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NUCLEAR WASTE MANAGEMENT ORGANIZATION

SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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NWMO BACKGROUND PAPERS
6. TECHNICAL METHODS

6-13C SELECTION OF A SINGLE REPRESENTATIVE SEDIMENTARY ROCK FORMATION FOR THE STORAGE / DISPOSAL OF USED NUCLEAR FUEL

RWE NUKEM Limited

NWMO Background Papers

NWMO has commissioned a series of background papers which present concepts and contextual information about the state of our knowledge on important topics related to the management of radioactive waste. The intent of these background papers is to provide input to defining possible approaches for the long-term management of used nuclear fuel and to contribute to an informed dialogue with the public and other stakeholders. The papers currently available are posted on NWMO's web site. Additional papers may be commissioned.

The topics of the background papers can be classified under the following broad headings:

1. **Guiding Concepts –** describe key concepts which can help guide an informed dialogue with the public and other stakeholders on the topic of radioactive waste management. They include perspectives on risk, security, the precautionary approach, adaptive management, traditional knowledge and sustainable development.
2. **Social and Ethical Dimensions** - provide perspectives on the social and ethical dimensions of radioactive waste management. They include background papers prepared for roundtable discussions.
3. **Health and Safety –** provide information on the status of relevant research, technologies, standards and procedures to reduce radiation and security risk associated with radioactive waste management.
4. **Science and Environment –** provide information on the current status of relevant research on ecosystem processes and environmental management issues. They include descriptions of the current efforts, as well as the status of research into our understanding of the biosphere and geosphere.
5. **Economic Factors** - provide insight into the economic factors and financial requirements for the long-term management of used nuclear fuel.
6. **Technical Methods** - provide general descriptions of the three methods for the long-term management of used nuclear fuel as defined in the NFWA, as well as other possible methods and related system requirements.
7. **Institutions and Governance** - outline the current relevant legal, administrative and institutional requirements that may be applicable to the long-term management of spent nuclear fuel in Canada, including legislation, regulations, guidelines, protocols, directives, policies and procedures of various jurisdictions.

Selection of a Single Representative Sedimentary Rock Formation for the Storage / Disposal of Used Nuclear Fuel

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RWE NUKEM Limited
414 The Quadrant
Darwin House
Birchwood Park
Risley
Warrington
WA3 6AT
Telephone: +44 (0) 1925 866301
Facsimile: +44 (0) 1925 866401

Email info@rwe.nukem.co.uk
www.rwenukem.co.uk

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1 Introduction

In order to further investigate alternatives for the long-term management of used nuclear fuel, a need has been identified to undertake a high-level review of potential changes to the conceptual design and cost estimate for locating a Deep Geologic Repository (DGR) in sedimentary rock, and for locating an underground rock cavern Centralized Extended Storage (CES) facility in sedimentary rock, using the CTECH reports prepared for the JWO as the reference DGR and CES options [1 & 2]. As a basis for this review, both conceptual facilities are assumed to be located at a generic location in southern Ontario, with the characteristics and sequence of the sedimentary rock in that portion of Canada based on published information [3 & 4].

Two options, capable of hosting either long term management facility have been suggested from a review of the sedimentary sequences considered. These are:

- In shales at a depth of 500 m below surface; and
- In limestone at a depth of 750 m below surface.

Both of these rock formations are considered to be technically feasible for hosting an underground facility for used nuclear fuel [4]. This document presents the rationale for the selection of one of the above representative sedimentary rock sequences and depths, for the location of both long term management facilities, that will be applied in the high-level review.

To this aim, the factors affecting the selection of a rock formation and depth for a DGR have been characterized as scientific, experience and practice by others, and constructability. Scientific factors include low hydraulic conductivity and hydraulic gradient, sufficient depth below surface, sufficient thickness, simple geometry in respect of internal homogeneity and lateral continuity, and favourable retardation properties.

As the selection of a rock formation and depth for a CES facility is almost totally dependant on the facilities long term stability and constructability, it has been primarily reviewed on this basis.

2 Scientific Factors

Mazurek [4] concluded that Ordovician shales and limestones occurring beneath southern Ontario provide a highly suitable environment to host a DGR for spent fuel. This conclusion was based on the following factors:

- *The thickness of the Ordovician shales and limestones well exceeds 100 m, a value internationally regarded as a siting preference;*
- *The proposed depth below surface of the long-term facility in the host rock formations well exceeds 200 m, a value internationally regarded as a siting preference;*
- *The degree of vertical and horizontal heterogeneity of geological and hydrogeological attributes in the potential host formations is limited and reasonably well known;*
- *Hydrochemical evidence indicates very long underground residence times of formation waters and no resolvable cross-formational flow at depth over geological periods of time;*
- *A surficial fresh-water flow system is underlain by a stagnant hydrogeological regime. Given the absence of exfiltration areas for deep ground waters, flow does not occur or is very limited. Solute transport is probably dominated by diffusion;*
- *Deep infiltration of surficial waters is unlikely due to the high density of brines occurring in the deep underground and due to the presence of several low-permeability formations, such as shales or evaporites that confine the more permeable units; and*
- *Tunnelling in deeply buried shales and limestones appears to be feasible in spite of high horizontal stresses.*

The following factors emerge from a comparison for the disposal of used nuclear fuel in shales and limestones.

In general terms, the Ordovician shales have lower conductivities than their limestone counterparts. Mazurek [4] demonstrated that for southern Ontario shales and limestones, a recognizable correlation between rock type and conductivity exists with shales and dolomite-free (often argillaceous) limestones having the lowest conductivity, and with dolomites having the highest conductivity. Limestones in southern Ontario are frequently argillaceous and often contain shale interbeds. The limestones in southern Ontario differ from those existing in Europe, where the argillaceous material is generally absent and conductivities are more consistent with those associated with limestone aquifers. This would be one of the major reasons that, in general, disposal of used fuel has focused on shales in Europe rather than limestones.

Golder [3] expressed the opinion that the Ordovician rocks of southern Ontario in which the shales and limestones are hosted, are of very low permeability. The porewater within these rocks is typically brine and movement of porewater is very slow, in the order of millimetres per year, with mass transportation being dominated by chemical diffusion.

An important aspect of siting a DGR in shales is related to the self sealing ability of argillaceous rocks. As noted by Mazurek, self sealing is a naturally occurring process that leads to a reduction of fracture transmissivity. This phenomenon acts as a buffering process by which the hydraulic significance of natural fractures and faults or induced structures is diminished over time. This factor would favour the use of siting a DGR in shales.

It is concluded that either shales or limestones in southern Ontario would provide an acceptable and feasible medium into which a DGR may be constructed. However, shales have the advantage of lower permeability and self sealing attributes.

3 Experience and Practice by Others

There is a significant body of knowledge regarding the use of shales for used fuel disposal arising out of work carried out in Europe. The most significant of these are described by the following:

- Demonstration of the feasibility of disposal in Opalinus Clay in Switzerland by Nagra [5]. An international underground research laboratory has been established in Opalinus Clay at Mont Terri;

- Geoscientific characterization and safety assessment for the use of the Callovo-Oxfordian shales in the eastern Paris basin, France. Shaft sinking for an underground research laboratory at this location is currently underway; and

- *SAFIR 2* progress and safety assessment for Boom Clay by Ondraf / Niras in Belgium, where an underground research laboratory has been established.

The work carried out by the above referenced investigators has demonstrated the suitability of shales for siting of a DGR.

With one exception, limestones are not considered as host formations for radioactive wastes in any of the leading European programmes. In this case, the German Konrad project plans to dispose of low and intermediate level wastes in a disused carbonate-hosted iron ore mine in Jurassic limestone [6]. In the safety case for this project, the geosphere barrier is constituted by overlying, 170-400 m thick Lower Cretaceous shales, while no barrier function is attributed to the limestones that host the repository. The project was licensed by the German regulatory bodies in 2002.

4 Constructability

The Ordovician shales and limestones of southern Ontario have different geotechnical properties that have been described by Golder Associates [3]. The NGI (Norwegian Geotechnical Institute)-Q rating (NGI Tunnel Quality Index) for shales (Queenston and Georgian Bay formations) has been estimated to be 10.75 [equivalent Rock Mass Rating (RMR) of 65], which would be classified as “Good”. The NGI-Q ratings for the limestone (Lindsay formation) is approximately 31.7 (equivalent RMR of 75) which would be classified as “Good”. The limestone has a uniaxial compressive strength of 60 MPa, compared to 40 MPa for the shale. Other investigators determined the uniaxial compressive strength of the shales to be 24 MPa.

The shales are reported to exhibit anisotropic deformational behaviour and generally swell when unconfined. Horizontal stresses can be significantly greater than vertical stresses. Weathering occurs on exposure and support by means of shotcrete would be required in an underground environment.

The design of a DGR constructed in shale would differ from that constructed in limestone. The major differences would potentially be related to construction methods, ground support techniques, size of openings and size of the rock pillars between emplacement rooms.

From a constructability perspective, a DGR could be located in either rock type.

5 CES Location Issues

Unlike the host geology for a DGR, the rock formation in which a CES facility could be sited does not need to provide a long term radiological barrier to the biosphere since this function is provided by the used fuel package, which is monitored and controlled indefinitely. As such, the criteria on which a CES host formation is judged will be different to that for a DGR. Primarily, the main technical criteria on which a geologic formation may be assessed to host a deep CES facility include:

- Security from human intrusion;
- Constructability;

- Long term stability; and
- Cost.

The two Ontario representative rock sequences considered, offer similar levels of security to either inadvertent or malicious intrusion. Likewise, Golders [3] suggest that both sequences are suitable rock types for the construction of a DGR, a conclusion that could also be applied to a CES facility, albeit taking into consideration the possible different size of openings, width of pillars necessary and extent and method for ground support for underground excavations. These latter issues in turn influence the overall cost of the facility. In particular, openings in shales will potentially require greater ground support than would openings of the same size in limestones. However, with the representative limestone sequence at a depth of 750 m compared with the shale sequence at 500 m, the cost of accessing the limestone must be balanced against the need for providing potential additional ground support in the more easily accessible shales. This type of analysis could be carried out in the future as part of an optimization exercise for a CES facility.

Since this facility depth-comparison analysis has not been undertaken at this stage and with no international precedent for the siting of a CES facility deep underground, for the purposes of this review it is proposed to assess a CES facility located in the same rock sequence as that chosen for a DGR. Because of the similarity in a number of areas for the two facilities, this decision will allow a greater degree of information sharing across the two projects, thereby simplifying any comparison between the two reviews.

6 Conclusions

Based on international precedence and the self sealing properties offered by Ordovician shales, it is proposed to assess a DGR located in this representative rock sequence at the reference depth of 500 m below the surface.

Because of the similarity in a number of areas in the DGR and CES facilities, it is proposed to assess a CES facility located in the same rock sequence as that chosen for a DGR, that is, the Ordovician shales. This selection will provide a greater difference between the reference underground rock cavern CES facility at 50 m that required minimal rock support [2], and a deeper CES facility at 500 m which would require additional rock support. This selection will also allow a greater degree of information sharing between the CES and the DGR facilities, thereby simplifying any comparison between the two reviews.

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