The Disposal of Canada's Nuclear Fuel Waste

Report of the
OECD Nuclear Energy Agency
Review Group

27th April 1995

Natural Resources Canada · Ressources naturelles Canada

Canada

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Chapter 1. Introduction

1.1 Background to the Review

The Canadian Nuclear Fuel Waste Management Program has been operational for 17 years, having formally commenced in 1978. It has recently reached an important milestone at which a concept for safe disposal has been developed and is now being presented for assessment prior to obtaining approvals to move on to the next stage. The proposed new phase of work, which is planned to last some 25 years, involves the eventual selection of a site and the construction of a deep underground waste repository in the rocks of the Canadian Shield.

The review contained in this report has been carried out in parallel to the federal review process in which a number of organisations and groups have been asked to evaluate the product of the first phase of work. The review process began formally in 1988 although guidelines for the content of the Environmental Impact Statement (EIS) which presents the concept were not issued until 1992. The EIS was presented to the Canadian Government by Atomic Energy of Canada Ltd (AECL) in October 1994[1]. The EIS is supported by a nine volume report of Primary References containing information on how the EIS was performed and the plans for the siting work which is intended to commence following acceptance of the EIS recommendations.

Natural Resources Canada (NRCan) are responsible for developing policy on radioactive wastes and, in addition to the Minister of Natural Resources referring the concept to the Ministry of Environment for public review by an independent Panel, also sought the input of an international peer review group. NRCan approached the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA) to carry out this latter task and this report presents the results of the peer review.

1.2 The OECD/NEA Review Group

NRCan presented Terms of Reference to the Review Group (hereafter simply referred to as 'the Group') which are reproduced in full as Appendix 2. The Group comprised five members actively involved in national waste management programmes, one international consultant, two representatives of the OECD/NEA and two observers from regulatory bodies. The names and qualifications of the Group members are provided in Appendix 3. Dr. Charles McCombie acted as the Chairman of the Group.

After consideration of the documents provided, the Group met in Paris on 24th November 1994 and interpreted these terms of reference, coming to the conclusions listed below.

- The review should consider not simply the documents provided but, as an international peer review group, we should also bring into play our existing knowledge of the Canadian Program in the context of other, similar national programmes which have developed in parallel and had frequent interchange of ideas and expertise with the Canadian Program.
- We should also use our independent knowledge gained from experiences in our own and other national programmes.

[1] The role of AECL, Ontario Hydro and the various Government organisations involved in the Nuclear Fuel Waste Program and its review are outlined in Appendix 1.

- Given the importance of the safety case presented in the EIS and the central role of performance assessment (PA) in determining acceptability of a repository system and in guiding system design and repository siting, the Group felt that we would make best use of our expertise if we were to concentrate on the post-closure safety assessment aspects and the supporting information. Accordingly, we prioritised the review of the reports as follows:

PRIORITY	SUBJECT
1	The EIS itself; Post-Closure Safety Assessment
2	Vault Model; Geosphere Model
3	Engineered Barriers; Site Screening
4	Biosphere Model; Engineering the Facility
5	Public Involvement

- The Pre-Closure Safety Assessment Report was not considered at all as part of this review, not because we underestimated the crucial importance of this aspect but mainly because:

  - more extensive, transferable experience from other operating facilities exists
  - competent groups for an engineering review can be found
  - we felt confident that good engineering can assure adequate safety in this phase.

In addition, time and resources were not available to delve into the very considerable volume of technical reports, papers and data interpretations issued over the last 17 years which support the Primary References and these were only referred to in exceptional cases.

AECL, the proponent of the EIS, notes that the content of the final submission differs in some respects from the guidelines which were provided to them by the independent review Panel. The Group did not, however, compare the guidelines with the structure of the EIS, but we do note that the structure and content of this EIS are unusual in terms of its audience and purpose, and any eventual regulatory submission would be rather different in nature. AECL also notes the particular circumstances of this EIS compared to statements for other major developments, in that it addresses a concept rather than a specific site and site-specific design and that it evaluates a hypothetical system rather than a real, proposed system.

The Group worked as a team, dividing the detailed evaluation of the EIS and Primary References between them such that each member read in detail the Priority 1 reports, and one or more of the Priority 2-5 reports. Some limited recourse was made to internal reviews by staff members of the reviewers' organisations or their subcontractors where specialised technical insights were considered necessary.

A first review of the documents was carried out during December 1994. Later, a preliminary list of issues was identified for further discussion and sent to NRCan in early January 1995. The Group met again in Winnipeg on 22nd January to analyse comments and issues prior to a three day meeting with AECL at Whiteshell Laboratories from 23rd to 25th January which consisted of presentations and question-andanswer sessions with AECL technical staff. The Group also visited the Underground Research Laboratory (URL) to clarify issues concerning the nature and properties of the rock used in the Reference Case safety assessment (see Chapter 3).

The Group met again in Toronto on the 26th and 27th of January to summarise its findings and we gave a presentation of our preliminary conclusions to a small group representing NRCan, the independent review Panel, AECL and Ontario Hydro.

This final report was established on the basis of the preliminary conclusions reached during the review sessions in Canada and of a complete draft prepared by the NEA Secretariat and Dr. Chapman, acting as an NEA consultant, during February/March 1995. The final report does not attempt to record all the numerous, detailed discussions and comments made orally during the review sessions; it concentrates instead on the issues which were considered to be most important in view of the Terms of Reference of the Peer Review. It was approved in April 1995 by all members of the Group following comments by correspondence and final editing by the Secretariat.

1.3 Structure of the Report

In addition to the Introductory Chapter, the review is presented as follows:

- Five Chapters which **comment** on the EIS
  - Chapter 2: The Canadian Disposal Concept
  - Chapter 3: Post-Closure Assessment: Understanding the Performance of the Individual Safety Barriers
  - Chapter 4: Post-Closure Assessment: Total System Performance
  - Chapter 5: Siting and Constructing a Repository.
  - Chapter 6: The EIS documentation and its general conclusions and recommendations.
- Chapter 7 which presents the general conclusions of the NEA review.

Chapter 2. The Canadian Disposal Concept

2.1 The Concept in an International Context

The outline of the Canadian concept for disposal of spent nuclear fuel by burial in a series of engineered barriers in a deep underground repository is similar to that adopted by other countries. Whilst the details of disposal system design vary from country to country, the rationale and functions defined for each major component have been well-established by comparable international research and safety assessment programmes over a period of 15-20 years. Thus, the Canadian proposals fit within the mainstream of the broader international context.

The concept envisages no 'zero option' of doing nothing and preserving the *status quo* with respect to management of the wastes. Again, this is in line with current international thinking whereby it is the responsibility of present generations to prepare a solution to present-day problems (see the soon-to-be-published 'Collective Opinion' of the NEA Radioactive Waste Management Committee on this issue).

2.2 The Nature & Function of the Concept

The objectives of the Canadian Nuclear Fuel Waste Management Program, which concern the safety and feasibility of disposal and which have led to the production of the EIS, are stated by AECL to be as follows:

- To develop and demonstrate the technology for siting, construction, operation, decommissioning and closure of a disposal system in plutonic rock.
- To develop and demonstrate a methodology to evaluate the safety of a disposal system against established safety criteria, guidelines and standards.
- To determine whether technically suitable disposal sites are likely to exist in Canada.

The EIS is structured around two case studies, one pre-closure and one post-closure assessment. As noted earlier, the Group has reviewed the latter, which comprises a presentation of the concept, a discussion of the means of implementing it and a safety assessment based on a Reference Case disposal system design.

The Group recognises that the purpose of the EIS is to present a flexible and robust concept which achieves the objectives listed above and which, if implemented would allow the safe disposal of nuclear fuel wastes in Canada. The current review phase aims to assess this concept and determine whether it is acceptable to proceed to the next phase of the Program which will involve locating a preferred repository site. In this respect, the Group recognises that AECL propose going beyond the demonstration of methodology contained in the objectives cited above and now, by demonstrating technical readiness and safety feasibility, wish to enter an implementation phase.

AECL has chosen to base its safety case around a Reference Case based on information from a real site. In so doing AECL has gone beyond a purely generic presentation of the concept. This approach is supported by the Group since, by using actual site investigation data integrated at one site, criticisms of 'abstraction' that are sometimes levelled at similar exercises elsewhere can be avoided. However, an analysis based on the specific properties of one site does leave open the question of the transferability of the safety and engineering feasibility to other sites, with different characteristics, i.e., until a site is chosen only the potential of a concept can be judged.

The technical input to the EIS comes from more than a decade of work by AECL, Ontario Hydro and their contractors. During this period the proponents have managed an extensive programme of field and laboratory investigations and have participated in a number of international studies related to deep geological disposal. The Program has cost approximately Can$500M. It is the experience and view of the Group that the Program has been among the leading international projects concerning disposal in hard, fractured rocks, and that it has been carried out to high technical standards.

The Group recognises that the information arising from this Program for input to the EIS has to some extent been frozen around 1990, although some later R&D results have been used in the study. Although development work continues to address critical issues, it is not possible to factor all of the results into a major exercise such as production of the EIS. This is normal practice when performing a system assessment; and, during the discussions with AECL, the Group was able to see a number of areas of new information which added to that used in the EIS. It must be realised that even if the Canadian concept is judged as promising, there will still be a need to continuously follow international developments and perform R&D work in Canada.

Chapter 3. Post-Closure Assessment: Understanding the Performance of the Individual Safety Barriers

This Chapter describes the Group's review of the role and performance of the system components used as the basis for the Post-Closure Safety Assessment. Much of the information evaluated is brought together in the "Postclosure Assessment" volume of the EIS primary references. Supporting information is also located in several sections of the EIS and in the primary references.

The Chapter is divided into sections commenting on the vault, geosphere and biosphere subsystems.

3.1 The Vault

3.1.1 The Waste Form

Both the concept and the Reference Case studies concentrate on the disposal of spent fuel, although the possibility exists that vitrified HLW from spent fuel reprocessing may also need to be disposed of. The Group believes that disposal of HLW would not involve significant differences in the disposal concept or the safety assessment methodology and that the present work could readily be extended to embrace this situation. If, however, non-HLW were also considered for geological disposal, the concept would likely have to be enlarged and more work would be required.

From the point of view of disposal, CANDU fuel has more favourable characteristics than LWR fuel: its shorter fuel bundle length makes it more amenable to handling; the collapsed Zircaloy sheath improves the mechanical stability of the fuel rods by eliminating the gap between the fuel pellets and the cladding; and its low burn-up ensures relative low heat output, relatively fast decay to the same activity of the original uranium ore, and more limited potential for undesirable radiolysis effects. These properties allow some extra latitude in selecting container sizes and emplacement density.

There is considerable experience in waste-form studies in Canada, especially on evaluation of the properties and post-disposal behaviour of spent fuel. AECL has been centrally involved in providing data and developing models for assessing the long-term performance of spent-fuel as a waste form. This has included wide international exposure and active participation in a joint Swedish-Canadian-USA spent-fuel working group.

The treatment of the long-term behaviour of the fuel in the post-closure assessment is considered in-line with current international practices and understanding. The gap inventories of radionuclides (e.g., those radionuclides which are assumed to be released from the container immediately after breach) are conservatively chosen in the light of more recent Canadian and Swedish data. The fuel matrix dissolution times are intended to be realistic rather than conservative. By comparison with other international assessments, the realistic values chosen appear justifiable. In any case, the results of the safety assessment are not very sensitive to this factor.

The EIS study utilises a set of properties representative of the majority of CANDU fuel bundles, which was the correct approach to undertake in this conceptual phase. Later, as the Canadian programme progresses, attention should be given to other types of non-standardised CANDU fuel bundles. For example, the Group recalls that, in the past, a limited number of fuel rods was manufactured with a gas plenum and, therefore, with a non-collapsible sheath.

3.1.2 The Canister

The overall concept includes a number of options for the container material but the Reference Case study is based on the use of an internally-supported titanium shell. Titanium has been selected as the reference material due to its excellent corrosion resistance in a wide range of environmental conditions.

An extensive programme of work covering all corrosion modes has been carried on over the years. The Group judged these studies, including the work on microbiologically mediated corrosion, to be representative of the state-of-the-art. The model for crevice corrosion seems conservative. Questions were raised on the possibility of low-temperature delayed hydrogen cracking. Recent data were provided by AECL which allay this concern to some extent, although questions remain on the understanding of the initiation of this corrosion mechanism. Copper is also being considered as an alternative corrosion barrier.

Overall, the Group considered that

- the reference minimum lifetime of the container of 1,000 years used in the safety assessment is technically reasonable and acceptable within the present regulatory framework
- the corrosion lifetime of the container may indeed be much longer than 10,000 years, as it is suggested by AECL, but it would need to be properly justified[2], whether for Ti or for Cu
- residual uncertainties in lifetime are adequately convoluted in the early container failure fraction. The latter is related to the potential presence of manufacturing defects and current estimates are based on statistics from existing manufacturing processes. A better figure can be obtained only when the whole fabrication sequence, including welding and other hot cell operations, is demonstrated.

The utilisation in the waste package of relatively large amounts of iron-based materials, such as shell supporting structures, is deemed undesirable in the EIS, although no quantitative analyses of the problems of hydrogen production and removal are included. The Group considers that a final decision on whether to implement iron-based materials should consider this more fully and should be tied to the final demonstration that the Reference Case container has, indeed, the necessary mechanical stability. To this effect, the settling behaviour of the packed particulate material in the shell and baskets is still of some concern due to vibrations during transportation and the pre- and post-closure phases (the latter as a possible consequence of repeated, long-term exposure to seismic vibration). The ability of the particulate material to fill all useable void space will also need to be demonstrated later with actual bundles in a hot-cell operation. In any future licensing case, it will be necessary to give a more comprehensive analysis of the container for different scenarios.

Finally, given the current successful status of short-term corrosion data gathering and given the envisaged, fairly long time frames for the siting and construction of the actual repository, the Group advises the Canadian Program to start a parallel programme of long-term studies representative of in-situ conditions.

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[2] However, important effects in terms of ensuring long-term isolation of radionuclides can be achieved only by utilising very long-lived containers (e.g., >10^5 years' lifetime)

3.1.3 The Buffer and the Backfill

The clay-based buffer surrounding each waste container and the backfill materials to be emplaced in the galleries play an important role in the Reference Case safety assessment (see section 3.1.4.). The R&D programme on these materials has been extensive and detailed, including strong interactions with other national programmes and with international exercises, e.g., the Stripa Project, and a well-focused programme of work at the URL.

The choice of materials for the buffer (a clay and sand mixture) and for the backfill (crushed granite/lake clay) is pragmatic, attempting to compromise between the properties of each component and strike a desirable combination of such properties as swelling pressure, hydraulic and thermal conductivity, deformation under load, manufacturability, etc. This choice goes beyond proposals made in other countries, where pure compacted clays often still represent the reference case - although trends in the direction of the Canadian approach are obvious.

The long-term behaviour of the buffer/backfill material is an important concern in all national waste disposal programmes. The group considered that the important questions concerning the performance of the buffer and backfill as diffusion barriers were properly identified and, in the case of clays, specifically investigated. The Group appreciated the swelling experiments with field clays as natural analogues, since they give important clues as to the continued ability of clays to swell even after long periods under unsaturated conditions. Further, the Group found that the recent decision to limit the maximum clay temperature to 90^{0}C is conservative and that this would ensure that the initial design limit of 100 C is indeed met.

In common with other national programmes, the behaviour of the backfill/buffer during the so-called "re-saturation phase" of the repository is not directly evaluated, and instant resaturation upon closure is assumed. Further work will inevitably be necessary for a specific safety submission and might form part of the future work programme. In particular, resaturation calculations would be useful for the strengthening of the safety case given that resaturation times could be significant compared to the 10^4 years regulatory compliance period and that uneven wetting could have an influence on canister stresses, caused by heterogeneous swelling pressures.

3.1.4 The Vault Analysis

The vault analysis in the reference case is strongly influenced by the extremely favourable rock properties, which are discussed in more detail in Section 3.2. The high quality filling materials and host-rock ensure that transport through the buffer and backfill and out into the rock is purely by diffusion. In most other hard-rock programmes, the possibility of advective flow near the tunnel is allowed for. Since AECL also wishes to include more fractured host rocks as candidates for repositories, analyses of this type will eventually be needed.

At present, transport from the vault is calculated with a simple 1-D model backed-up by 3-D model calculations. This is common practice in safety assessments of deep geological repositories, where more complex research models are used to provide data for simplified safety assessment models. More explicit justification of the adequacy and validity of the 1-D modelling would have been of value.

In the AECL Reference Case, the predicted radionuclide transport is very sensitive to the relative positions of waste, buffer, backill and the nearest flowing zone in the rock. In particular, the flowing zone is placed above the level of the vault, thus, as the radionuclides migrate upwards and sideways towards the flowing zone, they are "attracted" and retained by the large sorptive sink constituted by the backfill materials emplaced in the vault galleries above the waste packages. The backfill would be a significantly less effective barrier if the flowing zone were located underneath the vault. This fact did not escape the AECL researchers, but it is not described sufficiently in the EIS.

In the Reference Case safety assessment, the vault is subdivided into different "release regions". This segmentation is possible only owing to the assumption of sparsely fractured rock and the absence of an excavation damage zone (EDZ). The assumed absence of a significant EDZ was justified by the experiments carried out in the URL. If confirmed, in situ, this finding would set the Canadian granitic plutons apart from similar rock types in other national programmes. The Canadian programme is actively working on this issue and the related problem of rock spalling in a high-stress environment. In particular it is being proposed to construct elliptical galleries for in-room emplacement which would avoid stress concentration on galleries surfaces and eliminate the potential for spalling. In-room emplacement would also make the performance of the repository less dependent on the location of a flowing zone, whether above or below the repository horizon. The Group felt that these studies could usefully be built into any future R&D programme at the URL.

Owing mostly to the decision not to employ iron-based materials in the waste package, gas generation and two-phase flow were not dealt with quantitatively in the safety assessment. The Group felt that it would be prudent and would help retain flexibility to deal with these issues if bounding calculations were presented to support the purely qualitative assertions.

3.2 The Geosphere

3.2.1 The Geosphere model

In common with other countries working in hard rocks, there are large conceptual uncertainties in the regional geological and hydrogeological models which form the basis for safety assessments. For example, evidence is sparse for whether major fracture zones act as continuous planar features when treated in three dimensions. AECL is aware of this issue and has carried out both 2-D and 3-D flow and transport modelling. The Group would anticipate that, in line with other national programmes, the future Program would continue to explore the impacts of spatial variability and heterogeneity on groundwater flow in and around a repository. The declared AECL goal of using analyses of the hydrogeology to 'fine-tune' the positioning of the vault is shared by many other programmes. The measurement and analysis tools necessary for such a step require further refinement.

As noted in 3.1, the Group found that, from their own experience of granitic rocks in other countries, the properties of the repository host rock used in the Reference Case study are unusual in being so sparsely fractured. No other country has located such extensive bodies of essentially unfractured rocks (i.e. containing no macroscopic network of interconnected fractures) in which to site a repository. Consequently, no other concept can rely on simple diffusion modelling for radionuclide transport away from the repository in a safety assessment. Such tight rock and the further absence of an EDZ also alleviate (but do not eliminate) the need for the understanding and modelling of mineralisation, colloid formation and transport, fracture flow, local redox properties, etc. The AECL team presented a convincing case for the existence and potential availability of the sparsely fractured rock, supported by a visit to the URL by the Group to examine its properties at first hand.

AECL also recognises that more detailed treatment of various issues is required if the search for suitable sites is not to be confined to rock formations of such high quality as that found in the URL. Otherwise, the widespread existence within the Shield of rock with similarly excellent confinement properties must be established as part of a siting programme. At present, the Reference Case is based very largely on observations in the URL. As part of the siting process it would be beneficial if the petrological and tectonic factors controlling the genesis and distribution of sparsely fractured rock within the Shield could be established more clearly. More specific discussion of the advantages of being in a 'tectonic shadow' and less simplified comparisons with the Scandinavian Shield would enhance the discussion.

Even though the properties of the sparsely fractured rock are so central to the safety assessment of the Reference Case, at present there is no substantial programme focused on its hydrogeology (e.g ventilation tests, scale-dependent tests), and hydrochemical information has only recently become available. Apparently, work of this type is planned or is in hand, although current work focuses on the moderately fractured rock. The Group would be strongly supportive of a more extensive programme of work on the hydraulic, hydrochemical and geotechnical properties of the sparsely fractured rock. Solute transport processes are determined by the micro-scale features of the rock body.

Although the sparsely fractured rock is a key feature of the Reference Case, the Group recognised that international experience and Canadian opinion indicates that 'less-good' (i.e. more fractured) rock could also provide adequate margins of safety, although analyses of the behaviour of fractured rock would be very different to those used in the Reference Case. Further progress in siting and safety assessment would benefit from the continued development of modelling and characterisation methods for such rock.

3.2.2. Geochemistry

The overall treatment of geochemistry within the Reference Case study was considered appropriate by the Group. However, there were a number of issues where further work is to be encouraged as the siting programme gets underway.

The detailed reconciliation of the extensive and high-quality suite of hydrochemical observations with groundwater flow models in the Whiteshell Research Area is not currently very advanced and the information used to support the Reference Case analysis was quite limited. The use of hydrogeochemistry for 'validation' of time-dependent groundwater flow models using palæohydrogeological techniques is an important area which could be investigated further in future. These techniques are likely to be an important aspect of a siting programme and AECL has devoted considerable resources to building a first-rate capability to take and analyse groundwater samples.

The overall importance of understanding geochemical controls on the repository environment is appreciated by AECL and further development of a geochemical (rather than largely hydrogeological) approach to repository siting is encouraged. For example, the controls on groundwater redox conditions and salinity need further evaluation in order to establish better mechanistic models, understanding of which may then affect the siting programme. These hydrochemical factors control many important performance-related processes, such as corrosion, buffer evolution and radionuclide solubility and speciation.

The issue of colloidal transport of radionuclides was not a feature of the Reference Case, as the sparsely fractured rock and the buffer act as effective filters for any colloids generated in the near-field. The Group agreed that this approach was acceptable for the Reference Case. However, this may not be the case for other sites where more fractured rock may be present, and continued study of natural groundwater colloids as well as those generated within the engineered barriers is to be encouraged.

3.3 The Biosphere Model

The biosphere analysis is indisputably one of the most complete and detailed carried out in any country. Its large reliance on actual field data is commendable. The Group felt that the emphasis on biosphere was appropriate in the context of national environmental awareness in Canada, where there may be a demand for broadly based discussions of impacts within all parts of the natural environment. In general, other countries address only the impact on humans, as this would protect, indirectly, other species. It is worthy of note that the unusually high level of detail in biosphere treatment does not seem to result in proportionally increased levels of effort invested, since the waste disposal biosphere studies appear to be well integrated with the other environmental assessments of AECL.

The biosphere work has availed itself of the international cooperation within the framework of the BIOMOVS programme. The development and use of a reference biosphere within this international context is a useful and important approach. The group encourages the continued involvement of the Canadian programme in those activities and, in particular, further analyses and documentation of the recent comparisons of Canadian and other models. These intercomparisons enhance confidence in the results of the biosphere analyses.

An important point is that the Group considered that the critical group selected for the analyses may well be unnecessarily conservative. It could be re-evaluated to ensure that it is based on both 'cautious and **reasonable** assumptions' (as formulated in the guidelines, ICRP-46).

Chapter 4. Post-Closure Assessment: Total System Performance

This Chapter comments on the methodology and results of the complete system safety assessment, which used the information and conceptual models described in the previous Chapter.

4.1 Regulations

The basic philosophy of long-term protection of humans and the natural environment and of using different timeframes within which assessment results are presented to reflect the increasing uncertainty of dose/risk calculations is common practice. However, the way of treating these matters varies from country to country and the group was somewhat surprised to learn that no direct discussions have taken place between AECL and AECB on the subject of the interpretation of the regulatory guidelines. There is room for interpretation in those areas of the Canadian regulations associated with timeframes, particularly:

- The 10,000 year 'cut-off' beyond which dose estimates are not required.
- The meaning of 'sudden and dramatic' releases and 'acute' doses to individuals for times beyond 10,000 years.
- What comprises or is expected of a 'reasoned argument' in this period.
- The definition of critical group in different circumstances.

The 10,000 year cut-off seems to be related entirely to the onset of a future glaciation. If this is the actual reason for using this figure, it needs to be discussed in this context by both regulator and proponent. Is it, for example, intended as a sharp, or an order of magnitude limit, or to be linked positively to glaciation in terms of the processes which are modelled in the run-up period to the cut-off? The EIS interprets it as a sharp limit although, commendably in the views of the Group, calculations are made up to 100,000 years. Doing dose calculations up to this time is reasonably in line with practice in other countries, but it does raise questions as to what kind of assessment is required (particularly with respect to the biosphere) for time periods when the country is glaciated or subjected to extensive permafrost. Such conditions may dominate much of the next 100,000 years. The main driving forces which might leàd to 'sudden and dramatic increases' in release (if not dose) beyond 10,000 years are permafrost and/or glaciation caused by a climate change and the physical processes associated with glaciation, so some sort of quantitative consideration of the processes involved does seem to be required. For example, for the period beyond 5,000 years there may be permafrost over substantial areas of Canada.

The quantitative interpretation of *"sudden and dramatic"* also raises questions. AECL considers predicted doses in the period after 10,000 years to be important only if they approach the "acute" level. However, it is not difficult to find cases where predicted doses rise by orders of magnitude after 10,000 years, but still remain well below acute levels[3]. The importance to be attached to such cases could be debated.

The interpretation of critical group needs further development. For the human intrusion scenario it is necessary to distinguish in the analysis between potential exposures to the persons who really undertake the intrusion and to third persons. The risk of increased exposures to "the intruder" is an unavoidable result of the accepted strategy to isolate the waste rather than to disperse it.

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[3] For instance, the estimated annual dose in the median value simulation rises by many orders of magnitude between 10,000 and 100,000 years and continues to increase thereafter.

The Group recommends that, as part of further concept development, dialogue with AECB take place to resolve these issues. These talks should also address the issue of suitable performance measures to support quantitatively the required "reasoned arguments" in the time period after 10,000 years.

4.2 PA Methodology

The Group believes that the EIS documentation does not adequately reflect the status of Canadian performance assessment methodology relative to that in other countries. Attention should be drawn to the pioneering step forward taken by AECL in the development of the SYVAC code and the probabilistic approach to safety assessment. SYVAC has a high profile internationally and has been used in a number of other programmes (e.g. Sweden, UK); the emphasis on the PSA approach is, however, stronger in the Canadian programme than in most other programmes.

Given the central role of SYVAC in the analyses, some discussion of the advantages and disadvantages of the approach (as opposed to a more discretised approach using scenario and consequence analysis) would have been valuable in the documentation. In our view, the advantages are seen to be:

- It illustrates the behaviour of the undisturbed evolution of the Reference Case by emphasising the expected outcome (the mean PSA dose value), rather than concentrating on the extreme values. This is a widely accepted approach internationally.
- It is an efficient way of performing and presenting sensitivity analyses and of incorporating parameter uncertainty and variability.
- It explores parameter space systematically and allows the consistent integration of all the subsystems of the model.

The disadvantages of the way that SYVAC has been applied in the EIS are seen to be:

- Compliance is judged by risk rather than by extreme consequences. This, however, does not mean that it is without interest to know the size of extreme consequences and the associated probabilities.
- The convolution of different types of uncertainty, variability and scenario probabilities into SYVAC runs can lead to a lack of transparency in the analyses of behaviour of the disposal system. The code uses up to 7,000 parameters although only a handful may play a decisive role. It would be helpful for the reader to know when such is the case, as, for instance, in the case of the calculations relating to ^{14}C. Furthermore, it is not made sufficiently clear that some of the parameters have fixed, deterministic values.
- It is difficult for the reader to identify the sequence of events and processes which comprises the circumstances of any given scenario (although the code user can apparently do this).
- The problem of completeness of scenarios is somewhat obscured (does a frequency distribution of results adequately represent the true probabilities of occurrence).

The linking of research codes and SYVAC modules is not straightforward and the capability of SYVAC to incorporate directly the research codes is limited due to the use of convolution integrals.

4.3 The PA Results

The Group notes that, for the case study, the results at 10,000 years are all well below the risk limit. Even at 100,000 years this is still the case, although there has been a marked increase in calculated doses.

The principal barriers to release are:

- an effective engineered barrier system, with low probability of early canister failure and very slow releases from the waste form;

- the very slow diffusive transport of radionuclides through the backfill and also through the near-field rock which is characterised by having no connected fracture network.

These are the most important features of the system. The Group identified a number of additional issues concerning the safety assessment results:

- It is useful to have a deterministic calculation to compare with the PSA results, but it is not obvious why AECL chose the median value to present the results. There is no parallel easy way to compare the mean values of probabilistic calculations and results of deterministic calculations with mean value parameters. It would, thus, have been instructive to look at outlying, high-consequence deterministic results and to discuss the circumstances under which they might arise.

- Transparency and ability to interpret and unfold the results are masked by the mixture of conservative, mean and probabilistic assumptions and presentations. It ought to be made clearer and defended that what is presented is the modelled system variability in a conservative framework.

- The assumptions behind the screening out of ^{137}Cs need to be checked. Is it conservative in all scenarios?

- Confidence in the convergence of the SYVAC results when only 40,000 runs were carried out will eventually need to be further supported, e.g., by case studies with an order of magnitude more runs.

- The Group considered the extrapolation of the very positive results from the reference case to other cases in the concept to be plausible, but certainly not adequately justified by the information available in the report.

- The question of how complete a treatment of other scenarios was made in the EIS was not fully answered. The scenario selection methodology ruled out scenarios which may have been instructive to analyse. Further testing of the scenario methodology over future years is recommended.

- Analysis of the results points out that large portions of dominant radionuclides remain in the waste form and container over time periods longer than 100,000 years. While this is meant to underline the enormous retention potential in the Reference Case, the presentation to the public should at the same time emphasize what happens to this remaining inventory - and almost unchanged hazard potential - over very long time periods.

The treatment of 'human intrusion' is a difficult issue in any assessment. AECL has chosen to take a highly quantitative approach to estimating the probabilities and consequences of intrusion. The Group felt that this approach, whilst in keeping with methods which have been used elsewhere, was too easy to challenge. Some recent recommendations (e.g. by the Royal Society in the UK and by a National Academy of Sciences group in the USA) have advocated separating the intrusion scenario from other analyses. The assumptions in the AECL analyses (especially the probabilities) are debateable and the whole premise of the analysis is that future human behaviour is quantifiable. The Group believes that the treatment of human intrusion requires further discussion between the regulatory authority and the proponent as it may not be amenable to consideration within the normal safety assessment framework. In this respect, the situation in Canada is little different to that in most other countries.

4.4 Reliability and Confidence.

The Group believes that the large margin of safety exhibited in the Reference Case analysis gives confidence that the concept is reliable and could be implemented to meet safety targets in real sites which have not too dissimilar characteristics from the reference conceptual site.

The use of expert judgement is an unavoidable part of the process of data interpretation and application within a safety assessment. There is a growing pressure worldwide to ensure that the elicitation process is well organised and documented. An appropriate range of peer views, not only by in-house experts, should be sought in order to minimise potential biases. The expertise of the data providers should be well established. The Group felt that the way in which this was done in the EIS was not clear, as the documentation does not discuss it. Future exercises should report on the process specifically.

The development, testing and validation of process models, such as those used in the EIS, is a continuing process and AECL has a programme of work planned in this respect. We encourage AECL to continue to develop its strategy, particularly on the prioritisation of issues to be studied. An overview of AECL's views on the most important current requirements in validation is not obvious in the EIS documentation and would be useful.

The quality assurance procedures used whilst performing a safety assessment, particularly with respect to the traceability of data and decisions, should be transparent. The group did not, however, specifically review this issue. In discussions, the AECL team seemed to have a sound, pragmatic approach, recognising that the QA demands will rise as one moves to siting and licensing phases.

Chapter 5. Siting and Constructing a Repository

This Chapter deals with the proposals made in the EIS documentation for an approach to siting a spent-fuel repository and engineering options for its design and construction.

5.1 Siting

The EIS presents a detailed description of how the siting process might operate. The Group were generally impressed by the thoroughness with which this issue had been addressed, although feeling that the time allocated (20 years) may be longer than is technically necessary (see below). The Group made the following specific comments:

- We believe that it would provide the greatest flexibility in site choice and would maximise the potential of the voluntarism approach if the **siting territories** were not to be prescribed too closely at the outset.
- Experience within the Group supports the AECL proposal that the principle of voluntarism be introduced at the earliest possible stage of the siting process.
- The qualitative listing of favourable attributes advanced by AECL is at an adequate level for the initial stages of siting. Prescriptive guidelines or criteria which are couched in too quantitative terms may be unhelpful since suitability depends not just on the siting characteristics, but upon the integrated system behaviour.
- Public involvement in siting has been properly thought through and is well described in the report. The approach is endorsed by the Group.
- We support the use of visualisation techniques using GIS and 3-D graphical geological simulation models to illustrate and explain features of areas and communities which will be important in decision-making.
- The approach advanced for characterising candidate sites in detail is broadly in-line with that used or proposed in many other countries. The Group considered that methodologies for narrowing down from areas to these candidate sites should be thought out at an early stage, and should not be too lengthy or involve overly detailed studies. In particular, the 12 year period proposed for selection of the single candidate site from among the three areas seems rather long.
- Site characterisation studies need to be broad based and put emphasis on both structural and hydrogeological investigations defining present-day conditions and on characterising the long-term chemical stability of the system, particularly in the near-field region, using hydrochemical and neotectonic studies of site stability.
- It is important to have in place an appropriate quality assurance programme at the start of site selection and characterisation to allow sensible and traceable decisions to be made.

- Co-ordination and integration of performance assessment, design and site investigation are essential at the site characterisation stage in order to allow properly founded operational decisions (e.g. shaft position, repository depth and orientation, etc). This does not necessarily imply the use of detailed, full system analyses.

- It is not essential, or even possible, to locate the 'best' site. The sparsely fractured rock (SFR) found at the URL is clearly very useful in building a safety case, but provides high margins of safety and finding it elsewhere is not essential. However, should there be a desire to try to locate equivalent rock, some work appears to be required to build an understanding as to the geological controls on why such SFR exists.

- AECL proposes to fix the ultimate depth and location of the vault at a chosen site on the basis of a quantitative understanding of the hydrogeology at a suitably fine scale. This is also an objective in some other national programmes. The resolution and the reliability of hydrogeological modelling must improve if this is to be feasible.

5.2 Engineering

The Group judged that the URL facility and the work that has been carried out on testing and characterising the geological environment, engineering materials, seals and backfills and excavation techniques are very impressive for this conceptual stage of a programme.

The Group encourages the practice design work that is planned to experiment with the location of a hypothetical repository at the URL site in order to account for specific geological features and stress properties. This will test further the flexibility of vault design to integrate with actual site characteristics.

The transient resaturation period, which will commence immediately after repository closure, is not well understood, could be quite long and may induce significant effects in terms of the evolution of the engineered barrier system. It is currently not included in the performance assessment modelling and, although this approach is also adopted at present in most other countries, future work should aim to characterise the resaturation process in more detail.

The elliptical vault, in-room container emplacement alternative is interesting and raises a number of new questions which will need to be evaluated in real scale tests:

- it could modify the results of the safety assessment as the diffusion distance through the backfill changes

- the rehydration behaviour could be complex in the immediate vicinity of the containers (with the borehole concept this is less of an issue)

- the stress and excavation damage zone (EDZ) implications of the design need testing

- the emplacement and settling behaviour of the different buffer blocks and loose fill will need testing

- the potential interactions of the concrete pad and the bentonite need to be addressed.

The EDZ is judged by AECL to have no impact in the sparsely fractured rock, but further work needs to be done on its behaviour in moderately fractured rock if the geological environment at a repository site is less favourable than at the URL (see comments in Chapter 3).

The Group is strongly in favour of an approach to the overall Program which would ensure the closest integration of repository design, performance assessment and site characterisation. We believe that this point is well-understood by AECL.

The issue of post-closure monitoring is difficult from both the technical and social viewpoints. It is debateable whether any sensible safety case can be made for monitoring post-closure. The repository system is expected to evolve very slowly and there are no performance related parameters which are clearly amenable to measurement and also of obvious safety relevance. However, there may be a social demand for some kind of monitoring which must be met.

Chapter 6. The EIS documentation and its general conclusions and recommendations

This Chapter first comments on the overall nature of the EIS documentation, then deals on a point-by-point basis with the conclusions and recommendations presented in the final section of the EIS.

6.1 The Documentation

In general, the Group found the EIS documentation to be well written and presented. The structure, emphasising the post-closure assessment, is well thought-out and also gives prominence to public involvement and evaluation of the pre-closure phase. Some of the techniques for visual presentation of safety assessment results are innovative and a useful aid to understanding. The EIS volume itself is well-presented largely self-contained and weights the presentation in a manner suitable for a broad readership. The supporting Primary References, which are more 'nuclear' biased, can be rather repetitive and difficult to follow through, in that not all the ideas are simply encapsulated as one moves from lower to higher level reports. They could benefit from:

- A 'vertical slice' of the post-closure safety assessment volume, guiding the reader explicitly through the key performance issues and sensitivities and how they were handled. This might be a separate summary report.
- In the individual documents, presentation of more of the key quantitative information on which the models or assumptions are based.
- The EIS is a weighted selection of other reports and is considered appropriate for the intended purpose. A similar report, weighted towards post-closure safety, could be useful, since this topic is treated only very briefly in the EIS and too extensively for many readers in the collected primary references.

6.2 The EIS Conclusions

Chapter 9 of the EIS report presents a number of conclusions. These are commented upon individually below.

The need for disposal

Current policy in virtually all countries agrees that radioactive waste disposal should be prepared for now and that geological disposal is the only currently viable method. This is also the view which emerged from the OECD/NEA Workshop on Ethical Aspects of Geological Disposal in September 1994 and one which is shared by most experts internationally.

Protection of human health and the natural environment

The multibarrier concept proposed is widely accepted, and the engineered barrier and wasteform are suitable for achieving safety. It is noted however that the specific demonstration of post-closure safety is for the Reference Case study only. These conclusions would have to be demonstrated for any other realisation of the concept as well. The Reference Case study gives very high margins of safety; higher than are actually required. The AECL assertion that new realisations would give equal or higher margins of safety must be substantiated by carrying out further work when other repository systems are considered.

We believe that pre-closure safety, including safety during transportation, can be achieved based on reasonably achievable or demonstrated mining and nuclear handling technology in Canada and in other countries. However, this aspect of the EIS was not reviewed by the Group.

The conclusion that current regulatory requirements could be satisfied is adequately justified at present, but final confirmation would have to be on a site-specific basis.

It is noted that AECL has calculated radiological consequences for other organisms than humans; this goes beyond what is required or done in most other countries, where protection of people is expected to provide adequate protection for other species.

Minimising the burden on future generations

The disposal concept reduces the burden on future generations whilst being sufficiently flexible to allow a significant element of choice to immediately future generations (e.g. in allowing retrievability).

Providing scope for public involvement during concept implementation

Canada is leading the way in the incorporation of public involvement in the decision-making process. The principles and strategy outlined are well formulated and are endorsed by the Group. Public involvement in the key areas of repository siting, the design and operation of surface facilities and the choice of transport routes is considered particularly important. The precise procedures for public involvement in the siting process are, however, still to be elaborated.

A disposal concept appropriate for Canada

The Group considers that geological disposal is the only **viable** disposal option for **every** country at present. Plutonic rocks are considered a sensible option for geological disposal, as shown by work in other national programmes.

AECL acknowledges that the concept is based on the study of a single generic geological disposal environment (plutonic rocks of the Canadian Shield). Although there are alternatives to the choice of disposal environment, the Group believes that the early decision to focus the Program was reasonable and has paid dividends in achieving an internally consistent concept. Other countries (e.g. Finland, Japan, Sweden and Switzerland) have already demonstrated, by similar safety assessment projects, that an acceptable solution can be achieved using a hard, fractured rock disposal concept. Given the extent of the Canadian Shield, spreading the net wider to look at other geological formations could be counterproductive in that it dilutes effort. We also point out that, for many years, international opinion has been that it is not possible to define the 'best solution'; it is simply necessary to find and demonstrate a clearly acceptable solution with adequate margins of safety.

The Group can see no technical reason to suggest that other geological options need to be evaluated in Canada. On the other hand, given the long time scale for final implementation of the concept, it would be prudent to continue studies of engineering barriers concepts, including alternatives.

The disposal concept could be achieved with available or achievable technology

The Group had a number of points to make concerning this conclusion.

- Site characterisation technology is readily available and sufficiently developed to allow the commencement of implementation.

- The disposal concept is based on reasonably achievable materials and technology. However, the demonstration and testing of some key technological features will have to continue or be initiated.

- Further large-scale demonstration may need to take place at a later date and would necessarily be site specific at that stage.

- The Group endorses the view that it is prudent that the concept does not rely on institutional controls for long-term safety.

- The necessity and the requirements for post closure monitoring need further consideration in all countries and, if considered a desirable course of action, the concepts and technology would need further development.

- Retrievability is feasible in principle in plutonic rocks but may have to be further elaborated for specific repository concepts. However, the treatment presented at this stage by AECL is considered adequate.

Safety assessment methodology

The safety assessment methodology has been developed and demonstrated to a level sufficient to progress past the generic stage. Further development will be required for application in other than the reference conditions, and the group believes that AECL has the capability, competence and maturity to achieve this. Moving ahead with the siting programme would give a better idea of the methodology which will need to be developed. We have not reviewed the pre-closure assessment but we believe that pre-closure safety can be achieved based on reasonably achievable or demonstrated mining and nuclear handling technology in Canada and in other countries.

Technically suitable sites

Based on generic understanding of crystalline rocks it is considered very likely that suitable sites will exist in the Canadian Shield. They may, however, have properties different from those used in the Reference Case study assessment. It is important to appreciate that the extremely effective safety barrier provided by the very low hydraulic conductivity rocks at the URL site are not essential for the location of a safe repository.

6.3 The EIS Recommendations

Chapter 9 of the EIS report also presents a number of recommendations. These are commented upon individually below.

That strategy be based on disposal in plutonic rocks of the Shield

We see no reason to change the current concept.

Organisational structure for implementing the concept

It is not the role of the Group to comment on political or organisational issues. However, we consider that:

- a clear allocation of responsibilities is vital;

- the preservation of know-how and human and intellectual resources is essential to sustain the capability for implementation;
- the existing Program participants have demonstrated high competence and built up considerable technical expertise. Advantage should be taken of this in the future Program.

Commitment to principles

All the principles discussed in the report and the proposed commitment to them are heartily endorsed by the Group. The Canadian programme is providing a positive example by its open approach.

That Canada should proceed to siting

We fully agree with this recommendation, which is considered to be in line with other countries which have achieved similar levels of maturity in their programmes. This progress is considered to be essential to provide the necessary impetus to focus and move the Program ahead. Commencement of the siting phase is the most effective way to utilise the capabilities that have been built up over the last 17 years and which are currently at their peak.

Chapter 7. General conclusions by the NEA review group

The Group understands that it is the intention of the EIS to demonstrate that a suitable solution can be found by applying the concept, but that the eventual solution might look somewhat different to the Reference Case. The Reference Case is, therefore, considered as a specific example, and it is recognized that other options or variants exist and may require additional study. Our recommendations thus focus on whether the EIS, as a whole, has demonstrated robust and flexible methodologies and technology which provide a basis for moving to the next step of siting.

Our evaluation indicates that a sound conceptual basis for designing a safe repository exists. There is still further development work to be done on many aspects of the vault and the engineered barriers design and the proponents have demonstrated their ability to tackle them. The situation is normal at this stage of concept development and is closely parallelled in other countries, where final system designs are still many years in the future. The future development of the design is unlikely to affect the siting programme proposed in the EIS. The concept appears, therefore, sufficiently flexible to allow the matching of various designs to the geological features of any site that would be geologically suitable for a repository.

The other major aspect of readiness concerns the availability of appropriate technologies for site selection and investigation. The work carried out by AECL in the WRA and other areas is certainly at the forefront of geotechnical site evaluation. We have, however, some reservations about the extent to which AECL has been able to test methodologies for examining and modelling rock with fracture properties which differ markedly from those of the URL site. The Group accepts that such methodologies exist in other programmes and that the AECL staff are well aware and conversant with them and would have no difficulty in transferring them to a future site investigation programme. Consequently we do not believe that this constitutes any reason to suggest that the Program is unready to proceed.

Another important feature of the Program, introduced around 1980, was the establishment of schedules allowing time for extended investigations in the conceptual, generic phase of the disposal Program. The decision point arrived at today was thus foreseen early. The extensive time needed for the decision process was not. Around six years have already elapsed since the proponents considered themselves to be in a position technically to develop and document a concept and total system performance assessment. It is now time to move ahead, as the issues that remain to be clarified can only be, and should be, resolved during a siting stage.

Concluding remarks from an international perspective

The Canadian Nuclear Waste Management Research Program started some 17 years ago and has, during those years, won international recognition as one of the leading efforts in this area. The Program and its technical teams have good contacts and relations with similar programmes in other countries. The contacts are at all pertinent levels and they have contributed towards overall progress in many countries in the field of nuclear waste disposal.

The EIS document and the supporting reference documents reflect an excellent understanding of the scientific issues involved corresponding to the internationally recognized state-of-the-art in the field. They also reflect a close exchange of knowledge and ideas with other countries. This impression was confirmed by the detailed discussions that took place during the OECD/NEA review. These made obvious the high degree of competence and motivation in the AECL staff.

Considering the above and current trends in other countries, we believe that:

- the careful, step-wise implementation of the proposed concept would represent an acceptable means by which Canada can safely dispose of its nuclear fuel waste; and

- the Program has reached a state of knowledge and a maturity where it would strongly benefit from moving ahead with the next proposed step - that is, initiating the process for siting a deep geological disposal facility in a similar way to which progress is now occurring in a number of countries. The focusing on real and high priority issues that necessarily follows with moving to the first implementation step will help to keep the Canadian programme at the forefront. We look forward to following the continued progress of the waste disposal programme in Canada.

Appendix 1

Responsibilities of the Various Organisations Involved in the Review Process

Canada is a federation of ten provinces and two territories with one central federal government. Each province has its own provincial government. Under the Constitution, each province has control (amongst other things) over its natural resources and the production of electricity. Under the Atomic Energy Control Act of 1946, the federal government has responsibility for the regulation and development of nuclear energy. The Atomic Energy Control Board (AECB) is the federal regulator established to administer the Act and to regulate the nuclear industry. Atomic Energy of Canada Limited (AECL) was established to develop and carry out R&D activities related to nuclear development.

In 1978, the governments of Canada and Ontario jointly announced the Canadian Nuclear Fuel Waste Management Program to develop a deep underground repository for the disposal of used nuclear fuel in intrusive rock of the Canadian Shield. The federal government's agent, AECL, was given the responsibility for developing the disposal concept. The provincial agent, Ontario Hydro, has supported AECL's work and developed options for the interim storage and transportation of the used nuclear fuel. In developing these technologies, Canada and Ontario agreed that siting would not be addressed until the disposal concept had been found to be safe, acceptable and technically feasible.

In 1988, after more than 10 years of R&D, AECL considered that the disposal concept was ready for review and asked the Minister of Natural Resources (then Energy, Mines and Resources) to refer the disposal concept for used nuclear fuel to the Minister of Environment for a public review. In 1989, the Minister of the Environment appointed an independent Panel to undertake an environmental assessment and review process (EARP) on the concept of deep geological disposal of used nuclear fuel wastes in Canada and related waste management issues.

In 1990, the Panel held a series of open houses and scoping sessions across Canada in the five provinces, New Brunswick, Quebec, Ontario, Manitoba and Saskatchewan to explain the EARP review process and to identify issues of concern to Canadians that should be addressed by AECL in the preparation of the Environmental Impact Statement (EIS) for the disposal concept. Extensive and varied participation from private citizens, associations and environmental groups resulted in the identification of a diverse range of related waste management issues ranging from technical to socio-economic and ethical concerns.

The information presented at the scoping sessions was used by the Panel in developing the EIS guidelines issued to AECL in March 1992. AECL subsequently prepared the EIS and submitted it, along with nine supporting Primary References, to the Panel in October 1994. The EIS is presently undergoing a 9-month public review to determine if it meets the guidelines. If there are no deficiencies, public hearings could begin later this year.

The NEA international peer review will be an important, independent, expert review of the disposal concept developed by AECL. It is anticipated that Natural Resources Canada will provide the report to the Panel, as part of the documentation for the upcoming public hearings scheduled to begin later this year. This report will form part of the information considered by the Panel when it comes forward with its recommendations to the two Ministers of Environment and Natural Resources on the acceptability of the disposal concept and the next steps for the long-term management of used nuclear fuel in Canada.

The Major Agencies and Departments Involved in the Public Review/ International Peer Review of the Disposal Concept

Canada - Federal Government

Natural Resources Canada

- Federal government department responsible for development of policy on radioactive waste and nuclear issues in Canada including those related to AECB and AECL.
- In 1988, referred the Canadian concept for disposal of used nuclear fuel to the Canadian Minister of Environment for public review by an independent panel.
- Sponsor for the international peer review of the disposal concept.

Federal Environmental Assessment and Review Office (Environment Canada)

- Responsible for the appointment of and secretariat support to the independent panel carrying out the public environmental assessment and review process on the disposal concept for used nuclear fuel.
- Responsible for coordinating the preparation of the Panel report to the two Ministers, Environment and Natural Resources.

Atomic Energy Control Board

- Nuclear regulatory and licensing authority for all nuclear facilities, including radioactive waste management facilities in Canada.

Atomic Energy of Canada Limited

- Federal crown agency responsible for nuclear research and development in Canada.
- Developed, in collaboration with Ontario Hydro, the Canadian disposal concept for used nuclear fuel.

Ontario

Ministry of Environment and Energy

- Provincial government department responsible for providing advice on energy (including nuclear and Ontario Hydro) and environmental issues to the Ontario government.

Ontario Hydro

- Provincial utility responsible for electricity generation in the Province of Ontario.
- Largest among the three provincial nuclear utilities with responsibility for over 90 per cent of the used nuclear fuel produced in Canada.

Other Nuclear Utilities

Hydro-Quebec

- Provincial utility responsible for electricity generation in the Province of Quebec.

New Brunswick Power Development Corporation

- Provincial utility responsible for electricity generation in the Province of New Brunswick.

Appendix 2

Terms of Reference for the International Peer Review Provided to OECD/NEA by NRCan.

Introduction

An international peer review of the Canadian concept for disposal of used nuclear fuel in Canada is to be carried out under the auspices of the OECD-NEA (Nuclear Energy Agency) by a group of NEA-appointed independent expert reviewers. This OECD-NEA Expert Group (Expert Group) will examine the Canadian concept for used nuclear fuel developed by Atomic Energy of Canada Limited (AECL) in collaboration with Ontario Hydro.

The results of this international peer review will be submitted by Natural Resources Canada, as documentation for hearings, to the Federal Environmental Assessment and Review Panel, which is presently undertaking a public review of the disposal concept of nuclear fuel wastes in Canada along with a broad range of nuclear fuel waste management issues. This public review will be one of the most important environmental assessments ever undertaken in Canada and will provide an essential foundation for future decisions on the long-term management of used nuclear fuel wastes.

Background

In 1977, after several years of research, an independent expert group was formed to address options for the long-term management of used nuclear fuel wastes. The resulting report by the Hare Commission concluded that geological disposal in crystalline, igneous rock of the Canadian Shield is the most promising option and recommended that it should be further investigated.

In 1978, the Canadian Nuclear Fuel Waste Management Program was initiated by the Government of Canada and the Province of Ontario to assess whether permanent disposal in a deep underground repository in intrusive rock is a safe, secure and desirable method of disposing of nuclear fuel wastes. Under this detailed and comprehensive research program, AECL carried out a long-term research program to develop a concept for safe disposal deep within intrusive rock of the Canadian Shield. Ontario Hydro has supported AECL's work and pursued its own related studies on interim storage and transportation of used nuclear fuel. The disposal concept is based on burial at depths of 500 to 1000 metres in stable rock of the Canadian Shield, using a multi-barrier approach with a series of engineered and natural barriers.

In 1981, the governments of Canada and Ontario jointly announced a process for the evaluation of the Canadian concept for disposal of used nuclear fuel waste. It was agreed then that the issue of siting will not be addressed until the concept itself has been found to be safe, acceptable and technically feasible.

In 1989, the Canadian Minister of the Environment appointed an independent Panel to conduct an environmental assessment and review of the concept of deep geological disposal of used nuclear fuel wastes in Canada and other related waste management issues. A Scientific Review Group of distinguished independent experts was established by the Panel to conduct a specific in-depth examination of the scientific acceptability of the disposal concept.

The International Review Process

The international peer review will be conducted under the auspices of the OECD-NEA as part of their international peer review services program. The OECD-NEA Secretariat will coordinate the international review including selection of the qualified experts for the review. The review will be sponsored by Natural Resources Canada.

An independent review by the Expert Group will allow the Canadian review process direct access to a range of expertise, by drawing on the experience of the world's leading experts in this area and their views on the approaches taken by other countries towards both the research and development for nuclear fuel waste disposal and the long-term management of these wastes. This will provide advice that will effectively complement the views and expertise of those experts already participating in the Canadian review process. As part of the peer review, it is anticipated that the Expert Group will meet with other scientific and technical groups and government agencies participating in the public review.

Scope Of The International Review

The Expert Group will provide a broad review of the Canadian concept for disposal of used nuclear fuel developed by AECL and Ontario Hydro to determine if the information supporting the concept is sufficiently representative and reliable and has been correctly analyzed from a scientific and technical standpoint. Most particularly, the Expert Group will review, from an international perspective, the soundness and appropriateness of the methodologies used and the arguments presented which form the foundation on which the concept has been developed.

In carrying out the review, the Expert Group may consider presenting their views on the Canadian concept for disposal of used nuclear fuel waste with reference to the approach being taken by other countries on the management and disposal of used nuclear fuel or high level wastes. In addition, the Expert Group may want to indicate what, if any, future scientific work might be required to make the transition to implementation should this take place.

Source documentation for this review will primarily consist of the Environmental Impact Statement, the Primary References, cited references and other information (see Appendix for list). (Note: Other relevant information used by the Expert Group should be listed in the final report resulting from this international review.)

It is anticipated that the review will include, from an international perspective and according to procedures to be utilized and documented by the Expert Group for this review:

- a review and comment on the scientific and technical information supporting the relevance of the concept with an indication of the degree of reliability and completeness in the context of an overall disposal concept assessment;

- a review of the modelling activities and techniques to build confidence, such as uncertainty and sensitivity analysis and validation, with a view to confirming that the proposed disposal system and its behaviour with time are sufficiently well understood and assessed;

- a review and discussion of the results of the overall safety assessment, notably with regard to the robustness of the final conclusions with underlying assumptions and expert judgements used in the assessment, and the overall degree of conservatism of the assessment;

- a general assessment of the degree of flexibility of the concept design and its applicability to the conditions that are found in the intrusive (plutonic) rock environment in the Canadian Shield; and

- a review and comment on the state of the technology associated with the disposal concept as it applies to its readiness to be implemented.

Because no site selection will occur until a disposal concept has been accepted as safe, the Expert Group should not consider any specific sites or any criteria that might be construed as being site-specific beyond what is implicitly included in the case study presented by AECL.

As is the case for the federal Environmental Assessment and Review Panel and the Scientific Review Group, the scope of the international peer review will exclude the energy policies of Canada and the Canadian provinces; the role of nuclear energy within these policies, including the construction, operation and safety of new or existing nuclear power plants; fuel reprocessing as an energy policy; and military applications of nuclear technology. In addition, the scope of the international review will exclude any assessment of socioeconomic or political considerations as well as any issues related to timing and institutional arrangements for implementation of disposal.

It is anticipated that the international peer review will be carried out over a 6-month period and be completed by about March 1995.

Deliverable

A report summarizing the findings from the international peer review will be submitted to Natural Resources Canada. This report will be a public document and will be made available to the Panel as part of the public review of the disposal concept.

Appendix to the Terms of Reference: List Of Documents

Environmental Impact Statement

Environmental Impact Statement on the Concept for Disposal of Canada's Nuclear Fuel Waste- (AECL 1994a)

Primary References

The Disposal of Canada's Nuclear Fuel Waste: Site Screening and Site Evaluation Technology (Davison et al. 1994a)

The Disposal of Canada's Nuclear Fuel Waste: Engineered Barriers Alternatives (Johnson et al. 1994b)

The Disposal of Canada's Nuclear Fuel Waste: Engineering for a Disposal Facility (Simmons and Baumgartner 1994)

The Disposal of Canada's Nuclear Fuel Waste: Preclosure Assessment of a Conceptual System (Grondin et al. 1994)

The Disposal of Canada's Nuclear Fuel Waste: Postclosure Assessment of a Reference System (Goodwin et al. 1994)

The Disposal of Canada's Nuclear Fuel Waste: The Vault Model for Postclosure Assessment (Johnson et al. 1994a)

The Disposal of Canada's Nuclear Fuel Waste: The Geosphere Model for Postclosure Assessment (Davison et al. 1994b)

The Disposal of Canada's Nuclear Fuel Waste: The Biosphere Model, BIOTRAC, for Postclosure Assessment (Davis et al. 1993)

Other Information

- References cited in the aforementioned documents as required.
- Atomic Energy Control Board, R-71, R-72 and R-104.
- Energy, Mines and Resources Canada - Nuclear Waste Disposal Concept and Waste Management Issues Referred for Environmental Review (includes EARP Panel Terms of Reference). News Release dated September 28, 1988.
- Review of other pertinent AECL/OH documents.
- Other information as identified by the reviewers themselves.

Appendix 3

Qualifications of Members of the OECD/NEA Review Group

Per-Eric Ahlström (SKB, Sweden)

Per-Eric Ahlström is a physicist with almost 20 years of experience in the field of radioactive waste management. He obtained his MSc in Engineering Physics from the Royal Institute of Technology in Stockholm in 1956. He has worked in various positions at Vattenfall, the largest Swedish electric power producer, as a reactor physicist and nuclear engineer from 1956 to 1984. In 1976-1978 he was assigned as project manager for the KBS-project. In 1979-1984 he was head of the nuclear reactor safety department at Vattenfall. He joined SKB in 1984 as director of its research and development division. Since 1993 he has been vice president at SKB with responsibility for scientific and technical co-ordination of the SKB programme for final disposal of spent nuclear fuel. Per-Eric Ahlström is a member of the OECD/NEA Radioactive Waste Management Committee.

Timo Äikäs (TVO, Finland)

Timo Äikäs obtained his BSc in Geology at the University of Helsinki in 1974, and his MSc in Engineering Geology at the University of Turku in 1977. He worked for several years with projects for groundwater supply, as well as for underground excavations, both in Finland and abroad. Since 1980 he has worked for Teollisuuden Voima Oy (TVO), initially as a consultant with the project for the final disposal of low- and medium-level radioactive wastes. Since 1986 he has acted as the manager of the site selection research programme for final disposal of spent fuel. He was involved with the OECD/NEA Stripa-Project from 1982-1991. He has been the Chairman of the NEA's Co-ordinating Group on Site Evaluation and Design of Experiments from its inception in 1990 to 1992.

Neil Chapman (Intera Ltd, UK)

Neil Chapman is a geologist with more than 18 years experience in the field of radioactive waste disposal. In 1971 he obtained his BSc in Geology at the University of Durham, England and, in 1974, his PhD in experimental petrology at the University of Edinburgh, Scotland. He worked for 13 years with the British Geological Survey, latterly as manager of the Fluid Processes Research Group. For the last five years he has managed the Geosciences Group in the Environmental Division of Intera Information Technologies Ltd, based in Melton Mowbray, England. He has acted as researcher, consultant and adviser to the national radioactive waste management programmes in more than 10 countries and has been involved in a number of international projects managed by the OECD/NEA, the IAEA and the European Commission. He has published more than eighty papers and four books on the subject of radioactive waste disposal.

Margaret Federline (United States NRC; Observer)

As Deputy Director of the Division of Waste Management at the U.S. Nuclear Regulatory Commission (USNRC), Mrs Federline draws upon over twenty-five years of experience in the fields of environmental assessment, radiation safety, and waste management gained in managerial, policy, and professional scientific positions with private industry and the Federal government. Prior to joining the Federal government in 1979, she managed a commercial analytical chemistry and industrial hygiene laboratory. After serving at the National Institute of Standards and Technology, she joined the USNRC in 1981 where she focused on the development of occupational radiation protection standards. As a senior advisor to the Executive Director and the Chairman of the USNRC, she contributed to the development of regulatory policy for the civilian uses of nuclear materials, including the licensing and operation of nuclear power plants, medical and industrial applications, as well as waste management and decommissioning. In 1991, Mrs Federline was selected for the Senior Executive Service, managing the development of performance assessment methodologies for waste management applications. In her current management position, Mrs Federline directs the USNRC programs for the regulation of low level and high level waste disposal, uranium recovery and decommissioning.

Charles McCombie (Nagra, Switzerland; Group Chairman)

Charles McCombie is a physicist with 25 years of experience in the nuclear field, more than 15 of which were in radioactive waste management. He obtained a BSc at Aberdeen (Scotland) in 1967 and a PhD (solid state physics) from Bristol (England) in 1971. His current positions are Technical Director of Nagra, the Swiss Co-operative for the Disposal of Radioactive Waste and member of the Management Board of GNW, the Co-operative encharged with constructing and operating a L/ILW waste disposal facility in Switzerland. He is a member of the International Radioactive Management Advisory Committee (INWAC) of the IAEA, the Radioactive Waste Management Committee (RWMC) of the OECD/NEA, the Board on Radioactive Waste Management of the U.S. National Academy of Sciences, the Scientific Advisory Board of the German Research Centre for Environmental Studies (GSF), and the Scientific Programme Committee of the Waste Management Programme at the Swiss Paul Scherrer Institute (PSI).

Alexander Nies (BMU, Germany)

Alexander Nies is a mathematician with more than 13 years experience in the field of radioactive waste disposal. He obtained his diploma in pure and applied mathematics in 1981 at the University of Munich followed by three years research in the nuclear fuel cycle at the Technical University of Berlin. He developed a probabilistic version of a performance assessment code for salt repositories during his seven years at the GSF research centre in Braunschweig, latterly as deputy head of the safety assessment division. From 1988 to 1991 he acted as chairman of the OECD/NEA Probabilistic Safety Assessment Group. Since 1991, he has been with the Federal Ministry for the Environment where he is managing supervisor of the Konrad repository project (for radioactive waste with negligible heat generation). He has published some twenty papers on the subject of radioactive waste disposal.

Sören Norrby (SKI, Sweden; Observer)

Sören Norrby is a chemist with more than 20 years experience in the field of radioactive waste management and disposal. He obtained his M.Sc. in Chemistry at the University of Uppsala, Sweden, in 1970. He worked for 5 years at Uppsala University on research projects mainly in the field of chemical radionuclide separation techniques. He then worked for 8 years at the Swedish Radiation Protection Institute (SSI) on radioactive waste management and disposal matters. He joined the Swedish Nuclear Power Inspectorate (SKI) in 1980 and, since 1987, he has been the Director of the Office of Nuclear Waste. He has been engaged in the regulatory review of nuclear waste management and disposal applications for the Swedish nuclear industry (e.g. intermediate storage facility for spent fuel and a repository for low and intermediate level waste). He is now engaged in the review of the Swedish programme on final disposal of spent nuclear fuel. He has served on several governmental committees to review Swedish legislation on nuclear waste. He is a member of the International Radioactive Management Advisory Committee (INWAC) of the IAEA, and a member of the Radioactive Waste Management Committee (RWMC) of the OECD/NEA.

Jean-Pierre Olivier (OECD/NEA; Secretariat)

Jean-Pierre Olivier is a chemist with more than 30 years experience in radiation protection, nuclear safety and radioactive waste management. He obtained his "licence ès Science" at the University of Clermont-Ferrand, France, in 1961, followed by post-graduate courses in nuclear metallurgy at the French National Institute of Nuclear Science and Technology, at Saclay. He joined the Nuclear Energy Agency of the OECD in 1964 and, since the early 70s, he has been at the centre of most of the NEA activities in the field of radioactive waste management, including the setting-up of the Radioactive Waste Management Committee in 1975. During this period, he was successively Deputy Head of the NEA Nuclear Safety Division (1979-1981) and Head of the Radiation Protection and Waste Management Division (since 1981). In this latter capacity, he has organised all the international peer reviews carried out so far by NEA, sometimes in cooperation with the Commission of the European Communities. He has been a member of many national and international expert groups and he is currently a member of the French governmental Commission in charge of the evaluation of the French Radioactive Waste Management Programme.

Claudio Pescatore (OECD/NEA; Secretariat)

Claudio Pescatore is a nuclear-chemical engineer with more than 15 years experience in the field of radioactive waste disposal. He obtained his Laurea in Applied Physics from the University of Bologna in 1975, following which he worked on research projects in rarefied gas dynamics. He then attended the University of Illinois at Urbana-Champaign from which, in 1982, he obtained his PhD with a thesis on modelling of nuclear waste forms leaching. He worked for 10 years at Brookhaven National Laboratory on research and technical assistance projects pertaining to the performance of waste package materials under disposal conditions in various environments, the performance of spent fuel in dry interim storage, and the performance assessment of low- and high-level waste sites. Since 1992 he has been a member of the NEA/OECD in the division of waste management on behalf of which he manages all performance assessment activities. He has acted as a consultant to several agencies and organisations in USA and Europe and has published widely on the subject of nuclear waste disposal.

Budhi Sagar (CNWRA, USA)

Dr. Sagar has B.S. and M.S. degrees in Civil Engineering and a Ph.D degree in Hydrology with over thirty years of professional experience that includes teaching, research, and consulting. His research interests span computational methods, stochastic analyses, and probabilistic system assessments. He is the author of several computer codes dealing with flow, heat transfer, and mass transport in fractured geologic media. He has written or collaborated on over 100 technical papers and reports. In his current position as the Technical Director of the Center for Nuclear Waste Regulatory Analyses (CNWRA), Dr. Sagar's responsibilities are to manage all ongoing technical activities at the CNWRA. He is the primary technical representative with the U.S. Nuclear Regulatory Commission, the sponsor of CNWRA. Dr. Sagar provides overall direction for conducting technical assistance work and research activities of the CNWRA, assures efficient manpower utilisation, controls budgets and schedules, and assures quality of work. He assists the CNWRA President in the conduct of overall administrative and operations activities.

Appendix 4

Statement Concerning Conflicts Of Interest

All of the members of the Review Group have been involved in the field of deep geological disposal of radioactive wastes for the last 10-20 years. In the course of their work, particularly in international projects, they have become familiar with the Canadian programme through frequent professional contacts with staff at AECL and Ontario Hydro and, in some cases, through participation in joint programmes. Much of the background to the Canadian concept has been discussed in international meetings and components of the AECL work have been included in OECD/NEA sponsored projects, such as the Stripa Project, which was completed in 1992 and which involved several members of the Review Group.

These diverse contacts, which have taken place over many years, have placed the Review Group in an excellent position to understand the Canadian concept and to evaluate it efficiently.

A draft version of one of the EIS report series (Goodwin et al., 1994) was reviewed for AECL by staff of Intera Information Technologies (UK) in 1992. This review did not involve Dr N. Chapman in any way. A draft version of the same report was also reviewed for AECL by a team of experts at SKB, Sweden, in 1992. Per-Eric Ahlström did not participate in that review.