Disposal of Highly Radioactive Waste: A Report to ICSU

by James Harrison

The disposal of radioactive wastes has received much attention from scientists, technologists and the general public. Although it is generally agreed that the technology for their safe disposal is now available, there are still many scientific and engineering questions to be answered. This article summarizes a recent review by ICSU of national and international research programs on the geological disposal of high-level radioactive wastes.

Introduction

Regardless of the pros and cons of the nuclear industry, nuclear active wastes are with us now, and safe means must be found for their disposal. High-level wastes are potentially hazardous for at least 10^5 years, and the behaviour of the nuclei contained must be considered over that period. It is important, therefore, to consider migration of nuclides in the biosphere, as well as from the repository to the biosphere.

Thousands of scientists in laboratories around the world are working on problems of radioactive waste disposal, though accessibility to their reports and publications varies widely. Partly for this reason the International Council of Scientific Unions (ICSU), acting on a suggestion by the U.S. National Academy of Sciences, decided in 1978 to survey existing research efforts on the safe disposal of high-level radioactive waste (HLW). Although this is a highly controversial and even politicized topic, ICSU is responsible to no government, has no vested interest in nuclear power (or any other kind of power), has access to the global scientific and technical community, and can come to conclusions purely on scientific grounds.

Figure 1: The nuclear power plant at Pickering, Ontario. (AECL)

The report of this survey (Harrison, 1982) concentrated on areas where there might have been insufficient research, and on disposal methods using technology presently available. In the report, disposal is taken to mean the sequestering of material with no intention to retrieve it, though this may be technically possible. On the other hand, storage is intended to be temporary. Site selection criteria should be determined by safety and science and not by economics and politics, though obviously these factors will be involved in the actual selection.

The Work of National and International Organizations

Four international organizations are particularly involved in research on radwaste disposal: the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA), the Commission of the European Communities (CEC), and the Council for Mutual Economic Assistance (CMEA). The latter coordinates research in the U.S.S.R. and most of the Eastern European countries. In general, these agencies coordinate and promote technological developments, provide safety guidelines, initiate research programs, and coordinate activities carried out by national organizations on both terrestrial and seabed disposal. All have a large program of freely available publications and support numerous technical meetings.

In Belgium, research is focussed on disposal in clay formations, in particular the Boom clay which underlies the Mol nuclear site. The main activities here consist of investigating the physical, chemical and hydrogeological properties of the Boom clay.

The British program covers disposal in geological formations on land and on and beneath the ocean bed. Although the research program nominally included evaporite and argillaceous rocks, in practice most attention has been devoted to crystalline rocks. The ocean research program focusses on sites in the northeast Atlantic. Following the decision to postpone geological field work in the U.K. (see Box 1), a larger fraction of the research program is now devoted to marine disposal.

Canada is concentrating on HLW disposal in the crystalline rocks of the Canadian Shield (see Box 2). The program covers all aspects of geological disposal, including site investigations, waste-form studies, engineering studies and safety assessments. In addition, Canada is a member of the NEA Seabed Working Group and has a limited program itself on sub-seabed disposal, concentrating on sediment properties and safety assessment methodology.

The Federal Republic of Germany is mainly concerned with salt formations, with the prime effort devoted to investigating the appropriateness of the Gorleben salt dome and on experimental work at the Assa salt mine. F.R.G. also participates in the NEA Seabed Working Group.

The program in France is similar to that of Canada in focussing on granitic formations and to a lesser extent on sub-seabed disposal. Research here is primarily in the areas of hydrogeology and sorptive properties of geological media. Sub-seabed research covers sediment properties, waste form behaviour, engineering aspects and marine biology.

Both terrestrial and sub-seabed disposal are being investigated in Japan. The rock types being studied here include granite, basalt, tuff and shale, using field surveys, laboratory experiments and newly developed mathematical models. Several cruises have surveyed potentially suitable sub-seabed disposal sites.

Workers in The Netherlands are studying options involving HLW disposal in salt domes on land and under coastal areas, as well as disposal on the sub-seafloor in the deep ocean. Site-specific work has been stopped pending the outcome of the present nuclear debate in this country. Deep ocean research has so far focussed on site surveys in the Atlantic.

In Sweden the sole concern is with disposal in hard rock, particularly granite. Research covers all aspects of geolo-

gical disposal and includes extensive field investigations, in situ and laboratory experiments, and mathematical modelling.

Switzerland also has a research program on geological disposal, the main interest being in crystalline rocks (granite gneiss). The objective of this work is to demonstrate by 1984 that HLW can be disposed of safely.

The only disposal option under consideration in the U.S.S.R. is emplacement in geological formations on land. The rock types under investigation are salt, granite and sandstone. Research activities include repository design and engineering and studies of bulk rock behaviour.

The United States has the largest of all programs studied by the ICSU Committee. Most effort here is being devoted to

Radwaste Research in the U.K.: Conflict Between Science and Public Policy

Britain's vigorous research program on geological disposal of HLW came to an abrupt end with the Government decision in December 1981 to concentrate on "confirming the applicability to the U.K. of findings from research in other countries." The feeling was that sufficient research had been done and all that was necessary to prepare for deep geological burial were desk studies, laboratory work and the use of data already available in order. This decision must be viewed against the background of vigorous public reaction to field research studies undertaken by the Institute of Geological Sciences (IGS) in the late 1970s and early 1980s.

In the early 1970s, the British Government recognized the need for information on the availability and nature of general waste disposal facilities throughout the British Isles. IGS geologists made a desk assessment of the risk of pollution to major and minor aquifers underlying nearly 2,500 waste disposal sites. Thus by 1974 IGS had entered the field of environmental protection and had built-up a considerable pool of data on the location and geology of water waste-disposal sites in England and Wales.

In 1975 the focus turned to highly radioactive wastes, and IGS geologists identified as potentially suitable for their disposal host rocks in a number of areas underlain by crystalline igneous and metamorphic rocks, evaporites and a range of argillaceous formations. However, in the period between early 1978 and 1981, only one of the 15 areas selected for detailed study (the Strath Halladale granite in Scotland) was actually investigated because of local reaction to this work.

The British research program had interesting and important implications for IGS, the major research agency involved. The Institute had embarked on a series of commissioned research projects of high scientific potential and interest, a series of laboratories had been established to investigate relevant problems within the

fields of experimental petrology, geochemistry and rock mechanics, and there were enormous opportunities for developing new research fields. For the staff concerned these opportunities more than made up for the undoubted problems of working in such a controversial field. The projects were adequately financed and they enabled young scientists to become involved in international exchanges and to broaden significantly their scientific outlook.

After the radioactive waste task force was formed in 1977, the scientific and technical staff increased from 13 to 32 by late 1981. Naturally, when the program was curtailed at the end of 1981, this number was markedly reduced. This illustrates one of the main problems associated with working on research projects relying so completely on commissioned funds - the lack of flexibility required in staffing. Just as policy decisions can lead to a requirement for more work and staff, they can equally well lead to a sudden curtailment of a particular research project and accompanying dramatic reduction in funding. Another problem is the concept that research can be turned on and off like a tap. Scientific teams take time to form and train, particularly if there has been no underlying research within the field and, therefore, no nucleus of knowledgeable staff on which the project can be based.

Of course, the principal problem confronting the researchers was the deep public concern and even distrust of the use of nuclear power and the disposal of wastes from it. Expression of research interest in any particular area usually led to the spread of grossly misinformed statements by local antinuclear groups and the press. It was not surprising, therefore, that local elected officials who had to decide applications for research projects voted to prevent exploratory drilling taking place even when they were advised by their professional officers that there was no sound reason under the planning legislation for doing so.

Problems for IGS reached a peak in the summer of 1980, particularly in Scotland where any geological activity was seen as contributing to the radioactive waste disposal program and was, therefore, the subject of harassment. Even parties of student geologists were implicated, for they were regarded as being used by the nuclear industry without their knowledge to provide data for the program. The geological profession as a whole was affected by the glare of publicity.

It is interesting to note that the reaction of local authorities to the early work on landfills was very positive, for they knew that this research would lead to guidelines helping them to carry out their own obligations with regard to waste disposal. On the other hand, the same authorities could see no benefit to themselves from the radwaste program. They felt that if they allowed the nuclear industry to gain any foothold within their area this could be the thin edge of a very large wedge.

This attitude had one very unsatisfactory effect on the nuclear waste disposal research program, for it meant that there was pressure to do as little work as possible before submitting a planning application for drilling. The siting and drilling of holes, of course, normally occurs in a late stage of any geological assessment program, following detailed map and surface geophysics, but in the British HLW program, geological mapping was cut down to the minimum required to site boreholes intelligently, and there was no opportunity to refine existing geophysical coverage. Thus the scientific program had to be adapted to meet non-scientific constraints placed upon it. One of the consequences of this was the acceptance that the cost of the research program could be increased by the need to drill further drillholes, if the data used to site the original boreholes were later proved to have been inadequate.

after Mather, 1983.

geological disposal on land but there is also a considerable program on sub-seabed disposal. Geological formations currently receiving most attention are basalt, granite, and tuff and domed and bedded salt. Within the seabed program, both Atlantic and Pacific sites are under study.

Australia, Austria, Denmark, Finland, Italy and Spain also have small programs of research into HLW disposal. In all these countries research is focussed on disposal in geological formations. Australia is pursuing the interesting line of immobilizing high-level wastes in synthetic rock material (SYNROC - see Box 3), and on the migration of naturally occurring radionuclides over long time periods. Danish research is primarily on salt domes, Finland is investigating disposal in granite, and Italy is concentrating on disposal in clay formations.

Thus, disposal in geological formations on land is the option to which most current research effort is being devoted, but there are also substantial studies of disposal beneath the bed of the ocean (see Brookins, 1984, for further details of

national and international programs). Very little research has been carried out on disposal on the ocean bed, though this option has yet to be ruled out on technical grounds. Research on environmental pathways forms a major part of larger national programs, while the smaller national programs tend to focus on specific topics such as preliminary site screening prior to the selection of the land and ocean sites that may bear detailed investigation. There is a common tendency in the longer-running research programs to include more work on engineering aspects.

Recommendations of ICSU Committee

The generation of heat by HLW falls off quickly, and in 50 years it is about 1% of that of wastes from freshly reprocessed fuel. Thus the thermal effects on the disposal medium are reduced, and it is possible to use less underground space for disposal. However many people now think it wiser to retain the solid wastes in storage until more is known about the effects of heat loading on the depository. The data now available are inadequate for the best choice of disposal

The Canadian Nuclear Fuel Waste Management Program

Atomic Energy of Canada Limited (AECL) is developing a plan for immobilization and containment of nuclear waste in relatively impermeable crystalline rocks such as those found in the Canadian Shield. The overall objective is to ensure that the disposed waste presents no unacceptable hazard to man or to his environment. The Waste Management Division of AECL employs some 160 scientific personnel of whom nearly half are involved in geoscientific research (Fig. 2).

AECL's program is proceeding in three carefully scheduled stages. Stage One (Concept Assessment) is a ten year program of research begun in 1981 to provide the scientific information necessary for assessing waste disposal in crystalline rocks. Stage Two (Site Selection) will be undertaken if the results to the assessment stage are acceptable to government. Stage Three (Construction) will involve the construction and testing of a demonstration "vault."

At an early stage of the Canadian research program an assessment was made of potential rock types that might be used as possible repositories, and the recommended option was deep burial in crystalline rock such as granite or gabbro. The approach is to use a number of man-made and natural barriers to achieve permanent isolation of harmful wastes stored in crystalline rocks (Fig. 3). Barriers under consideration include loading the waste into an insoluble medium, a waste container, a buffer material surrounding the containers, backfill placed in the vault and shaft, the vault design itself, and the near-zone and far-zone barriers. The last named is that part of the geological barrier sufficiently distant to be physically unimpaired by the repository. Also under consideration as barriers are the subsoil and dilution in the hydrosphere and atmosphere.

Engineered barriers include borosilicate or aluminosilicate glass loaded with non-volatile waste as a first step in immobilization. Sphe-ne-based glass ceramics are also being considered as a disposal medium. A second barrier requires the development of fabricated containers made, for example, from stainless steel, titanium or copper and designed with an anticipated life of 300-500 years. More advanced containers of nonmetallic materials or non-corroding thick metals may survive for many thousands of years.

Fabricated containers must be capable of supporting pressures of the vault and of withstanding

Figure 2: Studying drill cores to determine the degree of fracturing in plutonic rocks. (AECL)

the saline groundwaters present in the Canadian Shield. The third stage of protection will be provided by the buffer material surrounding the containers, and various materials such as bentonite clay with various additives are being studied. The vault and shaft must also be sealed with backfill to prevent the transfer of waste from the vault to the surface. Crushed rock in a clay matrix is an example of the options being considered here.

However, it is the geological barrier that in the long term has to provide for the isolation of waste materials. The engineered barriers will provide containment for the initial period during which a significant proportion of the heat and radiation is dissipated, but beyond this it is the integrity of shaft sealing and the retardant effect of the rock mass that will determine the feasibility of disposal in crystalline rock. The dissolution of waste by groundwater and subsequent transport of these materials to the geosphere is a process that must be fully understood.

The hydrogeologist has the most difficult task in assessing the geological barrier. It is necessary to understand and demonstrate the nature of fluid flow through crystalline rocks, a relatively new area of research. The low permeability of unfractured crystalline rock makes it difficult to obtain measurements of hydraulic

facilities, and more attention should be given to studies on specific sites, so that optimum choices can be made in due time. The first disposal site should be small, so that any unexpected results can be better controlled. The Committee recommended that more effort is needed to ensure secure storage of solidified high-level waste for periods up to 100 years.

Development of underground laboratories in all proposed host rock should be accelerated. Such laboratories could be used for interim storage, and materials could be tested in them and fluids monitored for the next 50 years or more. Some laboratories might even become small disposal sites.

More information is required on fracture systematics and resultant permeability, not only in the immediate host rocks but also in those providing containment. Techniques are needed to predict fracture systems and their relation to permeability on all scales. For example, larger cracks in rocks such as granite are cause for concern, but a myriad of

small fractures in rocks such as shale might actually inhibit the movement of fluids. Methods are needed to locate fractures and estimate flow volumes through them over longer periods.

Specialists in the study of the deposits formed during the last 5 million years or so should be more involved in research on HLW disposal. Studies on these deposits can provide much essential information for example on tectonic stability, on changes in climate, and on variations in water levels. Seismic studies are also necessary, but they do not allow predictions over the periods of time under consideration.

Mining methods and technologies should be carefully studied to ensure the most favourable conditions for HLW emplacement. Minimum disturbance to the rock during excavation is obviously an important requirement for the repository. New giant machines for boring large underground passageways, for example, would greatly reduce the use of explosives, which probably would mean fewer fractures. Engineers and scien-

Figure 3: Schematic illustration of the natural and engineered barriers to the escape of radwaste materials. (AECL).

conductivity and hydraulic head. Research is being undertaken on instrumentation and methods of sampling of the pore fluid for chemical analyses.

Actual geochemical and groundwater flow studies are now being undertaken in gabbroic and granitic rocks of Ontario. Borehole studies have gathered much data from depths to 1,000 m and geophysical borehole studies in these areas have revealed low-dipping fracture zones in the plutonic rocks to depths of 600 m. These zones are, of course, worrisome because of their high permeability and difficult detection from the surface. Presence of highly saline groundwater in these test areas was unexpected in the early stages of the research, but studies of water from mines across the Shield have now confirmed the widespread occurrence of saline groundwater at depths being considered for the repository. Preliminary results suggest that this may be of Devonian age, implying that certain groundwaters are capable of remaining within the geosphere for very long times.

Geological research is focussed on describing the nature and extent of fractures in plutons and on mineral development and rock alteration often associated with these fractures. Techniques for mapping fracture systems have been developed and are now being tested in the field. Important objectives here are the prediction of subsurface fractures systems from observations made at the

surface, and the correlation of fracture systems observed in boreholes. At present, it appears that the plutons are characterized by blocks of relatively impermeable rock a few km in lateral dimension and separated by major fractures.

The development of geophysical techniques is also a very important component of the Canadian program. The main point of interest is the potential for defining geological conditions at depth and for characterising the rock mass between boreholes. Seismic and magnetotelluric techniques appear to be particularly important for recognizing the shallow-dipping fracture systems that exist at depth. Borehole to borehole seismic energy has been used in tomographic analysis to produce images that are thought to correlate with geological properties such as degree of fracturing or alteration.

An underground research laboratory near Pinawa, Manitoba, is now under construction on a site leased from the Government for 21 years. The site is for research purposes and will not be used to store nuclear wastes. Of special importance in this project is the opportunity to study the effects of the 300 m shaft and a research vault on the flow of groundwater. The effect of excavation on groundwater is being continuously monitored through boreholes drilled and instrumented prior to the beginning of construction.

Research in applied chemistry and geochemistry is also being undertaken on the interaction of groundwater with the geosphere and the engineered barriers and waste. The objective of this program is to understand the interaction between groundwater and solids from the time when uncontaminated fluids interact with the rock, to the point where fluids enter the vault and finally exit into the geosphere. Most of the research here is aimed at retarding radionuclides in the geosphere following escape of contaminated water from the vault.

In the initial stages of research, sorption of nuclides from solution onto rock surfaces was measured empirically, but more recently the sorption processes have been examined in greater detail with techniques such as laser Raman spectroscopy. Such research is aimed at studying the precise site and nature of sorption onto the surface layer of the solid material. A program of computer modelling with rock-water interaction is also being carried out and chemical analysis and isotope studies of saline groundwater are a prime concern as well.

-after Skippen and Toth (in press).

tists in charge of setting the specifications for containment must work as a team to develop the best methods and procedures.

Careful analysis should be made of the possibility of disposal of HLW and other toxic wastes through the process of subduction. If further research shows that the sedimentary load is rafted under the crust in some areas of subduction, and if the speed of subduction can be predicted, ready-made disposal sites may be available (see Uyeda, 1983). All materials would thus be carried into the interior of the earth.

Intensified studies are needed on the influence of thermal perturbances on the containing medium, and its bearing on fluid flow, fluid chemistry, rock and sediment alteration, and other physical properties, so that the effects of thermal loading can be predicted with assurance. In the terrestrial environment, such studies will help determine the degree of fracturing of the rock, its subsequent permeability, and the hazard of lost containment. In the marine environment, the effects of pore-filled, fine-grained sediments must be better understood. For example, will the heat source cause a miniature eruption and eject the canister, or will it cement the sediments to produce a "rock" that could be fractured?

A pilot survey should be conducted, based on the coring of

several tens of meters of deep-sea sediments in several locations. The study of cores from such a survey, to determine, for example, past history of the cored area, rates of sedimentation, composition of the sediment, and possible geological disruptions, is essential for site selection and repository strategy.

Much more information is needed on both the chemical and mechanical characteristics of deep-sea sediments. In order to select candidate sites data are needed on grain size, composition, ion-exchange capacity, contained biota and consequent bioturbation.

A more careful assessment of the absorption of radionuclides by sediment systems is needed. Radionuclides can occur in various oxidation states that may behave differently from related elements in the atomic table. They could move erratically, especially as the strata will be disturbed by emplacement of canisters. Moreover, sorption characteristics of containing media at elevated temperatures appear to be little known.

More research is needed on processes taking place at the sediment-sea water boundary. Results of releasing the containing medium into the water at the seabed surface will depend on such factors as mixing and advection at the bound-

SYNROC - An Australian Approach

One problem with encasing liquid waste in borosilicate glass is that temperatures in the interior of the glass bodies might range up to 300°C within ten years after the parent fuel had been removed from the reactor. At such temperatures borosilicate glass disintegrates rapidly when contact is made with groundwater.

The nuclear industry has invested hundreds of millions of dollars in developing the technology of vitrification and is reluctant to abandon this strategy. Nevertheless there is general acceptance that at temperatures above 100°C, glass has a very poor resistance to leaching by groundwater. One approach to this problem, which is being followed in a number of countries, is to reduce the amount of high-level wastes in glass to about 10% and to store the waste near the surface for forty years or more before final burial. This would ensure that the glass does not reach temperatures over 100°C, so long as the repository was relatively shallow, say between 500-1,000 m depth.

A very different approach is being pioneered at the Australian National University in Canberra, under the direction of A.E. Ringwood and using geochemical principles. Many natural minerals can, of course, accept radioactive elements into their crystal lattices, and waste forms created

from such materials would be vastly more stable than borosilicate glasses.

In the twenty years or so since this concept first appeared in the scientific literature, there has been much work along these lines particularly in the U.S. and Australia. The Australian waste form is called SYNROC (synthetic rock), a dense crystalline titanate ceramic consisting primarily of "hollandite" ($\text{BaAl}_2\text{Ti}_2\text{O}_{16}$), zirconolite ($\text{CaZrTi}_2\text{O}_7$), and perovskite (CaTiO_3). These minerals can accept into their crystal structure most of the radioactive elements that occur in high level wastes, and they or their close natural relatives have demonstrated their ability to survive for millions of years in a wide range of geological environments.

The most notable property of SYNROC is its extremely high resistance to leaching by groundwater at relatively low temperatures (70°-100°C) and at temperatures up to and exceeding even 300°C. For monovalent and bivalent elements including the important fission products cesium and strontium, experiments show that SYNROC is about 1,000 times more resistant to leaching than borosilicate glasses. For multivalent elements like the long-lived transuranic elements neptunium, americium and plutonium, SYNROC is about 10,000 times more leach resistant. Unlike borosilicate glasses, high levels

of radiation damage do not markedly damage its structure or impair its capacity to immobilize high-level wastes.

SYNROC can contain three times more HLW per unit volume than today's borosilicate glasses, and its performance can be increased by accepting a lower level of HLW (e.g. 5-7%). One variety which provides extra protection consists of about 25% SYNROC minerals dispersed throughout a continuous matrix of rutile, one of the most leach-resistant minerals known. If such a waste form were buried, the rutile would have to dissolve before the groundwater reached the very stable hollandite, perovskite and zirconolite phases.

The Australian government is now providing support for a demonstration plant to produce SYNROC containing simulated nonradioactive wastes. The plant will have an output comparable to that of glassification plants attached to fuel reprocessing plants.

One of the advantages of SYNROC is that it could be stored at much greater depths than now being considered for the borosilicate glass. Ringwood suggests that it might be feasible to dispose of SYNROC wastes in an array of drillholes into impermeable rock formations extending to some 4 km depth and about 1 m in diameter, in order to "maximize the integrity" of both the geological and the immobilization barriers.

after Ringwood (1983).

dary and exchange between the boundary layer and the overlying stratified deep water.

Physical-chemical modelling is needed of diffusion processes in the seabed. Diffusion in undisturbed sediments is not well understood and much more verification is needed on what may happen as a result of emplacement of a heat source, the effects on convection and adsorption, effects on the biota, and the potential escape of radionuclides.

More effort is needed in physical oceanography to determine the dispersion and distribution of those radionuclides that may reach the water. What aspects of dispersion and dilution are most significant? The local transient effects of concentrations of radionuclides in the large discrete plumes or blobs of deep water that have recently been recognized might lead to higher doses to the biota, and the probabilities of occurrence and effects of events such as upwelling need to be evaluated.

More data are needed on rates of removal of radionuclides from the ocean by sedimentation and their return to the ocean from the seabed. Very fine-grained sediment descending through water containing radionuclides will certainly adsorb some of them and carry them to the bottom. The seabed sediments conceivably will lose some radionuclides to the water, and predictions on relative rates are needed.

Better understanding of the concentration of radionuclides in marine organisms is essential. Different radioactive elements may be concentrated in different parts of an organism, and it is especially important to determine the factors that lead to concentrations of radionuclides in the edible parts.

The factors that determine dose per unit of intake for radionuclides incorporated in biological materials need much more study. Rates of metabolism of radionuclides, and hence dose per unit intake, can depend on the chemical form in which they are ingested or inhaled, and further work on this topic is needed.

More effort should be given to the chemical speciation of radionuclides in groundwater and to research into methods for retarding their migration. Different radionuclides are adsorbed at different rates and by different media. Little is known about the kinetics of sorption reactions, and the transport may not be as low, relative to groundwater, as is thought.

Research should be intensified on the mechanisms involved in movement of radionuclides in the terrestrial environment, including freshwater, over long time periods. Considerable work has been done on transfer rates over the relatively short term (decades), but the time-scale of HLW is very long and, in general, there is insufficient knowledge to make adequate long-term predictions.

Major research is needed on all aspects of engineering related to emplacement. Scientists must ensure that engineers are involved in all aspects of planning the disposal of HLW, so that optimum designs and techniques can be assured. This collaboration must involve techniques for coring and drilling of holes, the design, construction and emplacement of canisters, and the plugging of boreholes both on land and in the seabed.

Summary

The Committee was confident that high-level radioactive waste can be disposed of safely, provided that some specific kinds of research are intensified. Of course it is impossible to eliminate all risks from any activity, and thus safe disposal means the reduction of these risks to an acceptable level. Disposal on land or beneath the sea demands a systems approach, and close cooperation beginning with the planning must involve all concerned. This includes the design of waste containers, the planning and building of the depository, and the transportation, emplacement and monitoring of the filled

depository. Procedures for encapsulating the high level waste must be developed so that they do not create more dangers to any in part of the population than the procedures would avoid disposal.

The Committee concluded that there would be many advantages for safe disposal if solid wastes were retained in appropriate storage facilities for 50 or more years, and urged the need for more research on such temporary if long term storage. Although current research efforts are mainly directed to HLW, their successful conclusion will ensure safe disposal of all toxic materials such as mercury and arsenic. Of course, the amount of civilian radioactive waste is small at present compared with that of the military, and depositories suitable for civilian waste could serve as prototypes for the military.

The General Assembly of ICSU, after accepting the Committee's report decided to examine the feasibility of a similar study on toxic wastes in general. A small ad hoc group which has been working on this problem will report its findings to ICSU this September.

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Dr. J.M. Harrison has had a long and distinguished career in international science. A former Director of the Geological Survey of Canada and Senior Assistant Deputy Minister of Energy, Mines and Resources, he was the first President of IUGS and is also a past-President of ICSU. He was the Chairman of the ICSU Committee which produced this report and is now heading the successor group looking into the disposal of toxic wastes.