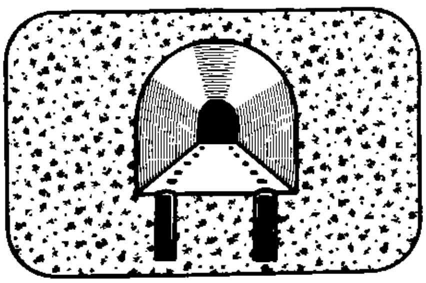

The Nuclear Fuel Waste Management Program. A Report to the Canadian Geoscience Council, September 7, 1983

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Drs. G.B. Skippen and J. Toth were appointed to the Technical Advisory Committee of Atomic Energy of Canada Limited (AECL) as geoscience experts nominated by the Canadian Geoscience Council. The Council supports the publication of their views as expressed in this article. The CGC will continue to monitor the research developments discussed in the article in order to be in a position to ultimately contribute to the process of Concept Assessment. Members of the geoscience community are invited to express their views on the report published below, and should send these to the President, Canadian Geoscience Council, c/o Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, N2L 3G1.

Introduction

The problem of the disposal of nuclear fuel waste still remains one of the most critical issues facing many nations, including Canada. In the mid-1970s the Canadian Geoscience Council recognized that serious difficulties were inherent with the Canadian Nuclear Fuel Waste Management Program. In particular, it considered that current geoscience research dealing with subsurface burial and containment of high-level waste was inadequate. The CGC organized a major public forum in 1978 in Toronto and published the proceedings in the following year (as *Geological Survey of Canada Paper 79-10*). It later helped establish a Joint Technical Advisory Committee to AECL and nominated two geoscience representatives to the committee (currently Drs. G.B. Skippen and J. Toth).

Since 1978, and following many of the recommendations in the CGC publication, there have been substantial changes to the AECL program. Much greater emphasis has been placed on the geoscience research; an underground research laboratory is under construction near Pinawa, Manitoba and scientific results are being more widely disseminated.

The Nuclear Fuel Waste Management Program

In 1978 the governments of Canada and Ontario entered into an agreement to jointly develop the technology for the safe and permanent disposal of waste materials for CANDU nuclear reactors operating in Canada. Atomic Energy of Canada Limited (AECL) has been given the responsibility for devising a method of disposing of high-level radioactive wastes; these wastes consist mainly of the actinides and fission products produced by a reactor. AECL is developing a plan for the immobilization and containment of waste in relatively impermeable plutonic rocks such as those found within the Canadian Shield. The objective is to ensure that there will be no significantly adverse effect on humankind or the environment from nuclear fuel waste at any time.

The development of a plan for high-level waste disposal is being carried out through the Canadian Nuclear Fuel Waste Management Program (NFWMP). The majority of AECL staff involved in this program are employed at the Whiteshell Nuclear Research Establishment near Pinawa, Manitoba. The Waste Management Division of AECL employs approximately 158 scientific personnel of whom 76 are involved in geoscience research. In addition to scientists employed directly by AECL, government scientists contribute to the waste management program through AECL contracts. A contract with Energy, Mines and Resources involves geoscientists (approximately 14 man-years) who have the principal responsibility for geology, geophysics and rock properties in the Waste Disposal Program. A contract with Environment Canada employs geoscientists (approximately 6 man-years) with expertise in hydrogeology. Many contracts also exist with universities and private firms. More than half of these contracts fall within the geosciences. External panels of specialists are established, where appropriate, to review particular aspects of the technical program. The Hydrogeology Program and the Underground Research Laboratory have been subjected to such review.

A Technical Advisory Committee (TAC) was established in 1979 by AECL to provide independent review on the extent and quality of the Nuclear Fuel Waste Management Program. The Committee consists of 13 scientists nominated by the following organizations: Biological Council of Canada, Chemical Institute of Canada, Engineering Institute of Canada, Canadian Geoscience Council, Canadian Institute of Mining and Metallurgy, Canadian Association of Physicists, Canadian Federation of Biological Societies, Canadian Information Processing Society. The Technical Advisory Committee prepares an annual report on the program. This report is widely circulated and available to any interested person, on request to committee members.

Outline of the Canadian Plan

The waste disposal program will proceed in three stages:
Stage 1. Concept Assessment. A ten-year program of generic research was begun in 1981 to provide scientific information necessary for the assessment of waste disposal in crystalline rock. This information is being used by AECL to produce a Concept Assessment Document that will be made available for full public discussion in 1988.

An Interagency Review Committee consisting of representatives from the Atomic Energy Control Board (AECB), Environment Canada and the Ontario Ministry of the Environment has been established to coordinate the evaluation of the Concept Assessment Document. The final evaluation of the concept will be made by AECB following public hearings. AECB will be issuing a set of criteria against which the concept will be judged.
Stage 2. Site Selection. Selection of possible sites for a waste disposal facility will be undertaken if the results of the assessment stage are acceptable to the governments of Canada and Ontario. Site selection criteria are also being developed by AECB.
Stage 3. Construction. A demonstration vault will be constructed and tested.

At an early stage in the Canadian research program, geological assessment was made of potential rock types that might serve as a host for a possible repository. The recommended option was deep burial in crystalline rocks such as granitic or gabbroic plutons. Research has therefore concentrated on finding an acceptable method of disposal in plutonic rock.

Some research on alternative disposal technologies continues in Canada to keep the NFWMP informed about progress in other countries on alternative methods of disposal. This research also evaluates the potential of alternative disposal media, such as shale, salt and clay, for application in Canada. AECB has recently indicated that AECL should submit documentation which details this review of alternative disposal technologies. This review will be considered with the Concept Assessment Document.

The Canadian approach to waste disposal uses a number of man-made and natural barriers to achieve permanent isolation of harmful wastes. A decision has not yet been taken on whether to store spent fuel bundles from the reactor or whether to chemically process the wastes to recover materials that can be recycled. Research is therefore proceeding on both of these options. The barriers that are under consideration include the loading of waste into an insoluble medium, a waste container, a buffer material surrounding the containers, the backfill placed in the vault and shaft, the vault design, the near-zone geological barrier, the far-zone geological barrier (i.e., that part of the geological barrier that is sufficiently distant to be physically unimpaired by the repository), the subsoil, and dilution in the hydrosphere and atmosphere.

Engineered Barriers

Man-made, or engineered, barriers may include boro- or alumino-silicate glasses loaded with non-volatile wastes as a first step in immobilization. Materials such as *sphene*-based glass ceramics also are being considered as a disposal medium. A second barrier requires the development of fabricated containers. Simple containers of stainless steel, titanium or copper are being designed with an anticipated life of 300 to 500 years. More advanced containers of non-metallic materials or non-corroding thick metals may be capable of containment for many thousands of years. Fabricated containers must be capable of supporting the pressures of the vault and of withstanding saline ground waters that are present in the Canadian Shield.

A third stage of protection will be provided by the buffer material surrounding the containers. A number of substances such as bentonite clay with various additives are under study. The vault and shaft must also be sealed with backfill to prevent the transfer of wastes from the vault to the surface. Crushed rock in a clay matrix is an example of the options being considered.

Geological Barriers

It is the geological barrier that must provide *long-term* isolation of waste materials. Engineered barriers will provide containment for an initial period while a significant proportion of the heat and radiation is dissipated. Beyond this initial period, 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.

A breach of the engineered barriers will provide ground waters with access to the vault. The dissolution of wastes by ground water and subsequent transport of these materials through the geosphere is a process that must be thoroughly understood. Specialists in geology, geophysics, rock mechanics, geochemistry and hydrogeology are working in a coordinated manner to determine the integrity of the geological barrier. It is, perhaps, the hydrogeologist whose task is the most critical in assessing the geological barrier.

Hydrogeology. Understanding and demonstrating the nature of flow through crystalline rock is a new area of research in hydrogeology. The low permeability of unfractured crystalline rock makes it difficult to obtain measurements of hydraulic conductivity and hydraulic head. It is also difficult to obtain adequate samples of pore fluid for chemical analysis. Hydrogeologists are therefore carrying out developmental research on instrumentation and methods for geochemical sampling. Considerable progress has been made in the past year in the use of newly designed instruments for making the necessary physical measurements.

A second aspect of the hydrogeological research is the application of newly developed methods to specific research areas. In addition to a site being developed for an underground research laboratory, there are four research areas used in the field studies: Chalk River in eastern Ontario, Whiteshell in eastern Manitoba, Atikokan in northwestern Ontario and East Bull Lake near Massey, Ontario. Chalk River is used for methodological development and is also the site of small-scale flow and radioisotope tracer studies. Geochemical and ground water flow studies began in the gabbroic rocks of East Bull Lake during the summer of 1983. Bore hole studies at Atikokan and Whiteshell have gathered ground water data from depths to 1000 metres. Geophysical and borehole studies in these areas have revealed low dipping fracture zones in the plutonic rocks to depths of 600 metres. These zones are of concern because of their high permeabilities and difficult detection from the surface.

The presence of highly saline ground waters at depths of a few hundred metres was discovered in the early stages of the hydrogeological program. Studies of waters from mines in localities across the Shield have confirmed the widespread occurrence of saline ground waters at depths being considered for the repository. This places an added importance on geochemical studies and will have a particular impact on the development of engineered barriers.

Hydrogeological research recently has been intensified with the announcement of a ten-million dollar study to determine regional ground water flow patterns in an area of approximately 400 square kilometres near Atikokan, Ontario. Surface investigations and an extensive drilling program will be used to generate information on physical parameters such as hydraulic head and conductivity. These measurements are used to characterize the geometry, extent and intensity of ground water flow in this area. The flow study includes part of the Dashwa Lake granitic pluton and will assess the effects of plutonic rocks on ground water flow systems.

The hydrogeological program includes theoretical studies of ground water flow by means of mathematical models. Such studies are intended to model regional flow within the Shield.

Geology. Geological research carried out by Energy, Mines and Resources is concerned with the structure and lithology of the rock mass through which ground waters must flow. Emphasis has been placed on describing the nature and extent of fractures in granitic and gabbroic complexes and on mineral development and rock alteration associated with fractures. Techniques for mapping fracture systems are being developed and tested at the Atikokan and Whiteshell test areas and will be further tested in the field program at East Bull Lake.

In addition to characterizing fracture systems observed in outcrops of crystalline rock, an important objective of the geological research is the prediction of subsurface fracture systems from observations made at the surface and the correlation of fracture systems observed in boreholes. These objectives require a knowledge of the structural history of the pluton and detailed logging and analysis of boreholes and drill-cores. The use of mineral assemblages as a means of identifying and correlating fracture systems has proven to be a particularly helpful approach. For example, four sets of fractures have been described in the Dashwa Lake Pluton. Early fractures have been filled with aplite. These are cut by later fractures with *epidote* and *chlorite*. A final set of more open fractures contain carbonate and clay minerals.

The present understanding of fracture patterns suggests that plutons are characterized by blocks of relatively impermeable rock of up to a few kilometres in lateral dimension. These blocks are separated by major fracture zones. Field projects are planned for this season at Atikokan and East Bull Lake, to further characterize fracture systems in plutonic rocks.

It is difficult to generalize geological observations made at a small number of research areas to an understanding of the more than 1300 large plutons that exist within the Canadian Shield of Ontario. The geological program is particularly inhibited by the political difficulty in obtaining permission for generic research on crystalline rock. An effort is being made by those responsible for the geological program to gain access to additional plutonic units in order to study fracture systems in outcrop.

Geophysics. The development of geophysical techniques for the NFWMP is a responsibility shared by the Earth Physics Branch and the Geological Survey. Nineteen geophysical techniques are listed in the Program Document (TR-152) of AECL as having application to the program. Experts in each of these techniques devote a portion of their research to the objectives of the Waste Management Program. The Technical Advisory Committee has advocated a degree of selectivity in further research on geophysical techniques so that funds can be concentrated on methods that show the greatest potential for contributing to the NFWMP.

The most important aspect of the geophysical program is its potential for defining geological conditions at depth and its potential for characterizing the rock mass between boreholes. Seismic and magnetotelluric techniques may be particularly important for recognizing shallowly dipping fracture systems that exist at depth but do not appear in outcrop. Such fracture systems are still difficult to recognize with existing seismic techniques where acoustic properties do not vary significantly across the fracture zone.

Borehole to borehole seismic energy has been analyzed by tomographic analysis to produce images that are thought to correlate with geological properties such as degree of fracturing or alteration. Such techniques have been successful over distances of 180 metres and the possibility exists in the near future of obtaining information across distances of up to 500 metres.

Energy, Mines and Resources has undertaken a review and evaluation of the various geophysical techniques that are currently under development. The review will be completed in 1983-84.

Rock Properties. Research on rock properties is primarily the responsibility of Energy, Mines and Resources through CANMET and the Geological Survey. Past work has concentrated on the properties of the rock matrix. Studies of pore structure assist in the modelling of ground water flow. Studies of thermal and mechanical properties will be useful in vault design and vault construction.

Although much of the research has concentrated on the properties of the rock matrix, there is an awareness in the program that estimates of the long-term response of the rock mass to thermal and mechanical perturbations will be an important factor in concept assessment. Emphasis on the rock properties research is shifting to studies of rock mass behaviour and to mathematical modelling of the long-term response of the rock mass to the construction of a repository.

Underground Research Laboratory. Construction of an Underground Research Laboratory (URL) began this spring at a site located ten kilometres north of Pinawa, Manitoba. The URL is being constructed in the Lac du Bonnet granitic batholith on 3.8 square kilometres leased from the Government of Manitoba for 21 years. The site is intended for research purposes and will not be used to store nuclear wastes.

Of particular importance in the URL project is the opportunity to study the effects of a 300-metre shaft and a research vault on ground water flow. The effect of the excavation on ground water is being continuously monitored through boreholes drilled and instrumented prior to the beginning of construction. The response of the rock mass to construction will also be monitored. Following completion of the laboratory, hydrogeological and geochemical experiments will be conducted to measure the rate at which chemical species migrate through granitic rock. A very important research program on shaft sealing and grouting will be undertaken. Longer term experiments on rock mechanics will be continued.

Construction at the URL site began in March, 1983 with excavation to a depth of 8 metres. Excavation continued during 1983 to a depth of 15 metres. Installation of underground experiments in the completed facility is scheduled for 1986.

Geochemistry. Geochemical research is carried out at the Whiteshell research establishment and through university and private contracts. Research on the interaction of ground waters with the geosphere and with the engineered barriers and waste is treated as a combined effort organized under Applied Chemistry and Geochemistry. This program attempts to understand ground water-solid interaction from the stage of uncontaminated fluids interacting with the rock to fluids entering the vault and finally flowing out of the vault and into the geosphere with waste contamination.

Most of the geochemical research is concerned with the retardation of radionuclides in the geosphere following escape of contaminated water from the vault. This work is being done in considerable detail and involves an experimental program to consider the transport of nuclides as dissolved ions, as complexed species in solution, as adsorbates on organic or inorganic particulate matter and on colloids.

In the initial stages of the research, retardation of ions in the geosphere was evaluated from measurements of the partitioning of ions between aqueous solution and crushed rock. More recently, the complex processes involved in mineral-solution-particulate interactions have been studied in greater detail, with attention to kinetics, mineral alteration, surface chemistry, solution composition, colloidal chemistry, etc. Detailed studies of individual chemical problems are complemented with laboratory-scale experiments on nuclide migration in blocks of granitic material. These migration experiments will eventually be expanded to a larger scale in the Underground Research Laboratory.

In addition to the direct measurement of nuclide retardation in experiments such as those described above, a program of computer modelling of rock-water interaction is being carried out. These models use thermodynamic data to predict the solubility of chemical species.

The discovery in the Canadian Shield of saline ground water at depths of a few hundred metres has initiated a new line of research. Chemical analysis and isotopic studies of these ground waters are being carried out to determine the source of such waters and their age. Some preliminary results suggest the possibility of a Paleozoic age for some of the saline waters. Such results would imply that ground waters are capable of remaining within the geosphere for very long times.

Environmental Research

In the eventuality that contamination might pass through the geosphere and into the biosphere, it will be important to understand the process of nuclide migration along the various pathways in the biosphere that lead to man. It is necessary to have a very careful analysis of these pathways to determine the risk that an individual and a population might experience. Research on this aspect of the program is carried on at Whiteshell and at Chalk River.

Environmental and Safety Assessment

The Environmental and Safety Assessment research group has the responsibility for preparing interim versions on the Concept Assessment Document and for developing the necessary integration of research results to produce an assessment of the concept. The assessments are divided into two major parts: the pre-closure assessment and the post-closure assessment. Responsibility for the pre-closure assessment has been given primarily to Ontario Hydro and will use methods that have been developed for the assessment of nuclear reactors and other nuclear facilities. The post-closure assessment relies heavily on the use of computer modelling to simulate possible chains of events extending far into the future. At the present, early stage in the generic research program it is premature to focus on the results of these simulations. It is possible to determine the sensitivity of the models to variations in specific parameters and thus to determine parameters that require intensive generic research. The results of the first environmental and safety assessment have been published in a technical record (TR-127) issued by AECL.

Program Budget

Budget allocations provide an insight to the priorities that have been assigned to various aspects of the research program. The direct operating monies for scientific research in 1982-83 are as follows:

	1982/83 (Budget) ($ x 10^6)	1982/83 (Actual) ($ x 10^6)
Waste Immobilization	2.1	1.7
Fuel Immobilization	1.8	1.7
Vault Sealing	0.8	0.9
Geosciences	9.2	10.1
Environmental Research	1.2	1.2
Environmental Assessment	1.1	1.1
	16.2	16.7

These figures indicate that 63 percent of direct operating monies are now committed to geoscience research.

A more detailed description of geoscience budgeting for 1982-83 is as follows:

Supporting Research	0.54
Interim Storage	0.11
Geology, Geophysics, Rock Properties	2.53
Hydrogeology	1.35
URL Surface Evaluation	2.25
Computation and Analysis	0.41
Engineering and Geomechanics (Includes planning and design of URL experiments)	1.04
Geochemistry	0.93
	9.16

The total annual budget for the NFWMP is $29 million per year with capital costs, equipment and overhead added to direct operating costs. Approximately $6 million in capital expenditures are devoted to geoscience in 1983-84 with $5 million for construction of the URL and $1 million for a new building at Whiteshell to house geoscience research.

Involvement of the Canadian Geoscience Community

A Canadian Geoscience Council paper, *Disposal of High-Level Radioactive Waste: The Canadian Geoscience Program*, was published in 1979 as *Paper 79-10* of the Geological Survey of Canada. This document was the result of a forum held in Toronto on October 24, 1978. The paper drew attention to the importance of the geoscience program in devising an acceptable plan for waste management. The report was critical of the geoscience program as it existed in 1978 because of insufficient hydrogeological research on crystalline rock and because of an inadequate program of research on radionuclide migration through the geosphere.

Members of the geoscience community commented further on the program before a Select Committee of the Ontario Legislature on January 24, 1980. It was recommended that critical areas of research within the program be given priority and that the quality of research be tested in a more public forum than that provided by internal AECL publication.

The observations made by the geoscience community have had a profound effect on the program. The proportion of staff and budget allocation to geoscience has more than doubled since 1978 in recognition of the priority now attached to this aspect of the research. Priorities within the program have been enunciated in a series of Program Documents which are available from AECL (e.g., TR-149 for Applied Chemistry and Geochemistry, TR-151 for Hydrogeology, TR-152 for Geology, Geophysics and Rock Properties, TR-153 for the Underground Research Laboratory and TR-195 for Engineering and Geomechanics). External Review Panels have provided careful assessments of particularly important projects, such as the Hydrogeology Program and the Underground Research Laboratory.

Results of the research are presented in public at Information Meetings held twice each year. Symposia are offered at major scientific meetings such as the Annual Meeting of the Geological Association of Canada to ensure that the scientific community is aware of current research within the program.

Concerns expressed by the geoscience community at the early stages of the NFWMP have had a significant influence on the subsequent development of the program. It is the opinion of CGC appointees to the Technical Advisory Committee that the NFWMP has put in place a program of geoscience research that will be appropriate in due course for Concept Assessment.

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