NUCLEAR WASTE MANAGEMENT ORGANIZATION

SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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NWMO BACKGROUND PAPERS
6. TECHNICAL METHODS

6-13A DEEP GEOLOGIC REPOSITORY IN SEDIMENTARY ROCK: HIGH-LEVEL REVIEW

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.

Deep Geologic Repository in Sedimentary Rock

High-Level Review

November 2004

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Notice to the Reader

This High-Level Review has been prepared by RWE NUKEM Limited (the “Consultant”), to present changes to the ‘in-room’ conceptual design for a deep geologic repository (DGR) to allow horizontal emplacement of used nuclear fuel within sedimentary rock. The scope is more fully described in the body of the document. The Consultant has used its professional judgement and exercised due care, pursuant to a purchase order dated September 2004 (the “Agreement”) with the Nuclear Waste Management Organisation (the “Client”), and has followed generally accepted methodology and procedures in carrying out this work. It is therefore the Consultant’s professional opinion that the assessment represents a viable solution consistent with the intended level of accuracy appropriate to a conceptual design.

This High-Level Review is meant to be read as a whole, and sections or parts thereof should not be read or relied upon out of context. In addition, the High-Level Review contains assumptions, data, and information from a number of sources and, unless expressly stated otherwise in the document, the Consultant did not verify those items independently. Notwithstanding this qualification, the Consultant is satisfied that the High-Level Review was compiled in accordance with generally accepted practices in a professional manner.

This High-Level Review is written solely for the benefit of the Client, for the purpose stated in the Agreement, and the Consultant’s liabilities are limited to those set out in the Agreement.

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1 Introduction

Early work undertaken by CTECH (a joint venture between RWE NUKEM and Canatom) on behalf of the Joint Waste Owners (JWO), provided an updated Canadian Deep Geologic Repository (DGR) design and cost estimate based on the emplacement of used fuel containers (UFCs) within extended horizontal tunnels excavated in a granite pluton on the Canadian Shield, 1000 m below ground level – termed 'in-room' emplacement [1 & 2].

As part of the programme for the long-term management of used nuclear fuel, the NWMO has identified a need to further examine different geologic formations that may be technically suitable alternative (non-crystalline rock) host geologies for a deep repository for used nuclear fuel. To address this need, the NWMO has requested a high-level review of the potential changes to the 'in-room' DGR design and its cost estimate, as a consequence of locating a DGR in sedimentary rock that utilises the proposed Nagra concept for used fuel disposal in a deep repository [3]. The Nagra design for horizontal emplacement of UFCs in sedimentary rock was selected since the concept has been developed specifically for sedimentary rock formations. The design of the facility assumes the emplacement of UFCs within 2.5 m diameter horizontal openings that are subsequently backfilled with bentonite pellets. The proposed Nagra design for a repository in sedimentary rock is also similar to the alternate horizontal borehole designs for crystalline rock that are currently under study in Sweden, Finland and Canada.

For the purposes of the review, the Nagra type DGR is assumed to be located at a generic location in southern Ontario due to the substantial information available on the characteristics and sequence of sedimentary rock in that portion of Canada (Golder Associates [4] & Mazurek [5]). 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 [6].

To address the NWMO need to evaluate the technical feasibility of Canada hosting a DGR in geomedia other than crystalline rock, this document presents the design and operating features included in the 'in-room' DGR arrangement that require modification to accommodate the introduction of a Nagra type DGR located in sedimentary rock at a depth of 500 m. At this stage of concept development, these features are only briefly discussed, as their inclusion is mainly to serve as an indication of the factors that should form the basis of a possible Nagra DGR design in sedimentary rock, should it be pursued. The document also provides a scoping estimate for implementing these modifications and their effect on the current 'in-room' DGR overall cost estimate [1].

2 DGR Underground Design in Sedimentary Rock

This section of the report provides a brief outline of the proposed DGR underground design, based on its location in sedimentary rock at a depth of 500 m. Other areas of the DGR facility not covered here are broadly similar to the 'in-room' DGR concept [1]. The design presented is considered to be appropriate for a hypothetical site with geologic and hydrogeologic conditions similar to those of the middle and upper Ordovician Shales in southern Ontario, also referred as the Queenston and Georgian Bay formations [4].

CANDU used fuel will be placed in used fuel containers (UFCs), identical to that proposed in [1]. The proposed UFC has a diameter of 1168 mm, a length of 3867 mm and will accommodate 324 fuel bundles. The UFC design consists of a 25 mm thick copper outer corrosion-barrier and an inner, carbon steel load-bearing component. The material selected for construction of the outer corrosion barrier is an oxygen-free, phosphorus-doped (OFP) copper, proposed for the construction of UFCs in the Swedish nuclear fuel waste management programme. The inner load-bearing component is in the form of a carbon steel vessel capable of withstanding all external pressure loads expected in a hypothetical geologic repository. It has been designed such that it will not be subjected to yielding or creep failure during the UFC design lifetime of 100,000 years.

Adopting the Nagra design approach [3], the UFC assemblies are placed in horizontal emplacement tunnels constructed from the DGR access roadways. The profile of the UFC emplacement tunnel is assumed to be similar to the circular cross section used in the Nagra concept. To minimise the tangential stress concentrations around the emplacement tunnels, the tunnels need to be oriented such that the tunnel axis is parallel to the maximum principal stress direction within the host rock. Based on the Nagra design the diameter of the emplacement tunnels is set at 2.5 m.

The Nagra DGR arrangement comprises a system of access tunnels and horizontal emplacement tunnels arranged into four distinct sections (Figure 1). Each section consists of 25 emplacement tunnels spaced at 40 m centre to centre. Each emplacement tunnel accommodates 112 UFC assemblies placed horizontally on bentonite pedestals with a longitudinal UFC centre to centre spacing of 6.9 m. The remainder of the emplacement tunnel is filled with bentonite that is introduced in pellet form. The proposed DGR design has a maximum capacity for 11,200 UFCs or 3,628,800 intact fuel bundles. Assuming an ideal site, with no faults or stress anomalies, the minimum overall dimensions of the UFC emplacement area are approximately 1.87 km by 2.17 km, which are significantly greater than the proposed overall dimensions for the 'in-room' concept designed to be located within crystalline rock of the Canadian Shield. These dimensions do not account for any adaptations that may be required at an actual site because of local conditions e.g. specific rock structures, faults and stress anomalies.

The DGR layout illustrated in Figure 1 assumes that the emplacement tunnels are constructed by methods that allow the general configuration of the DGR proposed in the 'in-room' option to be maintained. As described in section 4.10, a review of emplacement tunnel construction methods will be carried out that may result in the layout being amended. However, the spatial location of the UFCs should not change significantly.

3 Design Specification

A complete design specification for the UFC assembly is given in [7]. For the purposes of a DGR design to be located at a depth of 500 m, design information from the Nagra concept [3] has been adopted with the following clarifications:

i. geological data for the chosen generic location has been taken from literature available for southern Ontario [4 & 5];

ii. following emplacement, the surface temperature of a UFC shall not exceed 125°C. There should be a minimum of 0.25 m of buffer material with a temperature less than 100°C that will avoid undesirable phase transformation of the bentonite based buffer. Exceeding this limit may have an adverse effect on the swelling and self sealing properties of the buffer material [8, 9 and 10];

iii. the design of the emplacement tunnels will be based on the Nagra tunnel concept with a circular cross-section of nominal diameter 2.5 m; and

iv. the UFCs will be placed on a pedestal of highly compacted bentonite (HCB) blocks with the void around the UFCs being backfilled with highly-compacted bentonite pellets.

The major design parameters for a Nagra type DGR at depth within sedimentary rock, together with their sources, are listed in Table 2.

4 Anticipated Design Changes

The design of a Canadian ‘Nagra type’ DGR located in sedimentary rock would potentially differ from the design proposed for the ‘in-room’ DGR located in crystalline rock, in particular in respect to the surface infrastructure, access shafts, underground access tunnels and emplacement rooms [1]. In addition, the modified emplacement concept may require changes in the handling of the UFCs that will result in alterations to the operation and resourcing of various activities. All these changes have the potential to affect the overall cost of implementing a DGR located in sedimentary rock.

The following sub-sections set out the areas of the DGR facility that are affected by a change from ‘in-room’ emplacement to horizontal tunnel emplacement of UFCs in sedimentary rock. Each sub-section describes the anticipated revisions that will be required and briefly discusses the issues that need to be considered when developing a viable DGR design solution in sedimentary rock.

4.1 SEALING MATERIALS COMPACTION PLANT

- Amend the existing bentonite jacket production facility to manufacture UFC support pedestal bentonite blocks:

The 'in-room' concept included for the manufacture of bentonite blocks, to facilitate the provision of bentonite jackets to be assembled around UFCs prior to their emplacement in the repository. Although this is not a requirement for the current concept, there is a requirement to provide a support pedestal constructed from pre-compacted bentonite blocks for each UFC emplaced within the DGR. Therefore, at this stage it is assumed that the pedestal block production area within the SMCP is likely to be similar to that for the 'in-room' design production area for bentonite jacket blocks.

- Delete emplacement room dense backfill and buffer material block production and add capability to supply bentonite pellets for backfilling emplacement tunnels:

The 'in-room' DGR arrangement emplacement rooms are backfilled using a combination of pre-compacted buffer blocks (50% bentonite and 50% sand) and dense backfill blocks (70% crushed granite, 25% glacial clay and 5% bentonite), together with pneumatically delivered light backfill (50% crushed granite and 50% bentonite) used to fill the peripheral gap between the blockwork structure and the room perimeter. There will be a requirement within the current concept to backfill the remaining voids in the emplacement tunnels with bentonite pellets and it is anticipated that these will be transferred directly from the SMCP to the underground facilities. This may be in the form of pneumatic transfer or by utilising wagons that would be transferred via the waste shaft.

Backfilling of all access tunnels is assumed to be undertaken immediately prior to closure of the facility and therefore no access tunnel backfilling activities will be required during the operational phase. The exact method of backfilling these areas will be covered under the decommissioning activities.

- Review SMCP manning levels and shift patterns:

The number of block compaction machines within the facility will be greatly reduced due to the deletion of the requirement for dense backfill and buffer material blocks. This will have a direct effect on the manning levels and it is anticipated that single shift working may be sufficient to achieve the required rate of bentonite block production for the UFC pedestals. This assumption will need to be reviewed.

- Review export routes due to reduced capacity and no need to deliver UFC jacket blocks to Used Fuel Packaging Plant (UFPP):

The current 'in-room' DGR SMCP includes an export route for jacket blocks to the UFPP as well a rail link to the waste shaft to cater for the transfer of pre-compacted sealing material blocks required for the emplacement rooms. The potential elimination of a number of these items may result in a reduction in the number of rail sidings currently included. In addition, the reduction in the type and numbers of sealing material compaction machines required for the ‘in-room’ case may necessitate the SMCP plant layout and building size to be reviewed.

4.2 USED FUEL PACKAGING PLANT

- Delete need for Jacketing and Despatch Cells and replace with UFC export cells:

As described in section 4.1, UFCs emplaced within the tunnels do not require encasing in bentonite jackets. Therefore, the UFPP UFC jacketing and dispatch cells are no longer required. However, these shielded cells will need to be replaced by UFC export stations capable of allowing UFCs to be loaded in to a shielded UFC transport cask, to permit the UFC to be delivered to an underground emplacement tunnel. In designing these stations consideration needs to be given to the method of loading the UFC into the cask and delivery of the cask to the waste shaft headframe. To allow such a review to be undertaken, the operating requirements and design of the cask needs to be established. Review of the UFC transport cask is more fully covered in section 4.3.

- Amend loading procedure for the UFC transport cask and identify changes to plant layout:

The ‘in-room’ DGR UFPP UFC jacketing and dispatch cells may be utilised for loading the completed UFC into a cask for transfer underground. Based on the premise that UFCs will be radiologically shielded from plant operators at all times a review of casking arrangements for the completed assembly will be necessary. To allow such a review to be undertaken, the overall operating requirements of the cask and hence its design needs to be established. A review of the ‘in-room’ UFC transport cask design is covered in section 4.3.

4.3 UFC CASK HANDLING

- Review UFC transport cask design and handling techniques in conjunction with the casks operating parameters:

Based on the premise that UFCs will be transported from the UFPP to the emplacement tunnel fully shielded, as in the case for the ‘in-room’ DGR arrangement, a number of issues need to be established to enable a revised UFC transport cask to be specified. Consideration needs to be given to whether the UFC transport cask is to be used to emplace the UFC directly into a prepared emplacement tunnel, as well as being designed to transfer the UFC underground. As alternatives, the UFC may be transferred from the transport cask (probably underground) to a purpose designed mobile UFC deposition machine, the purpose of which would be to place the UFC in to a prepared tunnel, or alternatively, a combination of both these solutions. Resolution of these issues will provide a guide to establishing the method of loading a UFC in to a transport cask in the UFPP, and its preferred orientation during loading and transport underground.

- Review resources required for revised cask handling systems:

The handling of the revised UFC transport cask may lead to modified procedures and operating times from those established for the 'in-room' arrangement. The resources required to undertake these revised operations need to be established.

4.4 ROCK DISPOSAL

- Review rock disposal arrangements to be applicable for the different properties of excavated rock:

Rock disposal and rock dump design needs to be reviewed in respect of assumed geotechnical and geochemical characteristics of the excavated sedimentary rock that is expected to contain salt. The environmental impact arising from surface disposal should be assessed, including the implementation of controls and potential treatment in respect of run-off from precipitation.

Waste rock from shaft or underground development will probably not form a suitable material for aggregate or other construction purposes, and other sources will need to be assumed.

Although other facilities should be reviewed, only minor differences to a small number of the support facilities are envisaged.

4.5 WASTE SHAFT

- Review revised payload, shaft diameter and cask handling:

The function of the 'in-room' DGR waste shaft is to transfer a UFC transport cask underground, horizontally mounted on a rail car with a jacketed UFC payload. The total weight of this payload was 86.5 tonnes. The potential to reduce the dimensions of the current cask arrangement, due to the elimination of the UFC jacket, should ensure that a revised cask design does not compromise the original waste shaft hoisting proposals.

A further function of the 'in-room' DGR waste shaft was to transfer rail cars underground, loaded with emplacement room pre-compacted sealing material blocks. These loads, being a fraction of the UFC transport cask weight, did not impinge upon the hoisting limits. However, they together with the horizontally orientated cask rail car, set the overall waste shaft diameter. Although a revised transport cask design may potentially offer the use of a smaller shaft diameter, bentonite blocks will continue to be transported underground via the waste shaft. Therefore, because these blocks will be transported either on rail mounted or tyred vehicles of similar size to those used previously, the diameter of the 'in-room' waste shaft should remain essentially unaltered.

Although the rate of delivery of UFCs via the waste shaft is the same as required for the 'in-room' DGR arrangement, the usage of the shaft will require reviewing after taking in to consideration the chosen method for the transfer of bentonite pellets to backfill the emplacement tunnels.

- Waste shaft construction techniques:

The construction of the waste shaft may involve different techniques as it will have to be constructed through different rock types compared to a granite pluton assumed in the ‘in-room’ option [1]. These rock types are anticipated to include the potentially water-bearing Devonian and Silurian age dolostones, which are likely to require the application of cement or chemical grouting techniques, or alternatively freezing techniques, to control water ingress. Construction techniques used for shafts previously excavated through these formations need to be reviewed. The waste shaft will not be as deep as that for the ‘in-room’ concept (500 m rather than 1000 m) and it is envisaged it will be concrete lined as development advances.

4.6 SERVICE SHAFT

- Review usage in line with revised initial construction requirements and during emplacement operations:

The volumes of excavated rock to be transferred via the service shaft will be less than for the ‘in-room’ design based on the smaller dimensions of the emplacement tunnels compared to the emplacement rooms. This may affect manning levels required depending on the number of shifts that the service shaft is required to operate each day.

- Service shaft construction techniques:

The method of construction for the service shaft will need to address the same issues as those identified for the waste shaft.

4.7 MAINTENANCE COMPLEX EXHAUST SHAFT

- Construction techniques:

The method of construction for the maintenance complex exhaust shaft will need to address the same issues as those identified for the waste shaft.

4.8 UPCAST VENTILATION SHAFT

- Construction techniques:

The method of construction for the upcast ventilation shaft will need to address the same issues as those identified for the waste shaft.

4.9 DGR UNDERGROUND LAYOUT

- Amend layout of access and emplacement tunnels taking into consideration construction techniques, delivery logistics and underground ventilation requirements:

UFC and emplacement tunnel spacing will differ from that specified for the 'in-room' DGR due to the different emplacement method, thermal properties of the host geology and ambient temperature at the depth considered. In the absence of specific thermal analysis, proposed UFC spacing is based on information drawn from the Nagra concept [3] resulting in the layout described below. It should be noted that the thermo-mechanical analyses that have been undertaken for the 'in-room' DGR would need to be repeated for a DGR in sedimentary rock to ensure that the design requirements specified in Section 3 are satisfied. This may involve a near-field 3D thermo-mechanical analysis to give an accurate prediction of the UFC and backfill temperatures together with the rock stresses that may be attained in the vicinity of the emplacement tunnels. These calculations may be supplemented by carrying out a 3D far-field thermo-mechanical analysis to predict the thermal and stress conditions in the sedimentary rock formation around the DGR.

The arrangement of the 'in-room' DGR access tunnels and emplacement rooms will need to be modified to cater for horizontal tunnel emplacement. The layout will partially be a function of the method used to construct the emplacement tunnels and in this respect will need to satisfy the following requirements:

i. size of the tunnelling equipment proposed to be used and the space required for that equipment to operate;

ii. layout configuration resulting from use of a particular construction method may be limited by flexibility or limitations of machinery in use; and

iii. choice of track or rubber-tyred vehicle access for tunnel construction equipment and emplacement machine.

The proposed DGR arrangement for horizontal tunnel emplacement of spent nuclear fuel is arranged into four distinct sections (Figure 1). Each section consists of 25 emplacement tunnels spaced at 40 m centre to centre. Each emplacement tunnel accommodates 112 UFC assemblies placed horizontally in the tunnel on a bentonite pedestal with a longitudinal UFC centre to centre spacing of 6.9 m. The remainder of the emplacement tunnel is filled with bentonite which is introduced in pellet form. The proposed DGR design has a maximum capacity of 11,200 UFCs or 3,628,800 intact fuel bundles. Assuming an ideal site, with no faults or stress anomalies, the minimum overall dimensions of the UFC emplacement area are approximately 1.87 km by 2.17 km, which are significantly larger than proposed for the 'in-room' concept considered previously. These dimensions do not account for any adaptations that may be required at an actual site because of local conditions e.g. specific rock structures, faults and stress anomalies.

The DGR layout illustrated in Figure 1, assumes that the emplacement tunnels are constructed by methods that allow the general configuration of the DGR proposed in the 'in-room' option to be maintained. As described below, a review of emplacement tunnel construction methods will need to be carried out and may result in the layout being amended. However, the spatial location of the UFCs should not change significantly.

- Review access tunnel sizes to accommodate different construction and emplacement methods and to ensure rock stability in different media:

The DGR access tunnel dimensions depend on two factors:

i. function and purpose of tunnel; and

ii. methodology of construction.

As one of the primary functions of the access tunnels is to permit transfer of the UFC transport cask from the Waste Shaft to the emplacement tunnels, the size of the UFC transport cask and its orientation when transferred underground to the emplacement tunnel will be critical. The dimensions of the sealing material transport vehicles including load are also important factors. These issues need to be reviewed for the revised configuration taking into account the method of transferring the UFC assembly from the cask to the emplacement tunnels. Access tunnel size requirements will also be a function of the equipment required for efficient development and ventilation of the tunnel during construction.

The access tunnels could be excavated by a number of means that may be similar to those for emplacement tunnels described in section 4.10. As the access tunnels will remain open for many years, it will be necessary, as a minimum, to shotcrete the shales to provide geotechnical stability over time. Alternatively, concrete lining the access tunnels may be considered to provide the required durability.

4.10 EMPLACEMENT TUNNEL

- Determine construction methods and scheduling requirements for emplacement tunnels to maintain existing operational timescales and ensure tunnels are available as required for emplacement:

The construction of 2.5 m diameter tunnels in shale compared to the emplacement rooms used for 'in-room' emplacement of UFCs will necessitate different construction methods. Alternatives include drill and blast methods, tunnel boring using a tunnel boring machine (TBM) and continuous miners designed for use in sedimentary rocks, such as coal, salt and potash mines. The TBM option would necessitate a significantly different DGR layout than that currently illustrated by Figure 1, but could be accomplished by orientating the emplacement tunnels at an oblique angle to the access tunnels to allow the TBM to successfully negotiate the curve created by the transition from the access tunnel to the emplacement tunnel.

The method of spoil removal, the need for auxiliary ventilation and the durations and resources required also need to be considered. Except for drill and blast methods, the conventional means of disposing of spoil from continuous excavation methods would be by means of a conveyor or rail cars running on track. Drill and blast methods frequently utilise diesel equipment for spoil removal, but given the length of the emplacement tunnel a conveyor option would merit investigation. Use of conveyors would affect the layout and arrangements at the interface of the emplacement tunnel and access tunnel. Assuming conveyors were to be used within the emplacement tunnel, a review of spoil transportation options to the shaft via the access tunnels would be required. Options would include continuation of the conveyor system or transfer to a rubber-tyred vehicle for transport from the emplacement tunnel to the shaft.

Ventilation of the emplacement tunnel will need to be reviewed. The use of diesel equipment requiring large volumes of ventilating air should be avoided.

Nagra assumed that during excavation, the emplacement tunnels would be supported by rock bolts and mesh. Construction and emplacement would be scheduled so that the emplacement tunnels would only remain open for up to one to two years, as beyond this period there would be a likelihood of the need for shotcrete support to maintain a stable environment.

The selection of the construction method will affect the shape of the emplacement tunnel. The use of a TBM will result in a circular tunnel, as could a drill and blast approach. Other excavation methods, such as use of continuous mining, are more likely to result in an ellipsoid or rectangular shaped tunnel. Stability of the emplacement tunnel at a depth of 500 m in the anticipated stress regime will require investigation, particularly given the anisotropic stress regime.

- Review timing of emplacement tunnel construction:

The 'in-room' concept provided for the excavation of rooms on a campaign basis after construction of the access tunnels and a portion of the required emplacement room panels. The campaign approach was an effective means of reducing costs and could be considered for the current concept. However, the excavation schedule will need to take into account the premise adopted by Nagra that the emplacement tunnels should not remain open for more than two years. Assessment of the schedule would allow an estimation of the number of crews and fleets of excavation equipment required, in addition to permitting a review of the benefits of carrying out emplacement tunnel excavation on a campaign or continuous basis.

4.11 EMPLACEMENT METHOD

- The method of emplacing UFCs will be different from that proposed for the 'in-room' DGR. Therefore the emplacement method will need to be reviewed and amended to accommodate CANDU UFCs, taking into account the approach adopted by Nagra:

The chosen method for emplacing UFC assemblies within 2.5 m diameter horizontal tunnels up to 800m long needs to be reviewed to ensure the process can be undertaken remotely in a reliable way and allow safe recovery in case of malfunction. Nagra have established a design concept to allow emplacement of containers [3] based on a rail mounted transfer system to undertake this task. However, to ensure such a system, or modification of such a system, is capable of fulfilling this function handling CANDU UFCs, a number of issues need to be addressed, including:

i. the interface between emplacement equipment and emplacement tunnel – gamma gate or equivalent;

ii. the ability to locate and interface the emplacement equipment at the end of the emplacement tunnel and to introduce and remove the equipment in a repeatable manner;

iii. the ability of the proposed system to repeatedly transfer UFC assemblies along a tunnel and ensure they are placed in the required location;

iv. potential jamming of the UFC or emplacement equipment in the emplacement tunnel arising from rock fragments or rock pieces dislodging from the tunnel periphery; and

v. the ability to recover from fault conditions with the emplacement equipment.

4.12 EMPLACEMENT TUNNEL BACKFILLING

- Establish suitable method for placing UFC pedestal blocks and for the introduction of pelleted bentonite backfill:

The Nagra design assumes emplacement tunnel pedestal blocks are placed simultaneously with UFCs, utilising a single transfer device. To establish the most appropriate solution for a Canadian DGR arrangement, the Nagra emplacement approach together with other potential methods need to be considered. In undertaking this task all the issues that were identified which needed to be addressed to establish a viable UFC emplacement method are also applicable when considering the placement of the UFC bentonite pedestals.

The Nagra design assumes that pelleted bentonite is transported to the UFC emplacement position using a purpose designed backfill wagon and placed with the assistance of spiral conveyors, prior to the introduction of subsequent UFCs. A review of this approach compared to possible alternatives needs to be undertaken.

- Amend sealing material volumes required to backfill emplacement tunnels.

An assessment of the overall volumes of bentonite required to backfill the emplacement tunnels (including tunnel seals) will be necessary. It is anticipated that although the overall volume of material to be placed will be greatly reduced from the ‘in-room’ case, the actual quantity of bentonite may be similar. This being due to the fact that the ‘in-room’ concept utilises buffer and dense backfill materials to backfill rooms following UFC emplacement that incorporate a significant proportion of other materials, such as granite and glacial lake clay, in addition to bentonite.

4.13 EMPLACEMENT TUNNEL SEALING

- Review in line with smaller diameter openings and Nagra proposed approach:

To be consistent with the Nagra approach, the emplacement tunnels will be provided with a bentonite seal with a nominal length of 20 m. It is envisaged that this will be installed in a similar manner to the bentonite pellets within the emplacement tunnels.

Access tunnels will not be filled until the decommissioning phase when it is assumed that the same technique as that proposed for the 'in-room' design will be adopted. In this arrangement access tunnel will be sealed using two types of backfill material, namely:

i. lower dense backfill, consisting of 70% crushed granite, 25% glacial lake clay and 5% bentonite; and

ii. upper light backfill, comprising 50% crushed granite and 50% bentonite.

The lower dense backfill will be mechanically emplaced and compacted to a pre-determined depth, while the light backfill will be placed pneumatically because of the limited head room available.

However, alternative methods of backfilling access tunnels may be considered, such as placing a lower layer of pre-compacted buffer and dense backfill blocks prior to pneumatically placing clay based material to fill resultant voids, or possibly the Nagra method of backfilling access tunnels using a mixture of 70% silica sand and 30% bentonite.

4.14 EMPLACEMENT LOGISTICS

- Amend emplacement schedule and resources based on revised emplacement method and tunnel backfilling and sealing:

Issues to be considered when addressing the schedule for UFC emplacement in tunnels include:

i. the order in which emplacement tunnel construction, emplacement and sealing operations are conducted;

ii. identification of individual task operating times and their influence on the number of emplacement tunnels to be worked on concurrently;

iii. the length of time tunnels may be left without backfill; and

iv. traffic management and routing options.

4.15 UFC RETRIEVAL

- Briefly review alternative retrieval options consistent with revised emplacement concept:

The 'in-room' DGR design [1] reviewed the methods for releasing an emplaced UFC from saturated bentonite buffer material, examined by SKB [11]. This review showed that the use of low pressure hydrodynamic methods provided the best results. This method entailed flushing the bentonite repeatedly with saline water (4 – 6 percent salt) to form slurry capable of being pumped to a dewatering facility comprising either a filter press or centrifuge. The SKB future development programme includes the intention to demonstrate the release of a UFC encased in water-saturated bentonite located within a vertical borehole using such a low pressure hydrodynamic method.

To fulfil the requirements of the Nagra horizontal tunnel DGR concept, as with the 'in-room' case, a feasible retrieval approach needs to be demonstrated. However, similar to the 'in-room' case it is proposed that the cost of such retrieval is not included in the overall cost estimate for the implementation of the DGR. As much of the retrieval technology is still in the early stages of development, irrespective of the concept, it is assumed that there may be several retrieval methods that may be considered viable at this stage. The different options considered for the 'in-room' and Nagra concepts should be reviewed before any specific solution is adopted.

4.16 DECOMMISSIONING

- Amend sealing material volumes required to backfill access tunnels and shafts, taking into account the method of backfilling:

Based on the findings from previous sections, shaft and access tunnel cross sections and possible lengths may change from those proposed for the 'in-room' DGR design. Should this be the case, the change in volume of the underground openings require assessing to establish any alteration in the resources required to seal the repository upon final closure of the DGR. Although at this stage changes may be expected, it is not envisaged their impact will be significant on the overall costing of the project.

  - Consider impact of grouted rock surrounding the shafts if cement or chemical grouting techniques assumed to be used:

Methods to control water inflows from potentially water bearing strata will likely need to be adopted when constructing the shafts through the Devonian dolostones that lie above the Ordovician shales. The use of freezing techniques would negate the need to introduce chemicals or cement grout into the rock fabric, whereas any other methods are reliant on this taking place. The impact of these construction techniques need to be addressed.

  - Consider removal of access tunnel and shaft lining, if used, prior to backfilling and sealing:

In the “in-room” DGR concept, where the entire shaft is constructed in a granite pluton, it has been assumed that all the shaft concrete lining would be removed. In the Nagra option, the approach of removing the entire lining from surface to the shaft bottom versus only removing the lining within the Ordovician shales will be assessed. Upon review, it may be determined that removal of the lining within the shales where the DGR is located would provide a sufficient seal as a result of the self-sealing ability of the shales. Assuming this to be the case, removal of the lining above the shales would serve no purpose.

- Review decommissioning volumes for surface facility buildings.

Changes to the SMCP (Section 4.1) and the UFPP (Section 4.2), and any additional surface facilities, will require to be assessed to determine whether they impinge on the resources allocated for the decommissioning of similar facilities proposed for the ‘in-room’ DGR design. As in the case of the underground openings, it is not envisaged these changes will have a significant effect on the overall outturn.

5 Cost Implications

A scoping cost estimate has been prepared for implementing a Nagra type horizontal tunnel DGR in sedimentary rock 500 m below ground level. This was achieved by compiling a scoping estimate based on the ‘in-room’ DGR activities that were directly affected by the change in emplacement method and location of the DGR. For the purposes of this scoping estimate, those activities that were identified during the review of the ‘in-room’ work breakdown structure (WBS) to be indirectly affected by the change in emplacement method (second order effects), were not included. Furthermore, activities relating to the design or the production of specifications for directly related plant or equipment to accommodate the changes were also not included within the scoping estimate, as these activities would be required irrespective of the configuration of the design.

In preparing this scoping estimate the original ‘in-room’ DGR activity costs were adjusted by applying the most appropriate scaling method. These included techniques such as, proportioning cost to the length of tunnels prepared, re-estimating labour resources against the revised volumes of backfill required and component additions and removals from individual estimates. A description of the proportioning factors applied to each of the activities addressed and a description of the background behind their derivation is given in Table 1. In the case of emplacement tunnel construction, a revised estimate was prepared based on preliminary information provided by Sandvik covering construction advance rates and labour requirements. Table 1 lists those activities identified from the ‘in-room’ DGR WBS that have been re-estimated and gives both the ’in-room’ DGR and the Nagra horizontal tunnel in sedimentary rock DGR estimated costs.

Based on the estimating method described, the introduction of the DGR in sedimentary rock using the Nagra concept, in place of ‘in-room’ emplacement will result in an approximate decrease in cost of $675M over the cost of implementing an ‘in-room’ DGR design. Applying this decrease to the cost of an ‘in-room’ DGR gives an approximate total cost of $12,000M for the implementation of a DGR design in sedimentary rock 500 m below ground level.

6 Conclusions

For the arrangements considered, the introduction of horizontal tunnel emplacement of UFCs within a DGR located in sedimentary rock, in place of ‘in-room’ emplacement of UFCs in crystalline rock, requires the construction of 100 emplacement tunnels instead of the 104 emplacement rooms, within a significantly larger DGR footprint. The amount of rock to be excavated for the emplacement tunnels would be substantially less than for emplacement rooms in the ‘in-room’ DGR design and consequently the volume of sealing materials required is also greatly reduced.

Other significant areas of the DGR facility that are affected by the change in emplacement concept include the construction and operation of the SMCP, due to the reduced volumes of sealing materials required in the operations phase. In addition, ancillary emplacement operations are simplified, as the need for installing a large number of pre-compacted sealing material blocks around emplaced UFC assemblies is reduced to providing a bentonite pedestal beneath each UFC. However, the introduction of backfill in the form of bentonite pellets is an additional feature.

A further difference in the Nagra horizontal tunnel DGR design is the need to remotely transfer and locate UFC assemblies at distances up to 800m, with restricted access between the assemblies and the tunnel perimeter. In addition, ensuring the reliability and ability to recover from perceived fault conditions during UFC emplacement operations may prove onerous.

The cost estimate for implementing a horizontal tunnel DGR in sedimentary rock 500 m below ground level, based on using the Nagra concept, is approximately $12,000M; $675M less than the reference cost estimate for implementing an ’in-room’ DGR in crystalline rock [2].

Table 1 Scoping Cost Estimate for a DGR Design in Sedimentary Rock

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
1	550 20 25	SEALING MATERIALS ENGINEERING	Scope changed as there are no buffer or dense backfill blocks required for the operational phase and no requirement to provide UFC bentonite jacket blocks. However, bentonite pellets are required for backfilling the emplacement tunnels, as well as bentonite blocks for the UFC pedestal. Small reduction allowed for reduced number of block types to produce.	32,607	-3	31,629
2	550 20 30	EMPLACEMENT SYSTEMS ENGINEERING	Although the equipment will be substantially different, the level of complexity is likely to be similar. Therefore, similar cost assumed.	49,906	0	49,906
3	550 20 35	RETRIEVAL SYSTEMS ENGINEERING	Although the equipment will be substantially different, the level of complexity is likely to be similar. Therefore, similar cost assumed.	26,226	0	26,226
4	550 40 5 40 20 40	SERVICE/PRODUCTION SHAFT	Construction techniques and quantities will change and the following items have been reviewed to ascertain a revised cost: Shaft depth, collar costs, headframe costs, sinking plant costs, hoists, ropes and conveyances costs and shaft grouting.	52,058	-21	40,962
5	550 40 5 40 20 41	MAINTENANCE COMPLEX EXHAUST SHAFT	Construction techniques and quantities will change and the following items have been reviewed to ascertain a revised cost:	18,385	-27	13,337

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
			Shaft depth, collar costs, headframe costs, sinking plant costs, hoists, ropes and conveyances costs and shaft grouting.			
6	550 40 5 40 20 50	TUNNEL AND SERVICE AREA EXCAVATION	Tunnel construction to be by ABM30 continuous miner. Costs based on information provided by supplier (Sandvik). Tunnel support to be shotcrete, although pre-formed concrete lining should be considered in the future.	47,544	-39	28,871
7	550 40 20 10 40	UFPP EQUIPMENT DESIGN SUPPLY & INSTALLATION (AREA 3)	UFC jacketing machines will not be required. UFC transfer casks may vary in design, but at this stage it is assumed they will stay the same. Removal of jacketing equipment reduces overall cost by 4%.	128,278	-4	123,147
8	550 40 20 20	SEALING MATERIALS COMPACTION PLANT	Original building sized to accommodate 32 block compaction machines plus light backfill pneumatic delivery system and UFPP export area. Revised facility to accommodate approximately six UFC pedestal block compaction machines, granular bentonite delivery system and no UFPP export area. Therefore the cost of the revised facility is assumed to be 40% of the original SMCP.	339,500	-60	135,800
9	550 40 30 12	AUXILIARY BUILDING	Building design will be amended to accommodate different occupation requirements. However, at this stage it is assumed that this will be a second order effect on cost and no change has been	4,761	0	4,761

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
			included.			
10	550 40 40 10	U/G CONSTRUCTION STAGE	Unlikely to be any significant differences.	25,878	0	25,878
11	550 40 40 20	WASTE SHAFT	It is envisaged that the UFC cask dimensions and weight can be kept within current limits and therefore no change in size or hoist capacity will be required. Construction techniques and quantities will change and the following items have been reviewed to ascertain a revised cost: Shaft depth, collar costs, headframe costs, sinking plant costs, hoists, ropes and conveyances costs and shaft grouting.	48,439	-13	42,043
12	550 40 40 40	UPCAST VENTILATION SHAFT	Construction techniques and quantities will change and the following items have been reviewed to ascertain a revised cost: Shaft depth, sinking plant costs and shaft grouting.	15,802	-24	11,942
13	550 40 40 45	TUNNELS (Panel/Perimeter Access)	Tunnel construction to be by ABM30 continuous miner supplied by Sandvik. Length of tunnels increases to 21,300 m (excluding 550 40 5 40 20 50). Tunnels to be shotcreted. Advance rates based on information from Sandvik.	86,024	-40	51,498
14	550 40 40 60	EMPLACEMENT ROOMS (All Panel A & Lower Panel	The 'rooms' will now be emplacement tunnels assumed to be constructed on an ongoing	94,981	-35	61,453

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
		B)	'just in time' basis by TBM methods. Assume approximately 8 (this may change) tunnels constructed prior to start of operations by contractor taking approximately one year to complete with two machines.			
15	550 40 40 65	ANCILLIARY FACILITIES	Use of a TBM will reduce explosive magazine requirements, but will increase TBM parking space requirements. No material change.	1,962	0	1,962
16	550 40 40 70	UFC HANDLING SYSTEM (Equipment)	Although the design of the emplacement machines will change the overall costs are likely to be similar.	26,375	0	26,375
17	550 40 40 75	UNDERGROUND EQUIPMENT	Six locos originally included for that made up 80% of cost. Assumed only three now require with remaining vehicles / equipment list remaining representative of new requirements. Overall total cost reduced by $3,900K.	13,908	-28	10,014
18	550 40 40 80	SEALING MATERIALS EMPLACEMENT SYSTEM	Previous arrangement included for end plug cask, backfill block emplacement equipment and light backfill emplacement system. Revised system requires for bentonite pellet emplacement. UFC plinth installed during UFC emplacement. Unnecessary costs removed.	11,327	-72	3,172
19	550 40 70 35	VENTILATION SYSTEMS	Ventilation requirements will differ for TBM versus drill and blast. However there will be no material change.	9,404	0	9,404
20	550 45	OPERATIONS PROGRAM	This element is for the management and	257,367	3	265,088

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
	5	MANAGEMENT	administration of the DGR and in the original case included for Architect Engineers to manage contract miners during campaigns in the operations stage. This arrangement may change depending on whether ongoing mining is carried out on a campaign or a continuous basis. Assuming process tends towards continuous, additional management may increase by up to 3%.			
21	550 45 10	OPERATION MANAGEMENT & ADMINISTRATION	This element is for the management and administration of individual DGR facilities. Approximately 100 staff were employed in total. Of these there would be a reduction in SMCP (10) and underground operations management (10). Therefore assume 20% reduction.	323,362	-20	258,690
22	550 45 15	OPERATIONS INDIRECTS	All indirect labour and equipment to operate the DGR. At this stage it is envisaged only minor changes will result.	789,594	0	789,594
23	550 45 20 5	UFPP OPERATION	Other than the Jacketing and Dispatch cell operations, it is assumed that the number of operators will remain the same. Reducing the Jacketing and Dispatch operators by 50% reduces the total by 2%.	626,749	-2	614,214
24	550 45 20 15	SMCP OPERATION	Substantial reduction in manpower. Estimate of bentonite quantities used shown to be approximately the same. Overall, a reduction in cost of 43% is estimated.	542,069	-43	308,979

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
25	550 45 20 20	AUXILIARY SURFACE FACILITIES	Concrete batch plant and crusher plant throughput will be reduced due to the lower volumes of rock being removed. Reduce Group 3 manpower by 50% giving overall factor of 92% on all Groups.	57,927	-8	53,293
26	550 45 40 1	EMPLACEMENT IN UNDERGROUND ROOMS	This will now be EMPLACEMENT IN EMPLACEMENT TUNNELS. Manpower levels reduced as there are no block sealing materials to be separately placed. Tunnel bulkhead numbers will approximately double. From initial review overall cost will reduce by approximately 33%.	320,979	-33	215,056
27	550 45 40 2	DEMOBILIZATION	The demobilizations will be reduced as there will be no campaign mining by a contractor.	8,366	-75	2,092
28	550 45 40 3	U/G EQUIPMENT	Underground equipment will include addition of two TBM machines and two grouting jumbos.	4,854	+217	15,390
29	550 45 40 4	CAPITAL REPLACEMENT	Removal of need to replace heavy locos plus block transport rail cars and other ancillary vehicles.	56,250	-31	38,813
30	550 45 40 6	ENGINEERING (OPS STAGE)	Engineering for emplacement tunnel excavation provided by Owner over a period of 29 years compared to engineering needs restricted to periods of campaign mining.	22,854	+145	56,066
31	550 45 40 7	CAMP ADDIT'N/OPERAT'G	It is envisaged that personnel will be accommodated in the Town site rather than in	14,414	-100	0

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
			a dedicated Mining Camp. Costs deleted from this DETS.			
32	550 45 40 8	ROOM EXCAVATION (Upper Panel B & Lower Panel D)	Now EMPLACEMENT TUNNEL EXCAVATION. This will proceed on a 'Just in Time' basis for the first 29 years of operation. Excavation assumed to be by TBM.	56,195	+424	238,408
33	550 45 40 9	ROOM EXCAVATION (All Panel C)	Included in 550 45 40 8	56,195	-100	0
34	550 45 40 10	ROOM EXCAVATION (Upper Panel D)	Included in 550 45 40 8	28,338	-100	0
35	550 45 40 11	CON LABOUR INDIRECTS (RM EXCV)	These will be incorporated in the DETS for Operations Indirects (550 45 15) and will increase due to the fact that emplacement tunnel construction is continuous rather than on a campaign basis.	11,034	-100	0
36	550 45 40 12	CON PLANT INDIRECTS (RM EXCV)	These will be incorporated in the DETS for Operations Indirects (550 45 15) as for 550 45 40 11.	12,303	-100	0
37	550 60 10	DECOMMISSIONING FACILITIES	Element includes for provision of sealing materials preparation facility and waste processing facility. Both facilities still required. However, quantities of sealing materials may alter marginally. At this stage no change assumed.	329,727	0	329,727
38	550 60 30 6	ACCESS TUNNELS & DRIFTS	Adjustment for increase in access tunnels of +27%. Shotcrete to be removed at major seals.	132,378	+27	168,065

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
39	550 60 30 7	SERVICE SHAFT	Shaft decommissioning reduced as a function of reduced shaft depth of 500 m.	17,967	-46	9,707
40	550 60 30 8	WASTE SHAFT	Shaft decommissioning reduced as a function of reduced shaft depth of 500 m.	16,921	-47	8,885
41	550 60 30 10	MAINTENANCE AREA VENT SHAFT	Shaft decommissioning reduced as a function of reduced shaft depth of 500 m.	13,623	-49	6,931
42	550 60 30 11	UPCAST VENTILATION SHAFT	Shaft decommissioning reduced as a function of reduced shaft depth of 500 m.	13,611	-49	6,931
43	550 60 30 12	CONT'R LAB INDIRECTS (DECOMMISSIONING)	Tunnel backfilling requirements have increased. Assume backfilling of drifts is on the critical path of decommissioning schedule which becomes duration of this activity estimated to be 8.8 years.	21,269	-27	15,526
44	550 60 30 13	CONT'R PLANT INDIRECTS (DECOMMISSIONING)	As 550 60 30 12.	13,529	-27	9,876
45	550 60 50 1	USED FUEL PACKAGING PLANT (UFPP)	Minor changes to the Jacketing and Dispatch Cells having only a small effect on overall decommissioning cost.	13,071	0	13,071
46	550 60 50 2	SEALING MATERIALS MANUF FACILITY	Facility construction cost has been reduced to 40% of original. Cost required (mainly labour) to decommission smaller facility reduced by similar amount.	3,206	-60	1,282
47	550 60 50 4	UFC HANDLING SYSTEM	UFC handling equipment will alter in design. However, replacement equipment will still attract decommissioning charge assumed at this stage to be the same.	2,046	0	2,046
48	550 60	DECOMMISSIONING	Smaller SMCP results in less free release	64,403	-3	62,471

Ref No	WBS No for 'In-room'	Description for 'In-room' Design	Comment	Current 'In-room' Cost $k	% Change	Estimated Sedimentary Rock DGR Cost $k
	60	WASTE DISPOSAL	waste for disposal. Assuming half of original quantity gives an approximate 3% reduction in overall cost.			
49	550 90	PROGRAM MANAGEMENT	Program management and administration of the DGR facility up to the construction stage is likely not to change significantly for the revised arrangement.	285,044	0	285,044
		TOTAL		**5,149,010**	**-675,386**	**4,473,624**
		BALANCE		**7,525,877**		**7,525,877**
		OVERALL TOTAL		**12,674,887**		**11,999,501**

Table 2: Technical Specifications for Horizontal Tunnel Container Emplacement

Design Feature	Design Specification	Discussion
DGR Environment:		
Host Rock	Shale	Justified in Selection of Sedimentary Rock Report [6].
Rock strength (MPa)	40	From Golders report [4]. 22-23 MPa for Nagra – [3], P94.
Depth (m)	500	Justified in [6].
Ambient temperature (^{0}C)	16.5	0.019°C per m from Terms of Reference [12] plus surface ambient of 7^{0}C. [38 ^{0}C for Nagra – [3], P108].
Used Fuel Container:		
UFC length (mm)	3,867	Same as in-room concept [1]. Nagra SF container is 4,600 mm long – [3], P103.
UFC diameter (mm)	1,168	Same as in-room concept [1]. Nagra SF container is 1,050 mm diameter – [3], P103.
UFC mass (kg)	23,500	Same as in-room concept [1]. Nagra SF container is 26,000 kg – [3], P103.
Number bundles / UFC	324	Same as in-room concept [1].
UFC Initial thermal output (W)	1,138	Same as in-room concept [1]. Nagra heat output is a maximum of 1500 W per SF container – [3], P97.
Number of UFCs	11,111	Same as in-room concept [1]. Nagra reference case concept assumed a capacity of 2795 (2065, SF and 730 HLW) containers – [3], P96.
Buffer Pedestal:		
Material	100% bentonite	Same as in-room buffer jacket [1].
Dry density (kg/m^3)	1,750	Same as Nagra – [3], P106.
Final (sat.) density (kg/m^3)	2,150	Same as Nagra – [3], P131.
Tunnel Buffer material (Excluding Pedestals):		
Buffer Pellets		To fill tunnel
Dry density (kg/m^3)	1,500	Same as Nagra – [3], P106.
Final (sat.) density (kg/m^3)	2,150	Same as Nagra – [3], P131.
Emplacement Tunnel:		*Initial layout pending thermal & mechanical analyses.*
Tunnel Diameter (m)	2.5	Terms of Reference [12] (Same as Nagra – [3] P94 & 105).
UFC orientation	Single row along borehole centre	Same as Nagra – [3], P106.

Design Feature	Design Specification	Discussion
UFC spacing, centre-to-centre (m)	6.9	Nominal UFC length plus 3m between. 3m between adjacent containers for Nagra – [3], P106 (7.6m centre to centre for SF).
Emplacement tunnel length (m)	820m	800m for Nagra – [3], P94.
Bulkhead length (m)	20m in tunnel + 20m in transition area	20m of HCB in emplacement tunnels, plus 20m in transition area. Nagra – [13] P135.
Turning access length (m)	25	Same as in-room concept [1].
Distance from tunnel end to first UFC assembly (m)	5.1	Nominal allowance. 5m in Nagra – [13] P135.
Distance from bulkhead to last UFC assembly (m)	5.1	Nominal allowance. 5m in Nagra – [13] P135.
Number of UFCs / emplacement tunnel	112	To maintain the tunnel length around 800m and produce a relatively square layout.
Emplacement tunnel length for UFCs (m)	780	Based on number of UFCs per emplacement tunnel, the UFC spacing and the end distance to first/last container.
Repository Layout:	*Initial layout pending thermal & mechanical analyses.*	
Number of emplacement tunnels	100	Number of UFCs / UFCs per tunnel (approx.).
Maximum number of containers	11,200	UFCs per tunnel x number of tunnels.
Borehole spacing (centre-to-centre) (m)	40	Same as Nagra – [3], P94.
Number of repository sections	4	Same as in-room concept [1].
Number of emplacement tunnels / section	25	Number of tunnels / number of sections.
Repository width (m)	2170	2 x emplacement tunnel length + access tunnels (approx.). Similar to in-room concept [1].
Repository length (m)	1870	50 x emplacement tunnel spacing + access tunnels (approx.). Similar to in-room concept [1].
Repository area (km^2)	4.06	Width x Length.
Allowable period to fill excavated tunnel	1 – 2 years	As Nagra – [3], P106.

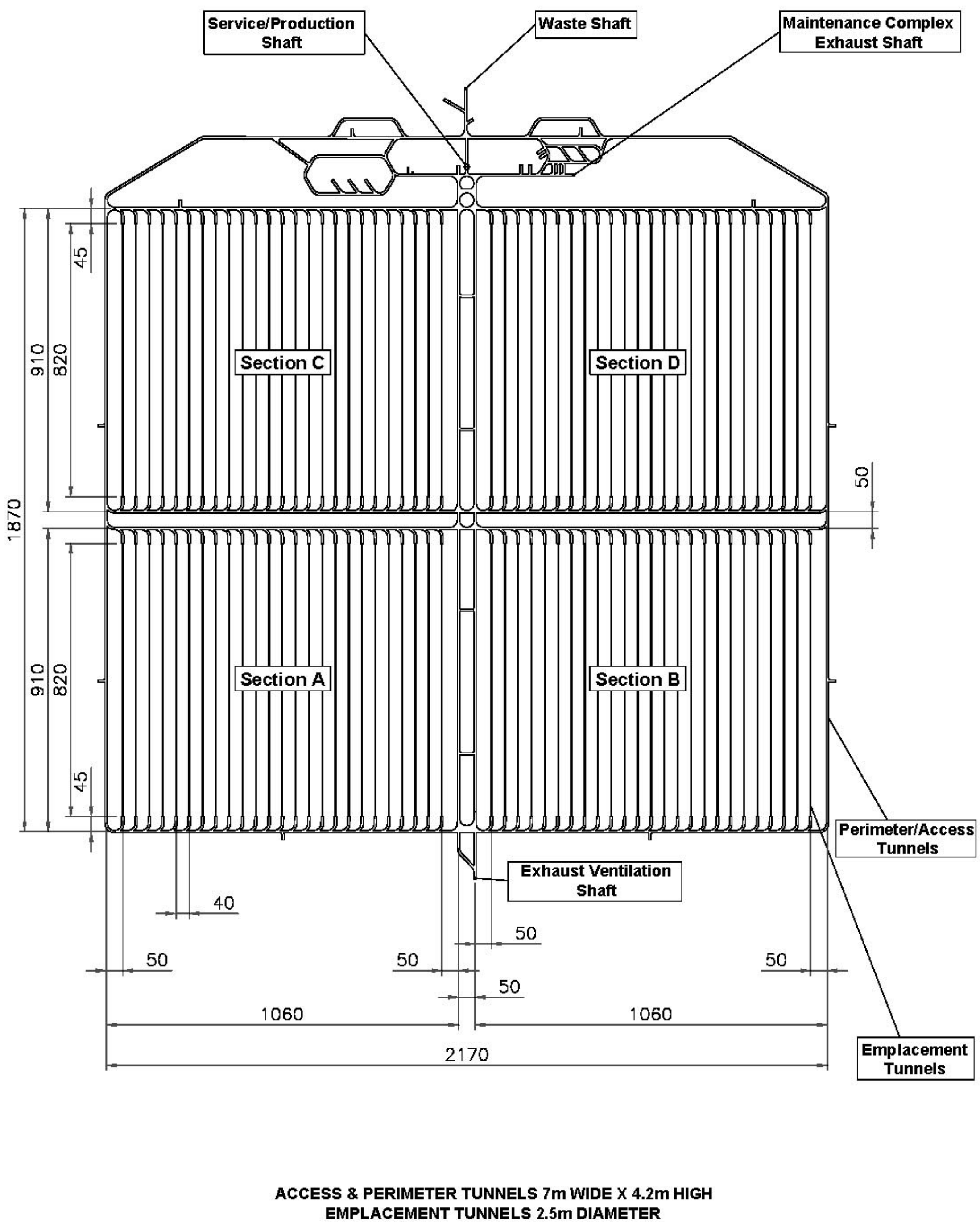

Figure 1 Proposed Layout for a DGR at 500 m depth in Sedimentary Rock

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