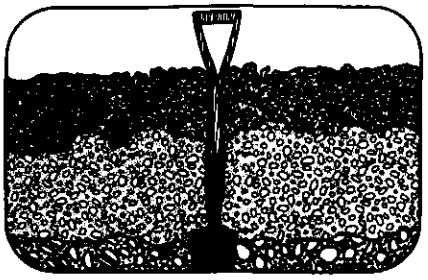
In view of the encouraging initial results and the need for a wide range of alternatives for the storage of nuclear waste, it was suggested that future feasibility studies for the disposal of high level radioactive waste in the marine environment should continue. More exact data must be gathered. In terms of biology, *in situ* experiments are needed to ensure a better understanding of the transfer of organic matter through the marine ecosystems. In terms of geology, a better understanding of the physical and chemical response to the heat and radio-activity in the sediment has a priority. It is important to know the interstitial fluid behaviour and ion exchange capacity of the sediment, mass fluidization of sediment by heat, physical and chemical modification of the sedimentary medium by high temperatures and finally, the visco-elastic properties of the sediment.

Survey of the sea-floor for prospective dumping sites must continue using progressively improved instrumentation. For this phase, Canada has both expertise and equipment to participate, given the necessary priority. The advantages of participation are many, despite the fact that serious consideration has not been given to sea-bed disposal at the present time. Even a limited participation will ensure that Canadian marine expertise will be keeping up with the developments in the technology of nuclear waste disposal in ocean environments. During the workshop it became evident that some nations may want to take greater risks in nuclear waste disposal and management on the sea-floor. To protect one of the largest marine coastlines of the world, Canada should be able to assess on a sound technical basis the feasibility of placing nuclear waste in the sea-bed. More detailed studies may produce overwhelming evidence that nuclear waste should not be dumped in the marine environment or at least that modification of existing disposal criteria is warranted. Convincing arguments can only be produced on a broad information base.

The theme of the workshop was to study criteria and techniques for the disposal of high level nuclear waste in the ocean environment without considering the retrieval of the waste. For all practical purposes the disposal of the waste on or in the sea-bed must be considered as final, owing to the difficulties of safe recovery. The impractical retrieval of the waste may be an important criterion in making final decisions for or against the usage of the sea-bed.

The prevailing policy in Canada is to store spent fuel from reactors in near-surface land based engineered structures for a possible retrieval. Once a decision has been made to re-utilize the reprocessed fissile material, the unusable high level waste will have to be disposed of. Besides long term management in surface facilities, the options are emplacement in geological formations accessible by land or sea-bed disposal. Although the former is the currently favoured option, sea-bed disposal has attractive features with regard to the degree of isolation and inaccessibility. If well understood, the sea-bed may offer an acceptable solution to the very long term disposal of high level radioactive wastes.

MS received June 15, 1976



Symposium on Quaternary Soils

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This was the third symposium on Quaternary Research organized by W. C. Mahaney of the Geography Department, Atkinson College, York University in the last three years. It took place at York University, May 21-23, 1976, and offered a varied but well-balanced program on Quaternary soils, including papers whose themes ranged from the soils of the deserts of California to those of the Yukon and the Eastern Canadian Arctic. Such a broad geographical spectrum of investigations into Quaternary soils was conducive to an exchange of information and views among Quaternary scientists from different disciplines, and as such, many of the discussions (formal and otherwise) were lively and informative. The two sessions on the first day dealt with soil dynamics and soil stratigraphy respectively. The latter session continued the following day, with a third session on soil morphogenesis on the final afternoon.

R. W. Simonson, former director of the Soil Classification and Correlation division, U. S. Department of Agriculture, opened the session on soil dynamics with a review of soil genesis in terms of a multiple-process model. Using numerous anecdotes and personal reflections based on years of experience, he discussed the various processes which may promote or inhibit soil horizonation.

Current viewpoints on the origin and classification of Podzolic soils in Canada were reviewed by J. A. McKeague, G. J. Ross, and D. S. Gamble (Agriculture