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NUCLEAR WASTE MANAGEMENT ORGANIZATION | SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

NWMO BACKGROUND PAPERS
6. TECHNICAL METHODS

6-13B CENTRALIZED EXTENDED STORAGE 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.

Centralized Extended Storage in Sedimentary Rock

High-Level Review

November 2004

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

Notice to the Reader

This High-Level Review has been prepared by RWE NUKEM Limited (the "Consultant"), to present changes to the reference, 50 m below surface, 'Casks in Rock Caverns' conceptual design for a centralized extended storage (CES) facility to allow it to be located at greater depth 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 (NWMO) (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.

Contents

1 Introduction

Early work undertaken by CTECH (a joint venture between RWE NUKEM and Canatom) on behalf of the Joint Waste Owners (JWO) provided conceptual designs and cost estimates for four alternatives for the extended storage of used nuclear fuel in a Centralized Extended Storage (CES) facility [1 & 2]. One of these alternatives comprised the storage of Casks in Rock Caverns (CRC) some 50 m below the surface.

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 and depths that may provide alternative host geologies for the extended storage of used nuclear fuel. From this requirement, the NWMO has requested a high-level review to be carried out of the potential changes to the CTECH CRC design and its cost estimate, as a consequence of locating it at greater depth in a sedimentary rock formation.

For the purposes of the review, the CRC facility 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 [3] & Mazurek [4]). Based on international precedence and the self sealing properties offered by Ordovician shales, it is proposed to assess a Deep Geologic Repository (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 CRC facilities, it is proposed to assess a CRC facility located in the same rock sequence and at the same depth as that chosen for a DGR, that is, the Ordovician shales at 500 m below the surface. This selection will provide a greater difference between the reference underground rock cavern CES at 50 m which required minimal rock support [1] and a deeper CRC facility at 500 m which would require additional rock support. This selection will also allow a greater degree of information sharing between the CRC and the DGR facilities, thereby simplifying any comparison between the two studies [5].

To answer the NWMO requirement, this document presents the design and operating features included in the CES CRC arrangement that require modification to accommodate the introduction of a CRC facility located in sedimentary rock at a depth of 500 m. At this stage 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 the final CES CRC design in sedimentary rock. The document also provides a scoping estimate for implementing these modifications and their effect on the current CRC overall cost estimate.

2 CES Underground Design in Sedimentary Rock

This section of the report provides a brief outline of the proposed CRC facility design, based on its location in sedimentary rock at a depth of 500 m. Other areas of the CRC facility not covered here are broadly similar to the CRC concept described by CTECH [1]. The design considered is appropriate for a hypothetical site with geologic and hydro-geologic conditions similar to those of the middle and upper Ordovician Shales in southern Ontario.

The CRC concept comprises the storage of CANDU used fuel bundles confined in self shielded storage casks that in turn are stored for an extended period in underground caverns excavated in competent shales. In general, CANDU used fuel bundles will be transferred from reactor sites to the CES facility using either, Dry Storage Containers (DSCs), module transport casks (Irradiated Fuel Transportation Casks (IFTC)) or basket transport casks. Following receipt at the CES facility, DSCs will be inspected prior to being transferred to the waste shaft cage using a cask transporter. Once underground a further cask transporter will convey the cask from the waste shaft to the appropriate storage cavern. Used fuel modules and baskets are received in their respective transport casks and repacked into either module storage casks or basket storage casks in a shielded cell within the CES facilities Processing Building. When filled theses casks are sealed and inspected prior to being transferred to the waste shaft cage using a cask transporter. Once underground a further cask transporter will convey the cask from the waste shaft to the appropriate storage cavern.

The CRC underground layout comprises a system of access tunnels connecting the waste, service and ventilation shafts to a single panel of eleven storage caverns 452 m long arranged in parallel as shown in Figure 1. The caverns, spaced at 50 m centre to centre each are able to accept up to 948 casks in 158 rows, three wide stacked two high. Ten of the caverns are used initially for storage with the eleventh set aside for the relocation of casks during the cavern refurbishment programmes.

The underground cask transporter will position the lower tier of casks within each storage cavern. Beyond this the underground cask transporter will set down casks at a transfer position to allow a cavern overhead gantry crane to place these casks in their storage position, on the upper tier.

The proposed CRC design has a maximum capacity for 9,480 Casks, or nominally 3,674,448 intact fuel bundles (to accommodate a requirement for 3,557,451 intact fuel bundles). Assuming an ideal site, with no faults or stress anomalies, the minimum overall dimensions of the cavern storage area including access tunnels are approximately 599 m by 567 m. 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.

3 Design Specification

The design information for an underground rock cavern CES facility located in sedimentary rock is broadly similar to that presented for a CRC facility situated at a depth of 50 m in competent rock, documented by CTECH [1]. Geological data for the chosen generic location for the sedimentary rock CRC facility has been taken from literature available for southern Ontario [3 & 4]. Key differences in the design of the two facilities are as follows:

i. access to the underground caverns may be by shafts rather than by ramp;

ii. the need to amend the underground ventilation arrangement;

iii. the need to accommodate an increase in the ambient temperature within the storage caverns;

iv. the need to take account of the host rock strength at the specified depth in particular the need for additional support for the underground openings; and

v. the design of the shafts should be based on the shaft designs presented by CTECH for deep geologic repositories for used nuclear fuel [6].

The major design parameters for a CRC facility at depth within sedimentary rock together with their sources are listed in Table 2.

4 Anticipated Changes to Pre-Construction Activities

The scope of the pre-construction activities, namely those relating to siting, system development, safety assessment, licensing and approvals and public affairs, identified for a CRC facility constructed 50 m below the surface will differ from the scope for similar activities for a CRC facility located within sedimentary rock at 500 m. The following sub-sections set out the areas where differences may occur:

4.1 SITING

Site investigation work will be more involved due to the increased depth of the proposed CRC facility and the anticipated different ground conditions in the host rock formation. Increases are envisaged in the effort required to carry out the technical management, creating and maintaining an information management system, implementing a quality assurance programme and undertaking geosphere and biosphere characterisation, modelling and evaluation studies.

4.2 SYSTEM DEVELOPMENT

Design changes relating to the different cask handling systems associated with a potential change in adopting shaft rather than ramp access need to be developed sufficiently for construction licence application. However, the effort to develop these schemes should not be significantly greater than the effort required to develop the original solutions.

4.3 SAFETY ASSESSMENT

The implications of making the safety case for a facility at a depth of 500 m rather than 50 m is likely to involve additional justification. It is envisaged that increased effort would be required to carry out safety assessment (SA) management, SA siting research and development (R&D), SA operating licence R&D and providing SA during the facility operating period.

4.4 LICENSING AND APPROVALS

The majority of effort required in obtaining licences and approvals for a CRC facility is associated with renewal and maintenance of the CNSC operating licence. At this stage it is envisaged this task would only be slightly more onerous for a facility at a depth of 500 m rather than 50 m.

4.5 PUBLIC AFFAIRS

Additional effort in public communication may be required to explain the complexity and features associated with storage of used fuel at a deeper CES CRC facility. Although the effort required to communicate the case for a shallow CRC is broadly in line with that assumed to apply for a deep geologic repository, it is anticipated a small increase in effort may be required for a CRC facility at a depth of 500 m.

5 Anticipated Design Changes

The design of a CES facility located in sedimentary rock would potentially differ from the design proposed for the CRC facility located at a nominal depth of 50 m in a granite pluton or other similar competent hard rock formation, in particular in respect to the access routes, underground access tunnels and storage caverns [1]. In addition, the modified storage concept may require changes in the handling of the casks 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 CES facility located in sedimentary rock.

The following sub-sections set out the areas of the CES facility that are affected by a change from near-surface storage to storage at 500 m 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 CES design solution in sedimentary rock.

5.1 UNDERGROUND ACCESS

- Establish the most appropriate method of access to the underground caverns:

It has been assumed for the purposes of this review that access to the underground caverns will be via vertical shafts as opposed to ramp access suggested for the CRC facility option located 50 m below the surface. However, to verify this assumption a review of the options available should be carried out, assessing them against an agreed set of criteria to enable a quantifiable conclusion to be drawn. The criteria to be used in undertaking this assessment should include:

i. the mass and dimensions of loads to be transferred;

ii. maintainability;

iii. safety; and

iv. cost, construction and operation.

5.2 STORAGE CASK HANDLING

- Storage cask handling techniques need to be reviewed in conjunction with possible alternative means of underground access:

It is assumed that the casks will be transported from the surface to the storage caverns using similar transporters to those used for the CRC facility located 50 m below the surface. The ability to transfer a cask and its transporter, or alternatively just a cask, to a depth of 500 m using a shaft needs to be addressed. In addition, other possible methods of transferring casks underground and placing them within storage caverns i.e. other than by transporter and gantry crane, also needs to be assessed. As a guide to potential shaft hoisting arrangements, it is recognised information is available from CTECH DGR design studies [6]. The resources necessary to implement alternative means of cask handling and transfer also needs to be considered.

5.3 ROCK DISPOSAL

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

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

Waste rock from shaft or underground development will probably not form a suitable material for aggregate for other construction purposes. Should this be the case, other sources of aggregate will need to be determined.

5.4 WASTE SHAFT

- Review required payload, shaft diameter and cask handling:

The function of the CRC waste shaft is to transfer module and basket storage casks 500 m underground to allow their placement in storage caverns. In the case of the CTECH CRC design [1] this activity is undertaken using a free steering tyred transporter, conveying casks underground via a ramp. Therefore, a need exists to determine the shaft design, i.e. shaft diameter and hoisting capacity, based on the dimensions and mass of the expected payload. To undertake this task, the various storage cask handling options both above and below ground need to be considered. These could include:

i. using separate cask transporters above and below ground and conveying the storage cask alone within the waste shaft cage;

ii. transporting the storage cask on a rail car from the process plant to the cavern via the waste shaft; and

iii. use of airbed technology.

The usage of the proposed waste shaft should be reviewed during its operating life to determine whether any rationalisation of proposed underground access is feasible, taking into account all construction and operations movements.

- Waste shaft construction techniques:

The method of construction for the waste shaft will need to be established for the rock types encountered at the chosen generic location. The rock types anticipated include the potentially water-bearing Devonian and Silurian age dolostones that 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 should be reviewed, together with the requirement for concrete lining as development advances.

5.5 SERVICE SHAFT

- Establish an appropriate shaft design based on initial underground excavation requirements and ongoing construction during operations:

To allow construction work to proceed in parallel with the placement of storage casks, it may be necessary to incorporate a service shaft within a CRC arrangement designed for operation at 500 m below the surface. To determine whether this is the case, the volumes of excavated rock to be transferred to the surface during these periods need to be established. Furthermore, all other movements that are required in the operation of the storage facility need to be identified, such as personnel and equipment access, to assess their potential implications on the overall service shaft hoisting requirements.

- 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.

5.6 VENTILATION INLET SHAFT

- Review the requirement for a separate ventilation inlet shaft:

A shaft may be required to act as a ventilation intake for the underground openings during operations, replacing the two inlets (via the ramps) proposed in the CTECH CRC design [1]. However, this may not be required if the proposed waste and service shafts are utilised for both initial excavation work and ventilation. Should an inlet shaft be required, its design and location will need to be determined to allow cask placements and ongoing construction to be undertaken in parallel during the operations phase.

- Ventilation intake shaft construction techniques:

Should a ventilation inlet shaft be required, the method of its construction will need to address the same issues as those identified for the waste shaft.

5.7 UPCAST VENTILATION SHAFT

- Establish an appropriate shaft design based on ongoing construction during operations:

The CTECH CRC design [1] incorporates three upcast ventilation shafts, to accommodate both the extract requirements during the construction of the caverns, as well as the extract from the caverns once casks are in situ. Each shaft covers one of the three cavern sections that are constructed in phases. The design of a single upcast shaft for a CRC facility at 500 m will need to accommodate the extract from all the underground operations, both construction and storage, while also taking in to account the increased ambient temperature due to the greater depth of the workings. Furthermore, based on the shafts' potential location in relation to the layout of the CRC design, a review should be undertaken of the shafts' capability to provide emergency egress, with facilities included in its design should this function be practicable.

- 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.

5.8 CRC UNDERGROUND LAYOUT

- Review the CRC underground layout of storage caverns and access tunnels taking into consideration the revised depth of the facility:

Differences in the layout of a CRC facility at 500 m compared with a facility at a depth of 50 m may occur due to possible changes in the:

i. host geology;

ii. method of access to the underground workings and the need to provide services; and

iii. ventilation requirements.

The host geology will have a bearing on the storage cavern dimensions and their lateral spacing that in turn set the overall footprint area of the CES facility. The layout of the 50 m deep storage facility incorporates 15 m wide caverns, 16 m high and 452 m long, with a pillar width of 35 m between caverns. These caverns accommodate three rows of casks, two high, along their length with sufficient space remaining to allow access to any stored cask following the removal of a maximum of three other casks. The feasibility of constructing stable excavations in deep shale formations was carried out by Golder Associates [3]. This study established that stable openings could be constructed with a span of 10 m. Based on a preliminary review of the rock strength assessment carried out by Golder Associates [3] , it is considered that caverns constructed in shale at 500 m with similar dimensions and lateral spacing to those constructed for the 50 m deep facility (e.g., 15 m span), are also expected to be stable and have an adequate factor of safety. Therefore, the proposed CRC layout comprises ten storage caverns with one spare cavern to allow cask relocation during the planned cavern refurbishment programmes.

The method of access to the underground works, either by ramp or shaft, will play a part in the arrangement of access tunnels in the receipt area of the facility to allow safe segregation of operational traffic flows from ongoing construction traffic. For a facility constructed at depth, in comparison with one near surface, improved operational efficiencies may be achieved by the construction of an underground equipment storage and maintenance complex. Such a complex should reduce the need for transfers to the surface by allowing routine and / or breakdown maintenance to be carried out underground. Based on this premise, and the fact that the proposed facility will be accessed by shafts, the CRC layout suggested includes a shaft loading / unloading area combined with an equipment storage and maintenance complex. The precise extent of the latter would be the subject of a more detailed review at a later stage.

The final layout of access tunnels and caverns of any underground storage facility needs to be able to provide adequate segregated ventilation, to both caverns containing storage casks and areas of the facility that are undergoing construction. To this aim access tunnels need to be provided to allow air flows to be directed to and from the various working areas at any stage of the development of the facility. This may be assisted by the use of suitably sited bulkhead doors to segregate and direct air flows where required. In addition, the access tunnels must allow for safe egress from the facility in the event of an unplanned incident whether it is nuclear or conventional related.

The proposed layout incorporates a perimeter access tunnel that provides unrestricted access between the downcast and upcast shaft complex's, for both nuclear and construction activities. This route also serves as a 'clean' ventilation circuit around the facility.

The CRC facility layout illustrated in Figure 1, assumes that the storage caverns are constructed by methods that allow the general configuration of the facility to be maintained. As described in the following section, a review of cavern construction methods will be carried out that may result in the layout being amended.

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

The CRC facility access tunnel dimensions depend on three factors:

i. function and purpose of the tunnel;

ii. method of construction; and

iii. cost.

As one of the primary functions of the access tunnels is to permit transfer of casks from the waste shaft to the storage caverns, the dimensions of the casks and their method of transport are important factors. The access tunnels must also be sized to allow the deployment of equipment required to excavate the storage caverns. In addition, as tunnels would be used to route the required ventilation flow through the store, their cross section should be sufficiently sized to prevent excessive air flow velocities.

The access tunnels may be excavated by a number of means that include:

i. drill and blast;

ii. tunnel boring; and

iii. continuous mining.

Each of the potential options need to be reviewed taking in to consideration the geologic medium at the generic location, the cost for their deployment and the potential size of the openings required to satisfy the factors mentioned in the previous paragraph. Irrespective of the construction method, due to the requirement for the access tunnels to remain open for many hundreds of years, it will be necessary to either shotcrete, or line (using pre-formed concrete) the tunnels to provide geotechnical stability over this extended timescale.

At this stage the dimensions of the various access tunnels proposed have not been fully assessed, therefore in order to allow scoping costs to be prepared a general access tunnel size of 7 m wide by 6 m high has been assumed to be consistent with the ramp dimensions suggested for the CRC located some 50 m below ground. At this height, the existing cask transportation configuration may be maintained for the CRC located at 500 m depth. However, the dimensions of the access tunnels should be reviewed during a more detailed phase of investigation.

5.9 STORAGE CAVERN

- Establish storage cavern construction method:

A detailed analysis of the construction methods to be used in constructing storage caverns has not been carried out. The costs of these facilities has been based on the unit cost per m^3 of excavating rock developed for a CRC located at a depth of 50 m, as the methodology of alternative approaches has not been investigated at this stage. However, it is believed from a preliminary analysis that the unit costs by other methods, such as some form of continuous mining would not be substantially different from those developed for drill and blast methods. A method involving continuous mining could involve multiple passes along the length of the cavern. At a more detailed phase of study, an investigation should be carried out to identify other construction options, with the most appropriate option being selected. Other options could include drill and blast methods using benching or longhole drilling, or a combination of continuous mining and drill and blast methods.

The storage caverns will be supported by means of rockbolts, screen and shotcrete to provide ground support. The support should be provided as soon as possible after excavation to avoid ground deterioration. Upon completion of the excavation of the cavern it may be necessary to refurbish part of the ground support if blast damage during excavation occurs. Shotcrete is considered to be an effective means of providing ground support, although alternatives such as pre-formed lining could be considered. The thickness of the shotcrete may be varied and additives such as carbon fibre used to strengthen the concrete fabric.

- Review the cask storage configuration taking in to account the cavern cross section.

The cavern profile developed for the CRC designed for a depth of 50 m accommodates three rows of casks, two high, along their length with sufficient space remaining to allow access to any stored cask following the removal of a maximum of three other casks. As part of the process in fixing the storage cavern dimensions, consideration needs to be given to the configuration of the casks within the store to ensure ease of access and to allow monitoring to be undertaken.

In setting the cask storage configuration, the cavern design needs to incorporate appropriate water management systems and also allow effective ventilation of the space. In addition, sufficient space needs to be provided to allow for the movement of the chosen cask handling equipment.

5.10 VENTILATION

- Establish ventilation requirements:

The ventilation requirements will need to be reviewed based on any revised layout and the higher ambient temperature. Due consideration needs to be given to segregation of nuclear and construction activities and the methods by which this can be achieved. In reviewing the inlet air requirements, an assessment should be carried out to establish whether a dedicated inlet shaft is necessary, or if this may be replaced by utilising either the waste or service shaft.

5.11 MAINTENANCE

- Review the maintenance requirements:

The current CRC facility philosophy incorporates a 'rolling' programme of storage cavern maintenance. The frequency of this maintenance may need to be reviewed in the light of the revised host geology and its greater depth. Although the activities to be undertaken will be similar for a facility in sedimentary rock at depth compared with one close to the surface, it is envisaged that more comprehensive maintenance of the underground structures and openings may be required.

Should shaft access be chosen, the maintenance of the shaft hoisting equipment will be an additional task not considered for the 50 m deep CRC facility.

5.12 REFURBISHMENT

- Review the frequency of cavern refurbishment:

Refurbishment of the CRC facility caverns at 50 m depth was anticipated every 300 years. This refurbishment period needs to be reviewed in the light of the host geology and its greater depth. Should a more frequent programme be considered appropriate, an alternative could be to coordinate with the proposed 100 year or 200 year cask repackaging requirement.

Should shaft access be chosen, these may also require refurbishment over the long time periods specified and therefore may also need to be reviewed.

5.13 CASK REPACKAGING

- Review cask repackaging process:

Long term storage philosophy for used fuel within storage casks is to replace casks over a given time period to overcome any deterioration in the casks condition. Earlier studies [1] assumed this period to be 100 years, when the fuel was removed from 'old' casks and repacked into 'new' casks. In the case of a CRC facility designed for a depth of 50 m, repackaging of casks was carried out within a specifically designed plant located at surface. Because of the greater depth of the revised CRC facility and the subsequent additional cask handling requirements, the procedure for returning casks to the surface for repacking would need to be reviewed in a future design optimization study to establish if the reference assumption remains valid.

5.14 FACILITY THROUGHPUT

- Review facility used fuel throughput:

The CRC facility to be located at a depth of 50 m was designed for a peak delivery to the facility of 120,000 used fuel bundles per year. The implications of this throughput on the revised CRC facility will need to be assessed to establish its continued validity and also any changes in resources required for its maintenance.

6 Cost Implications

A scoping cost estimate has been prepared for implementing a CRC CES facility in sedimentary rock, 500 m below ground level. This was achieved by compiling scoping costs for those activities that were directly affected by the change in depth from a CRC facility design located 50 m below ground level that was previously costed by CTECH [2]. For the purposes of this scoping estimate, activities identified during a review of the original CRC facility work breakdown structure (WBS) that were indirectly affected by the change (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 CRC facility activity costs have been adjusted by applying the most appropriate scaling method. These included techniques such as, applying a preliminary excavation cost per m^3, re-estimating labour resources against specific activities and adding or removing specific items from existing activity 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. Table 1 lists those activities identified from the original CRC facility WBS that have been re-estimated and gives the costs for both the 50 m and 500 m deep CRC facility designs.

Based on the method described, the introduction of a CRC in sedimentary rock, 500 m below ground level, in place of a near-surface CRC facility, will result in an approximate increase in cost of $437M over the cost of implementing the original CRC design. Applying this increase to the cost of a CRC facility located 50 m below the surface, gives an approximate total cost of $14,514M for the implementation of a CRC in sedimentary rock 500 m below ground level.

7 Conclusions

The introduction of a CRC storage facility located in sedimentary rock 500 m below ground level, in place of near-surface CRC storage facility, may require the construction and operation of shaft access rather than the use of a ramp.

The underground layout of access routes and tunnels will need to accommodate segregation of enhanced ventilation for stored casks and ongoing construction activities while also incorporating an equipment storage and maintenance complex.

The cost of implementing a CRC facility design at depth, based on using the near-surface CRC facility concept, is approximately $14,514M; $437M more than that for implementing a near-surface CRC facility.

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

Ref No	WBS No for CES CRC Design	Description for CES CRC Design	Comment	Current CES CRC Cost $k	% Change	Estimated CES in Sedimentary Rock Cost $k
1	564 15	SITING	Site investigation work will be more involved due to the increased depth and different ground conditions. Significant increases are envisaged in budgets for the technical management, database and information systems, QA, Geosphere and Biosphere characterisation, modelling and evaluation. Based on DGR siting cost information, a 300% increase in overall budget would seem appropriate.	47,789	+300	191,156
2	564 20	SYSTEM DEVELOPMENT	The development required for different handling systems associated with a potential change from ramp to shaft access underground. The changes are likely to be minor with no significant cost implications.	89,338	0	89,338
3	564 25	SAFETY ASSESSMENT	The implications of making the safety case for a facility at 500 m rather than 50 m is likely to involve additional justification. It is envisaged that significant increases in budget would be necessary for SA siting R&D, SA operating license R&D and SA facility	37,271	+200	111,813

Ref No	WBS No for CES CRC Design	Description for CES CRC Design	Comment	Current CES CRC Cost $k	% Change	Estimated CES in Sedimentary Rock Cost $k
			operations. Cross referencing to DGR SA cost data would suggest that a 200% increase would be appropriate.			
4	564 30	LICENSING AND APPROVALS	Safety assessment at 500 m recognised to be more complex than case for 50m and therefore Licensing and Approval are likely to be proportionally more difficult. However, as the bulk of the cost is associated with the renewal and maintenance of the CNSC operating license, only a small overall increase is anticipated. Allow 5% increase in cost.	205,824	+5	216,115
5	564 35	PUBLIC AFFAIRS	Additional effort in public communication may be required to explain the complexity and features associated with storage of used fuel at a deeper CRC central facility. Although the existing budget for a shallow CRC is broadly in line with that applied for a DGR, it is anticipated an increase in cost of say 10% would be appropriate.	64,281	+10	70,709
6	564 40 30 20 8	CONST'N MAT'L STOCKPILE AREA	Rock was stockpiled on site with a contingency figure of 15% as it was considered low risk. The treatment required for salt-bearing shales may be more complex to satisfy environmental concerns. Allow a 100% increase (50%	4,477	+100	8,954

Ref No	WBS No for CES CRC Design	Description for CES CRC Design	Comment	Current CES CRC Cost $k	% Change	Estimated CES in Sedimentary Rock Cost $k
			for additional treatment and 50% additional contingency).			
7a	564 40 40	STORAGE DESIGN & CONSTRUCTION (STAGE 1)	The underground layout of caverns will remain the same (nominally 15m wide by 16m high) but additional access tunnels in the form of a 'ring road' will be required to provide a ventilation circuit. Maintenance facilities will also be required for underground equipment. It is estimated that this will equate to 3,500m of 7m by 6 m tunnel to allow for the cask transporter. Excavation of the tunnels is assumed to be by continuous miner. The ramps will not be required as they will be replaced with shafts (See Items 7b to 7e). 5 caverns will be constructed as part of the initial phase.	207,341	+19	246,681
7b	550 40 40 20	WASTE SHAFT	It is assumed that a waste shaft will be required and will be similar to that being provided for the DGR in sedimentary rock. Estimated cost taken from 89148/REP/04, Item 11.	0		42,043
7c	550 40 5 40 20 40	SERVICE SHAFT	It is assumed that a service shaft will be required and will be similar to that being provided for the 0DGR in sedimentary rock. Estimated cost taken from 89148/REP/04, Item 4.	0		40,962

Ref No	WBS No for CES CRC Design	Description for CES CRC Design	Comment	Current CES CRC Cost $k	% Change	Estimated CES in Sedimentary Rock Cost $k
7d	550 40 5 40 20 41	VENTILATION INLET SHAFT	It is assumed that an inlet ventilation shaft will be required and will be similar to the maintenance complex exhaust shaft being provided for the DGR in sedimentary rock. Estimated cost taken from 89148/REP/04, Item 5.	0		13,337
7e	550 40 40 40	VENTILATION EXHAUST SHAFT	It is assumed that a ventilation exhaust shaft will be required and will be similar to that being provided for the DGR in sedimentary rock. Estimated cost taken from 89148/REP/04, Item 12.	0		11,942
8	564 40 500	COMMISSIONING MANAGEMENT	The majority of the costs are associated with the process buildings that will not change. Although access is via shafts rather than a ramp there should be little, if any, change to commissioning other areas. Allow a 20% increase to accommodate the commissioning of the shafts and their infrastructure.	275	+20	330
9	564 40 600	EQUIPMENT, SPARES AND CONSUMABLES	The majority of the costs are associated with the process equipment that will not change. To accommodate spares associated with operating the proposed shafts an increase of 10% has been assumed	327	+10	360
10	564 40 650	ENERGY CONSUMPTION	Energy consumption estimated across the site during the establishment phase	366	+10	403

Ref No	WBS No for CES CRC Design	Description for CES CRC Design	Comment	Current CES CRC Cost $k	% Change	Estimated CES in Sedimentary Rock Cost $k
			will increase due to the operation of the access shaft hoists. Assume a 10% increase.			
11	564 45 10 40	STORAGE OPERATIONS	There were originally 11 personnel involved. Assuming that additional personnel are required for the shaft transfers (assume 2) then an increase of 20% is considered reasonable.	32,570	+20	39,084
12	564 45 10 50 10	ADDITIONAL STORAGE CONSTRUCTION STAGE 2	This element was for the construction of caverns 6 to 8, plus access and ventilation corridors. Assume this is 60% of the cavern costs from 564 40 40 as access tunnels are already provided.	114,827	+3.8	119,195
13	564 45 10 50 20	ADDITIONAL STORAGE CONSTRUCTION STAGE 3	This element was for the construction of caverns 9 to 11, plus access and ventilation corridors. Assume this is 60% of the cavern costs from 564 40 40 as access tunnels are already provided.	90,245	+32.1	119,195
14	564 45 20 40	MONITORING AND SURVEILLANCE – EXTENDED MONITORING	Original estimate included a small amount for storage structure monitoring (2.5% of overall cost). It is assumed that an additional 5% should cater for the additional monitoring that may be associated with the underground structure.	190,671	+5	200,205
15	564 45 20 50	OPERATION INDIRECTS (EXTENDED	Maintenance aspect of the caverns estimated to be 5% of the design and	1,939,374	-2.8	1,885,372

Ref No	WBS No for CES CRC Design	Description for CES CRC Design	Comment	Current CES CRC Cost $k	% Change	Estimated CES in Sedimentary Rock Cost $k
		MONITORING)	construction costs (items 7, 12 and 13) three times every 100 years or 45% of total cost. No change to other maintenance costs.			
16	564 45 30 20	OPERATIONS – FACILITY REPEATS	Caverns to be refurbished every 100 years. Refurbishment to commencement after 70 years and assumed to be of 30 years duration. One additional cavern to be excavated to facilitate refurbishment commencing in year 70.	303,066	+14	345,425
17	564 45 40 10 800	STORAGE OPERATIONS (repacking module storage casks RPM, 100 year repackaging event)	Original estimate included one person to transfer casks between repackaging plant and caverns at the 100 year repackaging event. Assume that one further person is required to cater for shaft cask transfers. Allow 100% increase in cost (+2,721 k$).	2,721	+100	5,442
18	564 45 40 20	MODULE TO CASK 200 YEAR REPACKAGING	This work element includes for the transfer of cask to and from the repackaging facility during the 200 year repack event. To accommodate the anticipated increase in transport cost, the same assumption (+2,721 $k) as in Ref No 17 has been applied.	1,375,992	+0.2	1,378,744
19	564 45 40 30 10	MODULE TO CASK 300 YEAR REPACKAGING	This work element includes for the transfer of cask to and from the	1,375,992	+0.2	1,378,744

Ref No	WBS No for CES CRC Design	Description for CES CRC Design	Comment	Current CES CRC Cost $k	% Change	Estimated CES in Sedimentary Rock Cost $k
			repackaging facility during the 300 year repack event. To accommodate the anticipated increase in transport cost, the same assumption (+2,721 $k) as in Ref No 17 has been applied.			
20	564 45 40 40 800	STORAGE OPERATIONS (repacking basket storage casks RPB, 100 year repackaging event)	Original estimate included one person to transfer casks between repackaging plant and caverns at the 100 year repackaging event. Assume that one further person is required to cater for shaft cask transfers. Allow 100% increase in cost (+1,287 k$).	1,287	+100	2,574
21	564 45 50	BASKET TO CASK 200 YEAR REPACKAGING	This work element includes for the transfer of cask to and from the repackaging facility during the 200 year repack event. To accommodate the anticipated increase in transport cost, the same assumption (+1,287 k$) as in Ref No 20 has been applied.	151,773	+0.85	153,063
22	564 45 40 60 10	BASKET TO CASK 300 YEAR REPACKAGING	This work element includes for the transfer of cask to and from the repackaging facility during the 300 year repack event. To accommodate the anticipated increase in transport cost, the same assumption (+1,287 k$) as in Ref No 20 has been applied.	151,773	+0.85	153,063

Ref No	WBS No for CES CRC Design	Description for CES CRC Design	Comment	Current CES CRC Cost $k	% Change	Estimated CES in Sedimentary Rock Cost $k
		TOTAL		**6,387,580**	**436,668**	**6,824,248**
		BALANCE		**7,690,145**		**7,690,145**
		OVERALL TOTAL		**14,077,725**		**14,514,393**

Table 2: Technical Specifications for a CES Design in Sedimentary Rock

Design Feature	Design Specification	Discussion
CES Environment:		
Host Rock	Shale	Justified in 89148/REP/02 [5].
Rock strength (MPa)	40	From Golders report 021-1570 [3].
Depth (m)	500	Justified in 89148/REP/02 [5].
Ambient temperature (^{0}C)	16.5	.0190C per m from Terms of Reference [7] plus surface ambient of 7^{0}C.
Module Storage Cask:		
Cask Width (mm)	2,120	Figure 5.3 of 1105/MD18084/REP/08 [1].
Cask Depth (mm)	2,419	Figure 5.3 of 1105/MD18084/REP/08 [1].
Cask Height (mm)	3,550	Figure 5.3 of 1105/MD18084/REP/08 [1].
UFC mass (kg)	70,000	When fully loaded. Figure 5.3 of 1105/MD18084/REP/08 [1].
Number bundles / Cask	384	Figure 5.3 of 1105/MD18084/REP/08 [1].
Number of Module Storage Casks	8,528	1105/MD18084/REP/08 [1], P38.
Basket Storage Cask:		
Cask Diameter (mm)	2,200	Figure 5.5 of 1105/MD18084/REP/08 [1].
Cask Height (mm)	4,990	Figure 5.5 of 1105/MD18084/REP/08 [1].
UFC mass (kg)	43,700	When fully loaded. Figure 5.5 of 1105/MD18084/REP/08 [1].
Number bundles / Cask	420	Figure 5.3 of 1105/MD18084/REP/08 [1].
Number of Basket Storage Casks	678	1105/MD18084/REP/08 [1], P38.
Storage Cavern:		
Cavern Width (m)	15	1105/MD18084/REP/08 [1], P39.
Cavern Height (m)	16	1105/MD18084/REP/08 [1], P39.
Cask Configuration	3 wide, 2 high	1105/MD18084/REP/08 [1], P38.
Cask spacing, along the cavern (m)	2.85	This is an average spacing, a .75m walkway is provided between batches of 10 casks. 1105/MD18084/REP/08 [1], Figure 4.6.
Cavern Length (m)	452	1105/MD18084/REP/08 [1], Figure 4.1.
Number of Casks / cavern	948	1105/MD18084/REP/08 [1], P38.

Design Feature	Design Specification	Discussion
Repository Layout:		
Number of Caverns	11	9 for Module Casks, 1 for Basket Casks and 1 spare. 1105/MD18084/REP/08 [1], P38.
Cavern Spacing (centre-to-centre) (m)	50	1105/MD18084/REP/08 [1], Figure 4.6.
Repository width (m)	599	11 caverns plus pillars and access tunnels.
Repository length (m)	467	Length of caverns plus access tunnels.
Repository area (km^2)	0.28	Width x Length.

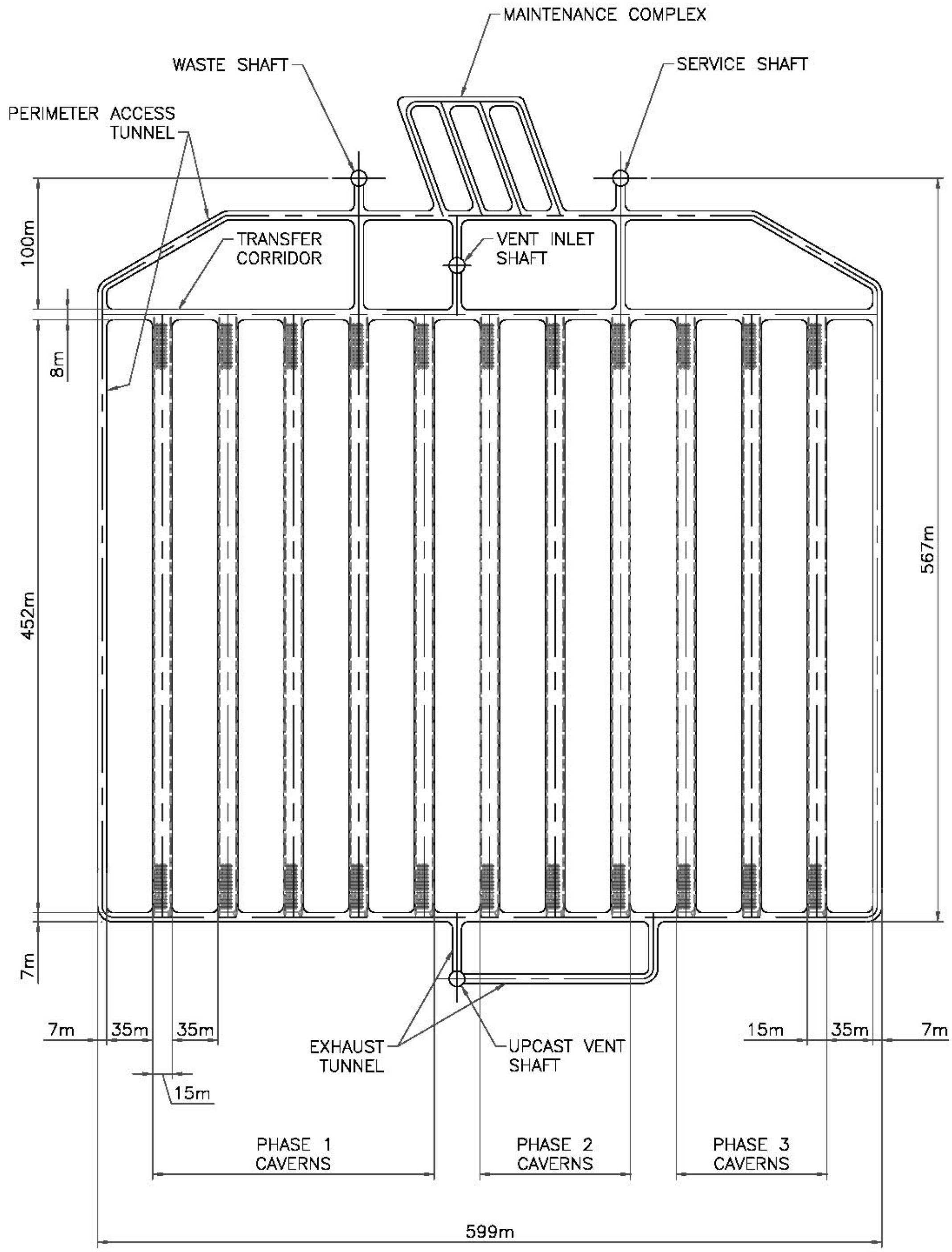

Figure 1 – Proposed Layout for a CES CRC at 500 m depth in Sedimentary Rock

8 References

1 Mair, A and Sheridan, J et al. '*Conceptual Designs for Four Centralized Extended Storage Facility Alternatives for Used Nuclear Fuel'.* CTECH Report 1105/MD18084/REP/08, Issue 2. April 2003.

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