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Commentary on The Canadian Nuclear Fuel Waste Management Program

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Article abstract

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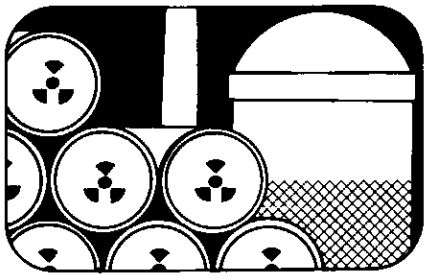

Commentary on The Canadian Nuclear Fuel Waste Management Program

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Summary
A summary of the first formal review of the Technical Advisory Committee (TAC) to Atomic Energy of Canada Limited on the Nuclear Fuel Waste Management Program is presented. The Program is described briefly and the composition and role of TAC in relation to the Program is outlined. Salient points and major recommendations are presented from the First Annual Report of TAC in which geoscience aspects of the Program were emphasized. It is the view of the Committee that overall, the whole Waste Management Program is well conceived, that there are many impressive accomplishments of high quality, that detailed research objectives are becoming more clearly delineated, that there is growing clarification as to the most critical areas in which research needs to be accomplished and that the increasing participation by university and industry scientists and engineers is reassuring.

Introduction
The Canadian Program on Nuclear Fuel Waste Management was established on a formal basis in June 1978 as a joint responsibility of the Federal Government and the Government of Ontario. The overall objective in the Canadian Program was stated as "the safe management of radioactive wastes, ensuring that there will be no adverse effects on man or on the environment at any time." (Boulton, 1978). The Program covers four aspects:

1) Safe interim storage of irradiated fuel from nuclear reactors.
2) Safe transportation of irradiated fuel.
3) The immobilization of used fuel or fuel wastes prior to disposal.
4) The permanent disposal of the immobilized material.

Under the June 1978 agreement between the governments of Canada and Ontario, Ontario Hydro has the responsibility for the development of interim storage and safe transportation of irradiated fuel. The overall coordination and management of the research and development program on the immobilization of fuel wastes and their subsequent disposal is the responsibility of the prime agency, Atomic Energy of Canada Limited (AECL).

In recognizing the trans-disciplinary nature of the disposal problem, the Program was structured to involve expertise from both inside and outside the government agencies. Some 12 university departments and over 20 industrial companies are now participating in the Program along with several government departments or agencies and AECL. Figure 1 outlines the various participants as well as some of the major research activities being pursued at the Whiteshell Nuclear Research Establishment (WNRE) of AECL. In all, over 250 professional scientists or engineers, including about 130 geoscientists are involved in some way with this Program.

The Technical Advisory Committee
As one might expect from a program of this size and scope, the output of information from all research activities would be voluminous. The need for an independent peer review group on technical matters during the research phase of such a broad and important effort was foreseen even before the Program itself was formalized. Such recommendations were made in the Hare Report (Aikin *et al.*, 1977), the Uffen Report (Uffen, 1978), and the interim report of the Porter Royal Commission on Electric Power Planning in Ontario (Porter, 1978). In response, the Technical Advisory Committee (TAC) was established in June 1979 by AECL. The purpose of the Committee is to advise AECL on the extent and quality of the technical research program on Canada's nuclear fuel waste management (the Disposal Program). The responsibilities of TAC are to review the content of proposed research programs, to suggest alternatives and additions as deemed appropriate, to review the scientific methodologies used, to assure that the best available technology is being applied to the Program, to review Program results and assure that conclusions drawn are valid within the limits that are claimed, and to recommend on any specific areas of work for which research should be undertaken, either by existing staff or through research contracts. The Committee reports to the AECL Program Director through its minutes, reports, specific recommendations and through an annual report which is to be a public document.

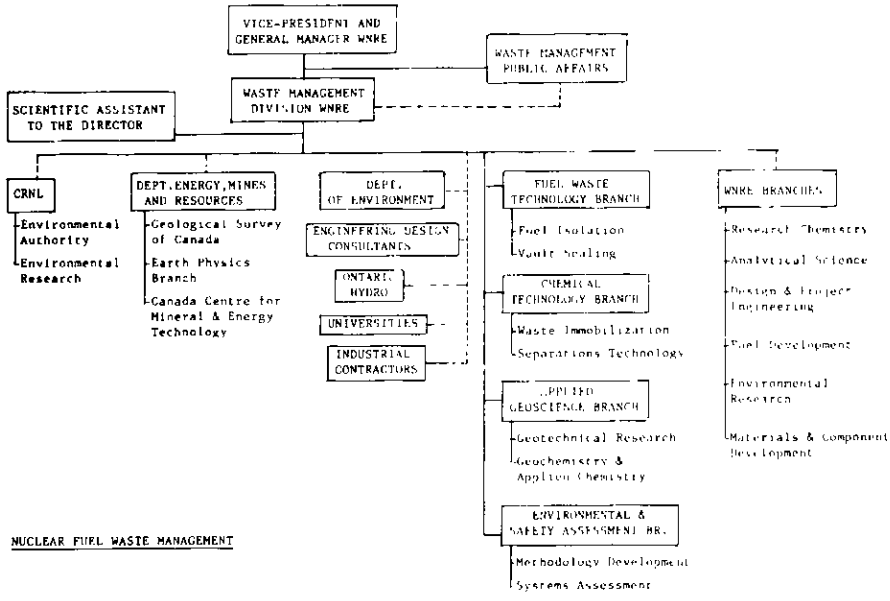

Figure 1 *Outline of various participants in the Nuclear Fuel Waste Management Program as well as major research activities being pursued at WNRE and CRNL. About 250 scientists or engineers, including about 130 geoscientists are involved in the Program.*

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The Committee's membership of 12 was selected entirely from a list of nominees submitted by the major scientific and engineering societies in Canada (Table I). A full-time science secretary and a secretary have been appointed to support TAC activities.

An essential feature of this type of committee, that of complete autonomy and independent peer judgment, has thus been met by appointment only of persons nominated by professional and scientific societies. To further assure this independence, its terms of reference also require the Committee to report in the public domain and provide full and free access to all aspects of the research process. The Committee also has resources available to it for the purpose of obtaining further specialist advice through consultants as it sees fit.

The concept of such an autonomous advisory committee, as recommended in the reports mentioned above, has been further endorsed, since its inception, by the Canadian Geoscience Council (Barnes, 1979), in the final report of the Porter Commission (Porter, 1980), and by the Ontario Legislative Select Committee on Hydro Affairs in its final report on Waste Fuel Management (MacDonald, 1980).

The First Annual Report of the Technical Advisory Committee was submitted on May 29, 1980. (Shemilt, 1980). In its report, the Committee concentrated on a review of the first phase of the Disposal Program which had been termed "Concept Verification". This phase, when completed, was expected to be followed by Site Selection and Acquisition, and Construction and Operation of a Demonstartion Disposal Facility. TAC made some 32 recommendations with regard to the Program. The majority of these were related to the geosciences since the Canadian Program for nuclear fuel waste management is based on deep geological disposal, and the "Concept Verification" phase was to be concerned with investigating the properties of a variety of geological formations. This involves the collecting of information which can be used to show whether disposal in these formations will meet the basic objective of isolating the radioactive wastes from man and his environment. As TAC observed, AECL has subdivided the Geoscience Program into 11 subject areas which are listed below with their main objectives:

1) Geological Data Base
- to complete an inventory of all mapped plutons in Ontario.
- to classify them on the basis of rock type , percentage outcrop, area, and fracture density.
- to study regional tectonic stability in Ontario.

2) Basic Geoscience Research and Development
- to develop advanced tools for use in geophysics, hydrogeology and long-term vault monitoring.
- to study the application of fracture mechanics to the estimation of time-dependent crack growth in crystalline rock.
- to provide basic research support as necessary.

3) Research Area Evaluation
- to thoroughly define the rock mass, its internal structure, and its hydrogeology.
- to test tools and techniques.
- to train personnel.

4) Hydrogeology
- to define the physical and chemical character of the groundwater system in the undisturbed rock mass.
- to predict the perturbations caused by the presence of the vault or any long-term natural changes.

5) Rock Properties
- to measure those properties and responses of rock which are necessary for geological classification, vault design, interpretation of geophysical surveys, and interpretation of hydrogeological and radionuclide migration studies.

6) Underground Testing
- to assess the effects of heat on rock properties and groundwater using electric heaters.
- to test, on an appropriate scale, the results of laboratory experiments and the prediction of mathematical models.
- to gain experience in subsurface facilities.

7) Vault Design
- to develop a detailed reference conceptual design of a nuclear waste vault to be situated in igneous rock and to investigate options to the reference design.
- to develop a detailed and optimized design of a demonstration nuclear waste vault to be situated in igneous rock.

Table I *Membership of the Technical Advisory Committee (TAC) on the Nuclear Fuel Waste Management Program.*

CIC (Chemical Institute of Canada)
Dr. Kenneth James McCallum
Dean of Graduate Studies and Research
University of Saskatchewan

EIC (Engineering Institute of Canada)
Dr. Branko Ladanyi
Head, Geotechnical Section
Department of Civil Engineering
Ecole Polytechnique
University of Montreal

Dr. Leslie W. Shemilt
Professor, Department of Chemical Engineering and former Dean of Engineering
McMaster University

CGC (Canadian Geoscience Council)
Dr. Robert N. Farvolden
Dean of Science
University of Waterloo

Dr. George Skippen
Dean of Science
Carleton University

CIMM (Canadian Institute of Mining and Metallurgy)
Dr. John Convey
Former Senior Advisor to the Canadian Government in Mining and Metallurgy

CAP (Canadian Association of Physicists)
Dr. Maurice H.L. Pryce
Former Professor of Physics
University of British Columbia

Dr. George M. Volkoff
Former Dean of Science
University of British Columbia

CFBS (Canadian Federation of Biological Societies)
Dr. Gordon F. Whitmore
Director,
Ontario Cancer Institute

Dr. Robert H. Haynes
Professor and former Chairman,
Department of Biology
York University

BCC (Biological Council of Canada)
Dr. H.B. Noel Hynes
Professor, Department of Biology
University of Waterloo

CIPS (Canadian Information Processing Society)
Dr. Tuncer I. Oren
Chairman, Department of Computer Science
University of Ottawa

8) Data Evaluation
- to provide a data management system and to develop methods of synthesizing and evaluating geoscience data.

9) Regional Studies
- to study and assess the long-term stability of geological formations.

10) Alternative Host Media
- to maintain alternatives to hard rock in the event that safe disposal in these formations cannot be verified.
- to be conversant with the work done on other host media by other nations, and to be aware of the relevance of this work to Canadian conditions.

11) International Cooperation
- to perform joint experiments with other countries in order to advance nuclear waste disposal technology.
- to promote better communication and information exchange internationally.

TAC has grouped these subject areas under the general headings of geology, geophysics, hydrology and geotechnical studies in its First Annual Report, and its views are summarized below, as pertaining to the status of the Program in April, 1980.

Geology
The geologic program is conducted by GSC and appears to have been well conceived. The granitic plutons of the Canadian Shield in Ontario have been identified and mapped, and 55 of the approximately 1,500 of them have been selected for airphoto analysis of linaments thought to be faults or other fractures. Detailed surface mapping has been done at the Field Research Areas at Chalk River and Atikokan. The analysis of drill core and geophysical logs obtained in 1979 and earlier are nearly complete, so that the distribution of rock types and fractures at depth has been established to the degree possible with present methods.

Statistical analyses of fracture measurements have been made to show that fracture occurrence at depths of up to 200-metres or so can be predicted from surface observations. The technique appears to be valid, but offers promise only if it can be extended to predict conditions at depths proposed for the vault, or at least provide a basis for comparison amongst sites of conditions at depository depth. A major weakness in this method is the classifying together of all discontinuities and linaments in both outcrop and core as fractures including those that have been sealed since Precambrian time. The great majority of the sealed fractures are not expected to contribute significantly to permeability. TAC proposed that some methods should be developed to discriminate between sealed and open fractures, and to predict the frequency of open fractures at depth from surface observations.

Other work done within the Geologic Program includes the evaluation of risk of excavation by glacial erosion and a major survey of shale and salt distribution in Canada on both a regional and continental scale.

Geophysics
The Earth Physics Branch (EPB) of the EMR is responsible for all aspects of the geophysics research related to the AECL Program. Geophysics has a vital role to play in:

1) establishing the seismic risk for any selected site and showing it is acceptably low;
2) providing data from surface measurements to support geologic studies in the search for suitable sites for further study;
3) providing sub-surface data from boreholes, including drill core, to provide needed information on rock distribution and properties.

Existing seismologic data have been reanalyzed and indicate that additional data are required to establish that the risk at a given site is acceptably low. However, due to failure by the existing approvals mechanism to provide permission for relevant field work, regional seismic risk analyses are delayed. The length of record is important in this analysis and as the field work is just a normal extension of the regular work of EPB, involving no hazard whatever, it was TAC's opinion that approval should be granted forthwith.

Because the goal of the work done in the AECL Program is different from the goal of most geophysical exploration, conventional techniques and methods employed in the latter will not always answer the needs of the former. This is true in the case of borehole geophysics and prediction of rock properties at depth from surface measurements. TAC was concerned that work should continue on research and development of suitable equipment for borehole geophysics, especially with the aim of making such equipment available in Canada. Because the university and private sectors in Canada have considerable strengths in geophysics, TAC endorsed strongly the efforts to involve them more in the Program. Recent publications have given more details on the Geophysics Program (Dence and Scott, 1979; Berry, 1979; Strangway, 1980).

Hydrogeology
Scientists working on the rock repository concept appear to agree that, in the final analysis, the hydrogeologic aspects will present the greatest uncertainties with regard to the integrity of the system. The hydrogeology research aspects of the Canadian Program are being conducted in part by Environment Canada through its National Hydrology Research Institue (NHRI) and in part by AECL staff.

Hydrogeology is another area where standard techniques are not directly applicable to the needs of the Nuclear Waste Management Program. Several difficulties are identified. Firstly, there are uncertainties associated with what the best analytical methods are. Fundamental laboratory research remains to be done on identifying and measuring the controlling parameters for migration of radionuclides from the vault along water-filled fractures. Subsequently, it still remains necessary to measure the parameters in the field. Much of the equipment that is available has been devised specifically for other purposes, such as the needs of the petroleum industry. Some adaptations necessary for our purposes are available in the USA only. It is slowly becoming clear just what measurements should be made, but the tools have not all been developed, and the techniques are not yet entirely dependable.

Secondly, adequate methods for analyzing the sort of field data that are to be collected do not exist. Much effort will have to be directed toward modelling of groundwater flow in fractures. The ample talent existing in Canada in this area should be mobilized through the support of research projects that approach this problem from several different routes.

Thirdly, an important requirement will be to specify the locus of the repository with respect to the groundwater flow system. The path to the groundwater discharge zone must be known before any final "pathways" analysis can be done. At present we know very little of groundwater systems in plutons in the Canadian Shield, and this situation must be corrected.

Finally, we have almost no field data to support any concept of transfer of groundwater to the surface water system or to the biosphere on the Canadian Shield. Thorough studies at the Chalk River Nuclear Laboratories of AECL and scattered information from other localities will be very useful, but are not yet comprehensive enough.

These difficulties emphasized to TAC the urgent need for a unified formal hydrogeological program and it so recommended. The repository Program

was originally developed without major input from hydrogeologists with experience and training in fracture flow. Hydrogeology was initially included only as a special aspect of many of the individual projects. Acting upon a recommendation from TAC, a detailed and comprehensive description of the Hydrogeologic Program is in the final stages of preparation. In view of the central role that hydrogeology plays in the repository Program, it was also felt by TAC that some prominent Canadian hydrogeologists, not yet directly participating in the Program, should be involved in a consultative format in the preparation of that program document. To this effect a Hydrogeology Review Panel has been established and is involved in its development.

Geotechnical Studies

The important properties of any potential repository rock revolve around its bulk permeability, its overall reactivity with groundwater, its performance during excavation and operation and long-term changes after closure.

In the area of rock and rock mass properties evaluation, the work to date has been focussed on the determination of physical properties of rocks and the geometry of fracture systems. In the area of mechanical properites, in particular, the work has been limited to determining the elastic properties of rock samples and their short-term uniaxial strengths. This is still far from getting the input data necessary for a finite element method applied to simulate the short and long-term behaviour of a disposal vault. The situation will improve when triaxial testing of rocks at high temperature is underway as planned. Current objectives, however, do not appear to include any long-term or creep testing of rocks.

The study of slow crack propagation and stress corrosion in rocks being carried out at WNRE is very valid basic research which should be continued, but its scope is too narrow to supply rock behaviour parameters relevant to the vault design. For the latter, a more systematic creep testing of crystalline rocks under stress, temperature and environmental conditions created by the vault, should be planned and started as soon as possible.

As far as the mechanical behaviour of a large-scale rock mass with a given fracture system is concerned, there seems to be no work done to either assess such behaviour from large scale tests or to simulate it mathematically. The former does not mean testing a very large sample of a cracked rock mass but instead, more effort should be put into developing tools for in situ testing of short and long-term properties of rock mass in boreholes. Another promising and necessary field, not mentioned in the Program is the further development of methods for mathematically simulating the large-scale behaviour of rock masses from the knowledge of the properties of the rock substance and its discontinuities. The objective of such a project would be the determination of basic rock mass behaviour parameters needed in the vault design.

In summary, the Geotechnical Research Program thus far has been oriented mainly toward geological mapping and description, as well as toward determining the natural state of the rock mass and certain of its physical properties. It is felt that this will furnish necessary but not sufficient information for site selection and vault design. The next step is a systematic study of the behaviour of the rock mass in the proper framework of constraints of time, temperature, stress and environmental changes.

Underground Research Laboratory

As the Program has developed, it has become evident that although a great deal of information appropriate to the assessment of the waste disposal concept can be obtained in the laboratory and by borehole testing in the field, it is essential to conduct experiments on a scale and in an environment which can only be achieved underground. For instance, in the mathematical simulation of large-scale behaviour of rock masses, the model studies have shown that practically any vault design problem can be tackled provided one has a proper data base for evaluating the constitutive laws for the rock mass and the state of ground stress at the level of the vault. The total lack of direct experience in the performance characteristics of nuclear waste vaults renders suspect the predictability of any such design. Thus, the design method can only be checked against that of an actual test vault. A proposal has been made to construct an Underground Research Laboratory (URL) in the Lac du Bonnet batholith near WNRE to answer this and many other questions. The proposal is to excavate several rooms of a few hundred metres in which experiments related to geology, hydrogeology, rock mechanics, geochemistry, sealing and buffer materials, etc. would be mounted. The Laboratory is scheduled for operation in the mid-1980's. TAC strongly supported, as a matter of Program urgency, the construction of the URL.

Alternative Geologic Media

A question which is central to the whole Disposal Program is the selection of the ultimate host medium. Different geological media such as salt, basalt and shale are potentially suitable, but because of the unique occurrence and extent of the Canadian Shield, the great majority of work has concentrated on the granitic pluton option. There have been strong recommendations (Barnes 1979; McDonald, 1980) to maintain an effective program of research on other potential host media such as sedimentary rocks. In view of the financial and technical resources available to Canada, it is the position of AECL and also the feeling of the Committee that work should be concentrated on one concept, that of granite plutons in the Canadian Shield. Nonetheless, in order to maintain sufficient competence in Canada in the event that we some day move in other directions, TAC strongly believes that resources should also continue to be allotted to research on salt and shale alternatives. A major review of salt formations in Canada has been completed and one covering shale and limestone formations in Ontario is in progress (Sanford, 1980). Through the Atlantic Geoscience Centre, Canada is also participating in the international Deep Sea Bed Disposal Study (Buckley, 1980). A watching brief on work done by other countries on various geologic formations is maintained through information exchange agreements. These include the Bilateral Canada-Sweden Agreement on the Stripa Mine Project and the Canada-European Economic Community Agreement which basically covers arrangements for exchange of technical information with regard to nuclear waste management research activities.

Other Program Areas

Although the First Annual Report of TAC concentrated on the review of geoscience work, other research activities within the Program are also important and as they develop more fully will be subject to more detailed review. These major elements are listed below with their main objectives.

Applied Chemistry. The stated objectives of the Applied Chemistry Program are to perform experiments that will provide data for the environmental assessment studies, and to develop and test nuclide migration models to assist in the assessment of the concept of deep underground disposal.

Fuel Immobilization. The overall objective of the Fuel Immobilization Program is to develop a containment system based on an outer corrosion-resistant metallic shell. The so-called containment target, or period of time for which it would resist any radionuclide release is 300 to 500 years.

Waste Immobilization. The objective for process and equipment development is to develop vitrification, calcination and other high-temperature processes for the immobilization of non-volatile high-level waste fission product and actinide oxides in glasses or other ceramics. A second objective is to evaluate current technology and develop advanced systems for recovery and immobilization of volatile radionuclides.

The objectives for waste product development have been to fabricate glass, crystalline and ceramic products for immobilization of high-level wastes, predicting long-term performance; and to develop criteria for selection of the best type of product.

Environmental Research. The objectives are to develop, document and experimentally validate procedures and data to forecast the migration of radionuclides and other waste materials through the environment to man.

Environmental Assessment. The current objective in this area is to carry out thorough, detailed and quantitative analyses, based of necessity on computer simulation techniques, of the environmental consequences of the emplacement of nuclear wastes in a deep underground vault in the Canadian Shield.

Conclusion

In what has been an intensive learning period during the first year of the Technical Advisory Committee, the Committee has critically reviewed the first phase, termed "Concept Verification", of the Disposal Program. The Committee felt that the first priority of the Program must be to show that a workable solution to the disposal question exists rather than to embark on a long-term search for some ideal or "best-possible" method of waste disposal. In this light, the Committee felt that a better description of this research phase is conveyed by the term "Concept Assessment". AECL has concurred with and adopted this recommendation, and all facets of the Program are now aimed at providing adequate scientific basis for assessment of the concept of deep geologic disposal. The criteria to be used for such assessment are of the utmost importance, and are demanding the attention of AECL, of TAC, and of such regulatory authorities as the Atomic Energy Control Board.

In the Committee's view overall, the program is well conceived, there are many impressive accomplishments of high quality, the objectives are becoming more clearly defined and the most critical areas in which more research is needed are being identified. The Committee was also assured by the increasing participation in the Program by university and industry scientists and engineers, and by the excellent understanding of relevant international research activities on the part of the principal investigators.

The Canadian Geoscience Council has shown special interest in the Canadian Program for Nuclear Waste Management. Major evidences for this included the organization of a special forum in October 1978 which resulted in the publication of an important series of papers on the Program (Barnes, 1979). The CGC also provided a series of recommendations at that time which have undoubtedly had a positive influence on the Program as both the 1980 annual report on the Program (Boulton and Gibson, 1979) and TAC's annual report (Shemilt, 1980) show. The CGC has also participated in a geoscience workshop and information meeting on the Program in mid-1980. From that meeting a further publication of scientific papers is also expected - a direct communication to the geoscience community. This concerting of efforts by the professional and scientific community in such a crucial enterprise is most important. The Technical Advisory Committee, based as it is on direct nomination from scientific and professional societies, also feels it has an important communicative role to play - as it seeks to transmit its studied views on the Program not only to the public at large, but also to its scientific colleagues. This report, in the pages of *Geoscience Canada*, is one such effort.

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