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Radioactive Materials Management

Conceptual Designs for Reactor-site Extended Storage Facility Alternatives for Used Nuclear Fuel

Alternatives for Atomic Energy of Canada Limited's Chalk River and Whiteshell Laboratory Sites

Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited

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Preface

Currently, used nuclear fuel is stored at seven reactor sites in Canada, in both wet and dry storage facilities. The used fuel storage facilities are owned by four companies, and are located on the following reactor sites :

Ontario Power Generation	Pickering, Bruce and Darlington
New Brunswick Power	Point Lepreau
Hydro-Québec	Gentilly
Atomic Energy of Canada Ltd	Chalk River and Whiteshell

This report focuses on the Reactor-Site Extended Storage (RES) alternatives for consideration at Atomic Energy of Canada Limited (AECL) Chalk River Laboratory and Whiteshell Laboratory sites. Implementation of a RES alternative would provide an extended dry storage facility on a reactor site. In the context of this study extended storage means permanent or indefinite storage with the necessary maintenance and facility repeats. Three RES alternatives have been developed for each AECL site and they are described in this report. Separate reports have been produced to describe the alternatives for consideration at the Ontario Power Generation [1], New Brunswick Power [2], and Hydro-Québec [3] sites.

Other options for the management of Canadian used nuclear fuel in the longer term include extended storage at a central location (Centralized Extended Storage, CES) or isolation by encapsulation and placement in an underground disposal facility (Deep Geologic Repository, DGR). Other reports describe possible designs for CES facility and the DGR facility options. The CES Design Report is available should more detail be required [4].
The information in the RES, CES and DGR reports will be used as possible input to a study of options described in the Nuclear Fuel Waste Act, to be carried out by the Nuclear Waste Management Organisation (NWMO). At the end of its study, the NWMO will be required to report to the Government of Canada, setting out its preferred approach for long-term management of used nuclear fuel.

Summary

This report provides technical descriptions of the RES used fuel storage alternatives being considered for Chalk River and Whiteshell sites. The alternatives under consideration within this report are:

- Silos
- Silos in Storage Buildings (SSB)
- Silos in Shallow Trenches (SST)

The Silos and SSB are above ground facilities, and the SST is partially below ground and will be mounded over with an earthen cover. The Silo alternative represents a continuation of the current AECL dry storage methodology.
The fuel inventories at both the Chalk River and the Whiteshell sites are now fully established. The used fuel storage facilities at both sites do not require any provision for an increase in the amount of used fuel stored.

Silos

Implementation of silos as the selected RES alternative would represent a continuation of the current on site interim storage arrangements.
The existing silos will be monitored and inspected in-line with an extended storage RES schedule. When the silos reach the end of their service life, ‘new’ silos will be constructed and the used fuel baskets will be transferred from the ‘old’ to the ‘new’ silos using a reversal of the initial silo loading operations.
Periodically, and on a longer timeframe than storage facility repeats, the used fuel bundles will be removed from their existing baskets and transferred to new baskets. This transfer will be effected within a shielded facility.

Silos in a Storage Building

Implementation of SSB as the selected RES extended storage alternative would initially require the construction of a single storage building over the existing storage silo array. This initial storage building will house all of the existing silos (some of which house material other than used fuel).
The earliest implementation date for an SSB, if chosen as the preferred RES alternative is assumed to be January 2016 for the Chalk River site and January 2018 for the Whiteshell site.

Under the scope of this report, subsequent silos and the associated storage building, will be dedicated to the used fuel inventory, however AECL may choose to incorporate non fuel material into silos within the same storage building structure.
Subsequent storage buildings will be constructed as close as is practical to the previous storage buildings to minimise the transfer routes from the ‘old’ silos to the ‘new’.

Silos in a Shallow Trench

Implementation of SST as the selected RES extended storage alternative would require the transfer of the used fuel from the current silos into silos within the Shallow Trench storage chamber.
The redundant ‘surface’ silos will be decommissioned and dismantled.

The Shallow Trench will be passively cooled, with the inlet and exhaust raisers penetrating above grade.
The earliest implementation date for an SST, if chosen as the preferred RES alternative is assumed to be January 2016 for the Chalk River site and January 2018 for the Whiteshell site.

When the SST silos reaches the end of their design life a new silo will be constructed and the fuel baskets transferred from the 'old' silo to the 'new' using a reversal of the silo loading operations. Transfer between the 'old' and 'new' silos will utilise the conventional basket transfer methodology. When the building fabric of the shallow trench requires replacement the fuel will be transferred into 'new' vaults within shallow trenches, the earthen cover can then be removed, the concrete roof, walls floor slab and vault can then be dismantled.

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1. Introduction

1.1. Introduction and Background

The purpose of this report is to identify and describe the current dry storage methodology at AECL's Chalk River and Whiteshell sites. It also describes the implementation of possible RES alternatives for these sites.

The current used fuel dry storage facility at the AECL sites provides interim storage of the used fuel. Implementation of a RES alternative will provide an extended dry storage facility for the used fuel. In the context of this study extended storage means permanent or indefinite storage, with the necessary maintenance and facility repeats.

Three Reactor-site Extended Study (RES) alternatives are being considered for the AECL sites.

- Silos
- Silos in Storage Buildings (SSB)
- Silos in Shallow Trenches (SST)

These three alternatives are described in detail in section 3 of this report. Each of the alternatives under consideration utilises the current dry storage practice at the AECL sites; i.e. the dry storage of used fuel in stainless steel baskets.

1.2. Organisation of Document

The design report is organised into the following sections.

Section 1 Introduction
This section provides an introduction to the report and sets it in the context of the study project.

Section 2 Current Dry Storage Operations.
This section describes the current dry storage activities on each of the reactor sites.

Section 3 Alternative Descriptions
This section provides generic descriptions of the alternatives under consideration, but does not apply the alternatives to specific sites.

Section 4 Site Specific Application of Alternatives
This section reviews each of the alternatives and considers the requirements for instigation of the alternatives to each site.

Section 5 References

1.3. Definitions

Some of the major terms used in this document are described below:

Basket is a sealed container designed to maintain the geometry of a used nuclear fuel bundle arrangement inside a cask, silo or vault. In this report it refers in particular to the type of fuel basket used by AECL.

Canister is the term used by AECL (and others) to describe a Silo. This document will generally use the term silo.

Extended storage means storage for periods of time significantly greater than 50 years from the time the facility is placed into service. In the context of this study it means permanent or indefinite storage.

IAEA International Atomic Energy Agency

Management in relation to used nuclear fuel, means long term management by means of storage or disposal including handling, treatment, conditioning or transport for the purpose of storage or disposal.

Non-Standard Fuel Waste means high-level waste comprised of enriched booster fuel, experimental fuels and other fuel-based nuclear waste.

Reactor Extended Storage (RES) facility is a facility used for the extended storage of used nuclear fuel. The storage facilities will be located at each of the current Reactor sites. Each fuel owner will implement a storage solution selected for the specific circumstances of that site.

Silo describes a cylindrical reinforced concrete structure with a carbon steel liner. It provides shielding and secondary containment for used fuel stored within baskets. The silo shield plug is welded to the silo liner after loading. Provision is made, via valved penetrations, for monitoring and sampling of the interspace between the baskets and the liner. Provision for IAEA safeguard seal, over the shield plug such that the plug can not be removed without breaking the seals are included.

Storage means the placement of used nuclear fuel in a nuclear facility where isolation, environmental protection and human control (e.g. monitoring) are provided. The facility provides containment and shielding as necessary, and dissipates decay heat from the used nuclear fuel. The used nuclear fuel will be stored in such a manner that it could be safely retrieved at any time during the facility service life for transfer to another facility. To ensure safe retrieval the used nuclear fuel will be stored in an environment that ensures the potential effects of fuel degradation over the long term would be mitigated.

Storage Building provides the environment for the long-term storage of the fuel, in the alternatives constructed at ground level. The buildings will be essentially modular and constructed over time to match fuel arrival on site. The buildings will be close together and interconnected to form a Storage Building Complex.

Storage Chamber provides the environment for the long-term storage of the fuel in shallow trenches. Each chamber comprises two storage bays. The chambers will be interconnected modular concrete structures constructed in an open trench and mounded over to form a complex accessible by a ramp from ground level.

Used Fuel means the irradiated fuel bundles removed from commercial or research nuclear fission reactor.

2. Current Dry Storage Operations

2.1. Chalk River Laboratories Site

Chalk River Laboratories (CRL) is a nuclear research establishment with a number of test reactors, fuel inspection and other facilities. The site is approximately 37 square kilometres and is a two hour drive Northwest of Ottawa.
Following the termination of operations at the National Power Demonstration (NPD) reactor which was sited at Rolphton, Ontario, in 1987, the reactor was defuelled and the used fuel shipped to the Chalk River Laboratories (CRL) for storage in its spent fuel bays. Previous shipments of NPD spent fuel had also been stored at CRL. This fuel was later sealed into baskets and was placed into storage silos.
The Chalk River dry l storage area comprises a base slab with 14 concrete silos (storage canisters). Only 11 of the concrete silos are used for fuel storage, the 12th is available as a spare position. The remaining two silos house calcined waste (Refer Figure 5).
The silos were built in 1988 to house fuel from a nearby CANDU research reactor (NPD). They were based on the prototype canisters at Whiteshell Laboratory, which were developed in the 1960/70s.

For the purposes of this study it has been assumed that no additional silos will be constructed at the Chalk River site. However it is possible that additional silos may be built to accommodate future fuel waste from generated either during reactor operations or decommissioning activities.

2.2. Whiteshell Laboratories Site

The Whiteshell Laboratories (WL) are situated in Manitoba. In 1974, the Whiteshell Laboratories started a program to demonstrate the viability of above ground dry storage of spent fuel. Two instrumented concrete canisters, with electrical heaters to simulate decay heat production, were built to verify design computer codes. Two different shapes were demonstrated; the first, a cylindrical canister similar to storage system employed at Point Lepreau; the second, an octagonal canister to store the square baskets containing Douglas Point spent fuel. Some fuel with a cooling time as short as 6 months was handled and stored safely.

The Whiteshell dry storage area comprises a concrete base slab and 16 storage silos. One of the silos contains Douglas Point used fuel bundles and the other 15 silos contain non-standard fuel waste. There is the equivalent of one silo in spare capacity amongst these 15 silos. These silos are not contained within a building; they have been constructed in the open and are passively cooled.

The aforementioned used fuel from the Douglas Point (DP) Reactor was transferred to the Whiteshell Laboratories (WL) for post irradiation examination. The balance of the Douglas Point reactor fuel is stored at the Bruce site. A total of 360 used fuel bundles from DP are currently held at WL. These fuel bundles are contained within 9 fuel baskets that in turn are stored within a concrete silo.

3. Alternative Descriptions

3.1. Silos

3.1.1 General Description

The storage of used nuclear fuel inside sealed steel baskets, with the baskets housed within a concrete silo (canister) is a dry fuel storage system which is used in Canada and in the wider field of used fuel dry storage. The silos are situated out doors and are passively cooled.
The concrete silos are a cylindrical reinforced concrete shell with an internal liner of epoxy coated carbon steel, the liner has an internal diameter of 84.5 cm. The external diameter of the silo is 2.59 m and the height is 6.2 m. A shield plug is inserted into the silo liner after completion of the loading operations (9 baskets).
Provision is made for IAEA safeguard seals to go over the shield plug such that the plug cannot be removed without breaking the seals.

3.1.2 Fuel Retrievability

Fuel retrieval is a reversal of the loading sequence, but the seal welds around the cover plate and the shield plug must be removed before individual baskets can be raised into the shielded fuel basket transfer flask.

3.1.3 Construction Materials

The silos are steel reinforced concrete structures. They are supported on reinforced concrete foundations above the water-table and are placed either directly on bedrock or suitable soils. No bearing capacity problems are anticipated. Settlement of the foundation under the silo load has been studied and is expected to be minimal over the life of the silos.
The concrete mix provides high resistance to weathering and contains additives to enhance the resistance of the silo to the environment.

3.1.4 Sequence of Operations

Silo loading operations (typical)

- Install working platform on duty silo
- Install fuel transfer flask guide mechanism, and bolt to silo
- Centre flask transporter under gantry crane
- Attach auxiliary hoist (10- tonne) to the silo shield plug
- Remove shield plug and raise flask, the two hoists are synchronised to maintain almost continuous shielding. All personnel will vacate the platform before the shield plug is removed.
- Lower basket transfer flask onto silo
- Raise basket off flask door
- Open flask door
- Lower basket into silo
- Disconnect basket from hoist
- Raise hoist
- Close flask door
- Remove flask
- Replace silo shield plug

- Repeat until silo is full (9 baskets)
- Seal weld shield plug
- Seal weld cover plate
- Install IAEA safeguard seals (IAEA Inspector).

3.1.5 Access

Man access to the flask or flask transporter to perform repair, maintenance or recovery activities do not present any unacceptable radiological risks.
The shielding that is provided by the concrete silo structure allows safe access to the body of the silo to facilitate monitoring and inspection.

3.1.6 Cooling and ventilation

The silos are constructed in the open and are cooled by natural convection air flow around the silo array. The maximum temperature for an average basket inside a sealed silo is 155ºC.

3.1.7 Containment

The design feature of the silo storage concept provides double containment of the stored irradiated fuel. The used fuel is packaged in sealed baskets. These provide the primary containment boundary for the used fuel. The sealed storage tube liner provides the secondary containment boundary. The enclosed atmosphere within the sealed silo liner tube provides an environment that can be monitored for fission products, whose presence would indicate a breach of the primary containment boundary.

3.1.8 Shielding

The fuel baskets are not self-shielded. The shielding is provided by the silos. The silo construction ensures that both the facility operators, who are regularly in close proximity to the silos, and the general public, who will be excluded from the storage complex by the facility security systems only receive acceptable levels of radiation exposure.

3.1.9 Water Control

The silos are isolated from surface and ground water by the inclusion of silo covers, surface preparation and a combination of ditching arrangements inside and outside the storage area. Water stops are installed inside the silos to a seal against the ingress of water. The concrete base slab around the silos is graded to promote surface to run-off of rain water or snow melt.

3.2. Silos in a Storage Building (SSB)

The Silos in Storage Buildings (SSB) alternative comprises the storage of fuel bundles in fuel baskets confined in a concrete silo. The silos are arranged within a storage building.

Fuel baskets are transferred to the SSB facility in the basket transfer flask. The basket transfer flask delivers the basket to the dedicated storage building on a powered basket transfer flask transporter.

Key features of the SSB extended storage concept include:

- The facility accepts fuel in basket format
- Fuel is stored within sealed baskets inside sealed tubes in concrete silos
- After fuel receipt, all subsequent fuel movements are under cover, (minimising effects of adverse weather and maximising fuel container life by reducing environmental impact on the 'housing')
- Additional capacity could be provided by the construction of additional storage buildings
- Basket emplacement within the silos is achieved using a transfer flask, this will be transferred to the duty silo building using a transporter and the transfer flask will then be raised onto the storage silo using the silo building crane
- Storage building cooling is achieved by natural convection, through vents and louvers in the building walls and roof.

3.2.1 Storage Buildings

The SSB alternative requires the long-term storage of used fuel in purpose built buildings housing silos for the storage of fuel baskets. The storage buildings are provided to protect the silos and to facilitate all weather operations. The buildings are not required to provide containment of radionuclide emissions, as this is a function of the seal welded liners within the silos, and the shielding is provided by the concrete of the silo structure.

The silo storage building contains an array of silos serviced by an electrically powered overhead gantry crane, with main and auxiliary hoist capability. The gantry crane spans both the silo array, and part of the adjacent operations corridor, which runs parallel to the silo array. The building structure framework for the silo storage buildings will be steel framed buildings with cladding sheets fixed to the primary steelwork. The roofs will be pitched and will be designed and constructed in line with Canadian building codes and regulations for warehouse type structures. The store floors will be finished concrete, and will be designed to cater for all predicted static and dynamic loads.

3.2.2 Fuel Retrievability

If the storage systems for baskets do not perform according to the specification, it will be possible to retrieve the used fuel from storage, to repair the storage system or transfer the used nuclear fuel to a new storage facility.

The SSB facility will be designed to allow safe retrieval of used nuclear fuel from the storage buildings at any point during the service life of the facility. The used fuel storage containers shall be stored so that any individual container can be retrieved at any time during the service life of the storage facility. The silo building crane must be maintained as operational to provide recovery access to the fuel baskets.

The retrieval of a used fuel basket from a specific silo within the SSB storage alternative would require removal of the closing seal weld and removal of the cover plate. The shield plug can then be removed, allowing access to the fuel baskets within.

3.2.3 Construction Materials

<u>Walls</u>

External. The storage building will have pre-cast concrete block walls 0.2m thick, from the ground level to a height of 4.2m. Exterior metal cladding will form the remainder of the wall structure. The metal cladding will incorporate vertical louvers at the upper wall elevations. These louvers form the air inlets for the passive cooling system of the silos within the storage building. The louvers will be designed to prevent the ingress of rain, snow or sand. Screens will

be incorporated into the louvers to reduce the potential for small animals or birds entering the storage facility.
Internal. Concrete block in high traffic areas.

Roof.

The storage building roof will be pre-finished steel material.
The roof will have provisions for drainage of rainwater and melted snow. Exhaust louvers will be incorporated into the roof. These louvers will be designed to allow the flow of 'exhaust air' and will also minimise the retention and build up of water, snow or ice.
The building will be grounded to protect against lightning.

Floor

The storage building floors will be reinforced concrete slabs designed to accommodate heavy wheeled traffic. They will be constructed for minimal maintenance, to retain surface alignment and provide a hard smooth and durable surface. Floors will be graded to provide drainage to floor drains.

3.2.4 Sequence of Operations

In overview, the initial receipt and fuel container transfer operations are outlined below.

Basket Operations

1. Retrieve fuel basket and transfer to SSB storage facility in basket transfer flask
2. Transfer loaded basket transfer flask to silo storage chamber
3. Arrange access to silo identified for loading
4. Locate silo roof gamma gate and withdraw liner shield plug into shielded housing
5. Raise transfer flask from powered transporter and locate onto silo roof gamma gate
6. Lower basket into silo storage liner
7. Repeat until liner is full (9 baskets)
8. Install silo liner shield plug
9. Remove silo roof gamma gate
10. Repeat operations for next silo storage liner

3.2.5 Access

Access into the silo storage building complex is via a roller shutter access door.
The basket transfer flask, is a self-shielded assembly. Baskets will be transferred to the storage buildings in the basket transfer flask, which will be mounted on the transporter. The flask transporter and any accompanying operational personnel will have a direct access to the storage building, through the roller shutter access door.

3.2.6 Cooling and ventilation

Storage Buildings

The silo storage buildings use passive ventilation to provide cooling for the used fuel storage structures. This is achieved by allowing cooling air into the storage building through low level wall louvers and out through high level roof louvers. This enables the decay heat to dissipate from used fuel in storage, to the atmosphere to maintain the storage area below an average ambient temperature of 38ºC in the proximity of silos. The louvers are designed to prevent the ingress of rain, snow and sand. Screens reduce the likelihood of small animals or birds entering the building through the ventilation system. The roof louvers are also designed to minimise the retention and build-up of water, snow or ice.

3.2.7 Shielding

The monolithic concrete structure and the closure plug unit in each storage silo provides the necessary radiation shielding. The silo construction provides a minimum shielding thickness of 860 mm of concrete, which ensures that the dose rate from the silos when fully loaded is below acceptable levels.

3.2.8 Containment

Fuel baskets, which are housed inside steel liners within concrete silos, provide two levels of containment for the used fuel. The primary containment for the fuel is the fuel basket. The basket is seal welded at the reactor site and is not compromised by any of the subsequent operations. The secondary containment, the silo liner, is only considered a containment boundary after successful completion of the top seal plate weld. The integrity of the secondary containment can be verified, since valved access lines are incorporated which penetrate the containment boundary. The air interspace between the containments can thus be monitored for fission products, whose presence would indicate a breach of the primary containment boundary.

3.2.9 Water Control

The storage buildings are engineered to ensure that the building fabric is generally weather tight. The only exceptions to this are the cooling penetrations. The storage buildings are cooled by the flow of ambient air through inlet louvers. These inlet louvers are arranged at low level, with the exhaust louvers at high level. Both sets of these louvers are arranged, and engineered such that the potential for the ingress of rain or snow is minimised. The floor in the storage buildings falls to a floor drain to collect any liquid arisings. This will drain to a collection sump where it can be sampled and disposed of accordingly. Space heaters may be provided to increase the ambient temperature in the store during cold weather and as the heat generated by the fuel bundles decreases in time to reduce condensation within the buildings.

3.3. Silos in Shallow Trenches (SST)

The Silos in Shallow Trenches (SST) concept comprises the storage of fuel baskets confined in concrete silos. The silos will be housed in a chamber with concrete floor, walls and roof constructed in a shallow trench and mounded over with earth cover. The chamber will be accessible by a ramp from ground level. The earthen cover will be applied over the roof and will be designed to protect the chamber structures against freeze/thaw and wetting and drying cycles, divert surface water, limit water infiltration, resist weathering, erosion and burrowing animals. The earthen cover will also lessen the visual impact of the storage complex.

Fuel baskets are transferred to the SST facility in the basket transfer flask. The basket transfer flask delivers the basket to the dedicated silo in the relevant storage chamber on a powered basket transfer flask transporter.
Key features of the SST extended storage concept include:

- The facility accepts fuel in basket format
- Fuel is stored within sealed tubes in concrete silos
- Additional capacity provided by the construction of storage chambers on a rolling program

- After fuel receipt, all subsequent fuel movements are under cover, (minimising effects of adverse weather and maximising fuel container life by reducing environmental impact on the 'housing')
- Basket emplacement within silos achieved using a transfer flask
- A single 30 tonne gantry crane is used to pick up the transfer flask and place it on top of the silo for transfer of the baskets into the silo storage tube
- A trolley cart running on rails in the access corridor is used to move the gantry cranes between the storage chambers
- The earthen cover is designed to minimise precipitation infiltration and promote surface run off
- The engineered earthen cover and concrete chamber structure provide an improved level of intrusion resistance
- Cooling and ventilation for the storage chambers will be achieved by natural ventilation to regulate the temperature inside the chambers to suit operational requirements
- The chamber complex will be constructed approximately 5m below site grade.

3.3.1 Storage Chambers

The design capacity of the storage chamber complex is based on the individual site inventory.

The silo inventory will be housed in storage chambers. It will contain an array of concrete silos serviced by a 30 tonne capacity electrically powered overhead gantry crane. The gantry crane will span the silo array.
The silo storage chamber will be linked to the receipt building, at grade level by a ramp.
The storage chamber and connecting corridors will be cast in place reinforced concrete structures designed and constructed in accordance with Canadian building codes and regulations for this type of structure. The floor, walls and roof will be designed and detailed to safely withstand all predicted loads. Each chamber and parts of the corridors at the front and the back will be structurally independent and separated by isolation joints from adjacent chambers. An adequate number of joints will be introduced along the length of the chamber to prevent uncontrolled cracking of the chamber walls and slabs. The exterior surface of the walls and roofs will be coated with a 40-mil polymer coating before placing the earth cover to ensure the long-term life of the storage complex.

3.3.2 Fuel Retrievability

If the SST storage system does not perform according to the specification, it will be possible to retrieve the used fuel from the storage silo, so as to repair the storage system or transfer the used nuclear fuel to a new storage facility.
The SST facility will be designed to allow safe retrieval of used nuclear fuel from the storage complex at any point during the service life of the facility. The used fuel storage containers shall be stored so that any individual container can be retrieved at any time during the service life of the storage facility. The silo building crane must be maintained as operational to provide recovery access to the fuel baskets. To retrieve a used fuel basket from a specific silo would require removal of the closing seal weld and removal of the cover plate. The shield plug can then be removed, allowing access to the fuel baskets within.

3.3.3 Silo Storage Chamber

The interior dimensions of the silo storage chambers will be 29m wide and of suitable length to house the fuel inventory. The floor of the chamber will be sloped toward the corridors at both ends. As a result, the height of the chamber varies from both ends to the centre. The chamber roof carrying the soil cover will be supported on the sidewalls. Each storage chamber will be provided with an elevated rail track mounted on 1.0m wide curb on each side to receive the 30 tonne gantry crane used for basket storage. The clear width between the side curbs and the clear height under the gantry are based on utilising the crane to pick up the transfer flask and place it on top of the silo for transfer of baskets to the storage silo.

3.3.4 Earthen Cover

The earthen cover above the storage chambers will be approximately 3.5m thick and will be crowned in the centre with one - percent slope to the sides. The cover will be made up of the following layers, from top to bottom:

- Topsoil layer, 0.7m
- Backfill material, 0.3m
- Drainage material, 0.3m
- 60-mil HDPE geomembrane
- Compacted clay liner, 0.3m
- Compacted backfill material, varies 1.9m maximum

The cover will have a side slope of 3 horizontal to 1 vertical. The service life of the earthen cover is assumed to exceed the concrete structure beneath, providing the outer surfaces of the earthen cover are properly maintained.

3.3.5 Sequence of Operations

In overview, the initial receipt and fuel container transfer operations are outlined below.

Basket Operations

1. Retrieve fuel basket and transfer to SST storage facility in basket transfer flask
2. Transfer loaded basket transfer flask to silo storage chamber
3. Arrange access to silo identified for loading
4. Locate silo roof gamma gate and withdraw liner shield plug into shielded housing
5. Raise transfer flask from powered transporter and locate onto silo roof gamma gate
6. Lower basket into silo storage liner
7. Repeat until liner is full (9 baskets)
8. Install silo liner shield plug
9. Remove silo roof gamma gate
10. Repeat operations for next silo storage liner

3.3.6 Access

Access to the chambers will be via an enclosed ramp that goes from the surface to the chamber via the access corridor at a 2.5 % gradient. The interior dimensions of the ramp will be 8m wide and 6m high. The ramp will be reinforced concrete similar to the chamber construction.

3.3.7 Cooling and Ventilation

Cooling and ventilation for the storage chambers will be provided by natural ventilation based on the principles of the raiser effect, supplemented by heat released from the silos. A vertical raiser constructed on top of the chamber will rise above grade level to induce the raiser effect required for ventilation. Rain hoods will be provided at the top of the raisers to prevent any ingress of rain or snow. An air intake house with weather louvers will be located at grade level above the access corridor, at one end of the storage chamber, to allow ambient air to infiltrate the trench, due to the negative pressure generated within the chamber, created by the raiser effect.

The airflow through the storage chamber will be set manually by adjusting the dampers or openings located at the exhaust raiser. The damper or opening will be adjusted and locked in place to provide the necessary air flow through the chamber.

During initial periods of storage and when personnel are conducting inspections of the storage facility, forced air ventilation systems located above the access corridor may be utilised to supplement the passive ventilation system. This will only be necessary before the storage chamber is fully loaded, as a partially loaded storage chamber may not provide enough energy to initiate the natural convection flow of air.
Escape ladders to grade level will be provided in the ventilation corridor for emergency exit.

3.3.8 Shielding

The shielding provided by the silos ensures that both the facility operators, who are regularly in close proximity to the storage structures, and the general public, who will be excluded from the storage/processing complex by the facility security systems only receive acceptable levels of radiation exposure. The design and construction of the storage trenches provides supplementary shielding to personnel who are outside the trench, thereby further reducing the available dose rate to the public.

3.3.9 Water Control

Water control is a function of site conditions and the implementation of specific construction design solutions. For the purposes of this study it is assumed that the SST will be constructed in a low permeability glacial till deposit where the water table is located at least 1m or more below ground surface.
The following measures have been incorporated into the construction and design to minimise the potential for the ingress of water into the chambers.

- A high-density polyethylene liner will be incorporated in the earth cover above the chamber complex.
- The earth cover will be sloped toward perimeter lined ditches to collect surface runoff from precipitation.
- Perforated drainpipe will be installed outside around the perimeter of the chambers and corridors to prevent seasonal rise of the ground water table above the floor slab level. The perforated pipes located between the walls of the chambers will drain into solid pipes encased in concrete placed under the floor slabs.
- Water from the ditches and drainpipes will be collected in catch basins and pumped to the site collection pond.
- Water stops will be provided in all construction and control joints in the floors, walls and roofs of the chamber complex.

- As an added precaution, the floor of the chambers will be sloped toward trenches in the access and ventilation corridors. The trenches will be sloped towards collection sumps.
- Water entering the chamber complex will be pumped to a separate pond for monitoring before being discharged.

The collection sumps within the chambers will be equipped with monitors and alarms to provide indication of the operational condition of the pumping systems. Water level monitoring within the sumps will be provided to warn of any increase in level, above that normally allowed. Failure of the pumping system to control the water level will result in remedial action being initiated. This remedial action could include introducing a temporary additional pumping system, or the introduction of a system with increased capacity. Short-term increase in the water levels within storage chambers would not represent a safety significant event.

4. Site Specific Application of Alternatives

This section of the report describes the site-specific application of the following alternatives on the Chalk River and Whiteshell sites:

- Silos
- Silos in Storage Buildings (SSB)
- Silos in Shallow Trenches (SST)

Should there be decision made to implement reactor-site extended storage based on the Silo technology, then this alternative could be implemented immediately following government decision. AECL would continue to store fuel in silos as is being done at the present time. New approvals would be sought, as necessary, for refurbishment/replacement of the storage structures, periodic repackaging of the fuel and decommissioning of facilities. For the purpose of this study it has been assumed that a government decision to implement reactor-site extended storage would be made no sooner than July 2006.

Should there be decision made to implement either the SSB or SST technology, then additional time would be required following the decision to transition to new dry storage systems on each of the reactor sites. Additional time would be required to locate suitable sites, to develop site specific designs, to gain all necessary approvals, and to construct and commission new facilities. Therefore, for the purposes of this study, it has been assumed that the earliest in-service date for a facility based on either SSB or SST technology would be January 2016. Following in-service, the new dry storage facilities would operate indefinitely with refurbishment/replacement of the storage structures and periodic repackaging of the fuel.

The RES alternatives under consideration for the AECL sites utilise the used fuel basket as the primary containment in storage.

The existing interim used fuel dry storage facilities at the AECL sites will be used until the end of their service lives (Refer Table 1).

It is envisaged that the fuel baskets removed from the existing storage facilities, have not reached the end of their service lives, and can be transferred to storage in replacement storage facilities outlined below.

4.1. Chalk River Laboratories Site

There are approximately 4,853 equivalent fuel bundles in an array of 14 dry storage silos on the CRL site. Most of the bundles are "standard" natural UO_2 fuel bundles. The remainder of the inventory is comprised of slightly enriched fuel bundles and partial bundles, and loose elements. These non-standard fuel wastes are stored in 95 baskets in 11 silos.
In addition there are calcined wastes stored in 2 silos and there is one silo maintained as a spare position.

4.1.1 Silos

Implementation of silos as the selected RES alternative will not require any changes to the current on site storage philosophy. The existing silo array (Refer Figure 5) comprises a total of 14 silos. As the silos (14 off) reach the end of their design life (Refer Table 1), a repeat silo array will need to be constructed. This silo array will be constructed as close as practical to the existing silo array. Transfer between the ‘old’ and ‘new’ silos will utilise the conventional basket transfer methodology, in a reversal of the original silo loading operations.

4.1.2 Silos in a Storage Building (SSB)

Implementation of the SSB as the selected RES alternative will initially require the construction of a storage building over the existing silo array. The design life of the silos and the storage buildings are both 100 years. If a storage building is constructed over the existing silos, the silos will reach the end of their design life before the storage building. It would not be economically practical to demolish and replace silos in the erected building, therefore the silos and the storage building should both be considered to have reached the end of their design life when the original silos approach 100 years (Refer Table 1). When replacement silos are required basket transfers between the ‘old’ and ‘new’ silos will utilise the conventional shielded basket transfer flask sequence of operations, these operations will be a reversal of the original loading techniques.
The SSB facility at Chalk River will comprise a single storage building. The silo storage building will be constructed over the existing silo array. The silo storage building will house a basket flask handling crane, capable of lifting the basket transfer flask up to the silo loading/unloading operating height. Locally arranged platforming arranged around the storage silo being loaded will ensure safe access for operators performing loading/unloading operations.

4.1.3 Silos in Shallow Trenches (SST)

Implementation of SST as the selected RES alternative requires the creation of a series of silos, housed within a shallow trench, although continued storage in the existing facilities until the end of their design service-life may be considered.
Conversion to a SST facility will require the transfer of all of the fuel baskets from the original silo storage into the silos within the shallow trench. The basket transfer will be accomplished using the conventional basket transfer flask. This flask will be used to retrieve the baskets from the silos and will then interface with the shallow trench gantry crane and the silo gamma gate. Sequenced operation of the silo gamma gate, the shielded transfer flask gamma gate and the flask hoist will enable basket transfers from the flask into the silo.
The SST facility at Chalk River will comprise a single storage chamber. The storage chamber will have capacity for fourteen (14) storage silos, arranged in an array. The total fuel inventory (4,853 fuel bundles, stored in 95 fuel baskets) will occupy eleven (11) storage silos (9 baskets per filled silo), two (2) will house calcined wastes, with the fourteenth (14th) silo available as a spare position (Refer Figure 8).

The existing silo array will become redundant after the fuel baskets have been transferred into the 'new' shallow trench silos. The existing silos will be decommissioned and dismantled. Each silo comprises approximately 11 tonnes of steel and 70 tonnes of concrete.

When the SST silos reaches the end of their design life a new vault will be constructed and the fuel baskets transferred from the 'old vault to the 'new' using a reversal of the vault loading operations. Transfer between the 'old' and 'new' vaults will utilise the conventional basket transfer methodology. When the concrete structure of the shallow trench requires replacement the fuel will be transferred into 'new' vaults within shallow trenches, the earthen cover can then be removed, the concrete roof, walls floor slab and vault can be dismantled.
The waste volumes generated from the dismantling of the storage chamber are approximately 350 tonnes of steel and 7,100 tonnes of concrete.
Once a storage trench has been cleared a replacement vault and trench can be constructed on the same land as the previous construction, and the earthen cover can be replaced.

A single inlet air louver and one ventilation exhaust raiser will serve to passively ventilate the storage complex, thereby providing cooling for the silos in the storage chamber.

4.2. Whiteshell Laboratories Site

The Whiteshell Labourites (WL) Site was originally responsible for the Post Irradiation Examination (PIE) of used fuel that had been transferred from the Douglas Point reactor site. This used fuel from Douglas Point is held in dry storage at WL. Other Non-standard fuel waste material is also held in baskets, in dry storage within the WL storage silo array.

4.2.1 Silos

Implementation of silo storage as the selected RES alternative will not require any changes to the current on site storage philosophy.
The existing silo array (Refer Figure 11) comprises a total of 16 silos.
The silo array is located on a prepared site about 1000 m to the Northeast of the plant site. The site was excavated to a depth 0.6 m and then backfilled with gravel to the original elevation. The centre-to-centre silo spacing is 7.5 m within a row and the silo rows are 9 m centre-to-centre apart. Each silo is located on a pad of reinforced concrete 3.66 m square and 0.2 m thick.
The existing silos are used to house used fuel baskets and non-standard fuel waste. Each used fuel storage silo is designed to accommodate 9 baskets.
As the used fuel silos reaches the end of their design life (Refer Table 1), a repeat silo array will need to be constructed. This silo array will be constructed as close as practical to the existing array. Transfer between the 'old' and 'new' silos will utilise the conventional basket transfer methodology, in a reversal of the original silo loading operations.

4.2.2 Silos in a Storage Building (SSB)

The SSB facility at Whiteshell will comprise a single storage building. The storage building will be designed and constructed to house sixteen (16 silos). The total fuel inventory (360 fuel bundles, stored in 9 fuel baskets) will occupy 1 storage silo, the remaining silos will contain non-standard fuel waste or will be designated as spare (Refer Figure 12).
The initial silo storage building will be constructed over the existing silo array. The design life of the silos and the storage buildings are both 100 years. If a storage building is constructed over the existing silo array, the silos will reach the end their design life before the storage building. It would not be practical to demolish and replace silos within the erected building, therefore the

silos and the storage building should both be considered to have reached the end of their design life when the original silos approach 100 years. When a replacement silo array is required basket transfers between the 'old' and 'new' silos will utilise the conventional shielded basket transfer flask operating techniques.

The earliest a SSB alternative could be implemented, if it became the preferred RES alternative would be January 2018.

The silo storage building will house a basket flask handling crane, capable of lifting the basket transfer flask up to the loading/unloading operating height.

Locally arranged platforming around the storage silo being loaded will provide safe access for operators performing loading/unloading operations.

4.2.3 Silos in Shallow Trenches (SST)

The SST facility at Whiteshell will comprise a single storage chamber. The storage chamber will house sixteen (16) storage silos. The used fuel inventory (360 fuel bundles, stored in 9 fuel baskets) will occupy 1 storage silo, the remaining silos will contain non-standard fuel waste, with one silo designated as a spare (Refer Figure 13).

The existing silo array will become redundant after the fuel baskets have been transferred into the 'new' shallow trench silo. The existing silos will be decommissioned and dismantled. The earliest a SST alternative could be implemented, if it became the preferred RES alternative would be January 2018.

Each silo comprises approximately 11 tonnes of steel and 70 tonnes of concrete.

When the building fabric of the shallow trench requires replacement (Refer Table 1) the fuel will be transferred into 'new' silos within shallow trenches, the earthen cover can then be removed, the concrete roof, walls floor slab and chamber can be dismantled.

The waste volumes generated from the dismantling of the storage chamber are approximately 400 tones of steel and 8,000 tonnes of concrete.

4.3. Operations – Extended Monitoring

The extended monitoring stage of the operational phase will be a relatively dormant, passive operational phase. The principal activities undertaken during the extended monitoring stage are described below.

4.3.1 Storage structures

With particular respect to the SST, buried concrete structures, if designed and constructed to meet stringent quality control requirements and the temperature and humidity inside is maintained within a moderate range, will last for hundreds of years essentially maintenance free. However, a program for periodic checking of the concrete floors, walls and roofs for signs of deterioration will be established as part of the monitoring program. The internal drainage systems will have to be checked to ensure that the pumps are in good operating condition and that the trenches and collection sumps are free of sediments. The outside drainage systems and the level of the ground water table will also have to be monitored to ensure that the perforated pipes are not blocked and the collection sumps and pumps are in good operating condition. Signs of leakage of water from precipitation through the HDPE geomembrane will also have to be monitored.

4.3.2 Fuel Condition Monitoring

Throughout the period of extended storage, fuel condition monitoring activities will be performed. It is not intended to remove used fuel from its storage location, for the purpose of examination.

The fuel condition monitoring will comprise:

- Direct monitoring/surveillance during fuel during packaging operations
- Selection of fuel samples for examination during re-packaging (i.e. a verification step at every repeat cycle)
- Continuous monitoring of storage facility parameters (such as temperature, ventilation exhaust gases) at various locations
- Operation of a test facility where test containers or modules are monitored in greater detail, e.g. via sampling of containment gases and monitoring of the containment structure internal temperatures
- Implementation of a parallel program for shielded-cell examination of the fuel stored in the test facility.

The test facility will be equipped to support non-routine operations. It shall be capable of housing the test containers and monitoring the relevant storage parameters.

Generically, where the alternatives provide the possibility of monitoring the atmosphere local to the fuel bundle containers, an in situ monitoring program will be implemented. In the case of basket storage, this will involve the sampling of the storage tube atmosphere.
With operating experience, it may be possible to extend the intervals between inspections.

During repackaging events, fuel will be withdrawn from module canister, module and basket containers. These infrequent events provide the opportunity for facility operators to directly view and assess the condition of fuel bundles and make comparison with test facility predicted observations.

4.3.3 Silos

The silo storage system is a passive system, requiring minimal attention by operational staff a monitoring and inspection programme will be followed to verify that the system is functioning correctly.
The programme will be broadly in-line with the schedule outlined below:

An annual physical inspection of the silo site, the foundations, the security fence and the surveillance equipment. Particular attention to be paid to the silo fabric, to check for any deterioration, cracking or spallation of the concrete.

Activities will include a radiation survey and internal silo atmospheric monitoring by connection to valved tappings in each silo liner, which terminate at dedicated connection points on the silo outer walls.

4.3.4 SST

Although the vault storage system is a passive system, requiring minimal attention by operational staff a monitoring and inspection programme will be followed to verify that the system is functioning correctly.

The programme will be broadly in-line with the schedule outlined below:
An annual physical inspection of the vault site, the foundations, the security fence and the surveillance equipment. Particular attention to be paid to the vault fabric, to check for any deterioration, cracking or spallation of the concrete.
Activities will include a radiation survey and internal storage tube atmospheric monitoring by connection to valved tappings in each storage tube, which terminate at dedicated connection points on the vault outer walls.

4.4. Operations – Facility Repeats

Storage facilities and principal containment structures have a finite life span. An estimate of the likely minimum service life of the various fuel containers and the structures used to house the fuel containers are presented in Table 1.
It will be necessary to move fuel baskets from an ageing storage complex to new facilities. Depending on the alternative under consideration, this may be achieved by the staged building of additional storage capacity, permitting the transfer of fuel containers from one storage location to another. Once the used fuel has been transferred and the storage unit has been emptied, the redundant building will be demolished.
It is assumed that the storage structures will receive suitable maintenance throughout their service lives, but may ultimately deteriorate, due to normal wear and tear, and weathering processes. Periodically, the storage facilities will be replaced or refurbished, appropriate to the extended storage alternative under consideration. In some instances, the extended storage facility may be beyond repair. It is assumed that the order in which the individual units (storage buildings or shallow trench chambers) reach the end of their service life will replicate the order in which the facilities were constructed.

Broadly, the steps necessary to perform a building repeat cycle are:
- Construction of a new storage facility,
- Provision of appropriate fuel package handling equipment,
- Establish a fuel transfer route,
- Transfer fuel packages from the redundant storage facility,
- Refurbish empty storage facility, if appropriate,
- Demolish empty storage facility, if appropriate.

4.4.1 Silo

As a silo reaches the end of its design life, a replacement silo will be constructed in readiness for a transfer of the fuel baskets from the ‘old’ silo to the ‘new’. The transfer of the baskets will be a reversal of the initial loading operations.
The redundant silo structure will be monitored, and if necessary decontaminated and dismantled. Each silo comprises approximately 11 tonnes of steel and 70 tonnes of concrete. The concrete can be crushed and reinforcing bar will be removed for separate disposal.

4.4.2 SST

There are two aspects of the SST alternative that will require independent repeat, these are:

Silos

As 4.4.1 silos above.

Storage Chambers

When the storage chamber reaches the end of its service life it will be necessary to remove all of the fuel from the silos, in line with the procedure outlined above. The silos will be dismantled and the storage chamber will then become the focus of the dismantling activities.
Once the old storage chamber has been emptied, the earthen cover is removed, and the concrete roof, wall and floor slabs will be dismantled. The waste volumes generated from the dismantling of the storage chamber are 350 tonnes of steel and 7,100 tonnes of concrete, for the Chalk River chamber and 400 tones of steel and 8,000 tonnes of concrete for the Whiteshell chamber.
The concrete will be crushed and reinforcing bar removed for separate disposal.
Once a storage chamber has been cleared a replacement storage chamber can, when necessary be constructed and the earthen cover restored.

4.5. Operations – Repackaging

4.5.1 General

Periodically, and on a longer time frame than storage facility repeats, the used fuel bundles will be removed from their existing baskets and transferred to new baskets. This transfer will be effected within a shielded facility. The shielded facility will be housed within a larger building, the Processing Building.
The building will be capable of receiving baskets in shielded flasks, delivered on suitably powered trucks.
The shielded cell complex will permit the opening of seal welded baskets and the withdrawal of the fuel bundles within. The fuel bundles will be inserted into ‘fresh baskets’, and the basket assembly seal welded.
Baskets containing non-standard fuel and calcined waste will be treated similarly to the baskets containing used fuel. The facilities required for repackaging the non-standard fuel waste will include a shielded cell and will be similar to those required for the used fuel. These facilities are not considered in detail within this report.

4.5.2 Fuel Basket Repackaging

The fuel basket transfer operations will be performed in a dedicated shielded cell. The shielded cell will handle a feed of individual fuel baskets. Each basket will be recovered from the existing storage facility by the means described in the facility repeats section. Rather than going directly to a new storage facility, the basket will be diverted to the repackaging cell, and loaded through the shielded cell roof, via a dedicated shielded port.
The existing basket will then be transferred to a dedicated position within the cell, using an in cell handler. The peripheral seal weld and the central lifting post welds will be machined or ground off. Any gaseous fume and weld grinding particulate will be contained within the dedicated enclosure, and drawn off via a local ventilation extract system. The existing basket is then returned to its set down position, and the basket lid lifted from the basket body. Concurrent with the basket weld removal operations, a new basket will be loaded into the cell. The new basket lid will then be lifted clear of the body.

Within the shielded cell, a fuel bundle transfer hoist will be deployed. The machine will have two set down positions, one for the existing basket body, complete with fuel bundles, the second set down position will accept the new basket body. The two basket bodies will be aligned (either by rotation of two turntable bases on which the baskets will sit, or the in cell handler will employ an optical recognition system) to permit accurate fuel bundle transfer operations.

The fuel bundle transfer hoist will comprise a lightweight x-y motion crane, with a z-axis retractable mast. The hoist will be furnished with a 4-jaw grab, which will have a limited gripping effect. The operator, viewing the procedure through shielded windows and cameras as appropriate, will hoist, cross travel and lower individual fuel bundles from the existing basket to the new basket. Once the transfer process has been completed, the basket lids will be returned to their respective bodies and the baskets returned to their set down positions, using the in cell handler.

The new basket, with fuel bundle contents, will then be transferred to an in cell basket transfer bogie, which will shuttle the fuel basket into a basket welding cell. Following completion of the welding operations (basket lid to base, and basket lid to central lifting post), the in cell basket transfer bogie will return the fuel basket to the main shielded cell. The in cell transfer bogie will be aligned with a dedicated shielded port in the cell roof, and the fuel basket winched into a shielded transfer flask.

The now redundant basket will be lifted from its dedicated set down position, and lowered through a shielded hatch into a decontamination cell, located at a level below the shielded cell. Each basket weighs 450 kg of steel, and occupies a volume of 0.476 m^3. Once decontaminated there is considerable potential for volume reduction of this material prior to its release from the site as scrap.

5. References

1 Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel. (Ontario Power Generation) CTECH Report No: 1105/MD18084/REP/12 December 2002

2 Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel. (New Brunswick Power) CTECH Report No: 1105/MD18084/REP/13 December 2002

3 Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel. (Hydro-Québec) CTECH Report No: 1105/MD18084/REP/14 December 2002

4 Conceptual Designs for Four Centralized Extended Storage Facility Alternatives for Used Nuclear Fuel. CTECH Report No: 1105/MD18084/REP/08 September 2002.

Table 1: Assumed Service Lives for Facility Components

Component	Silos	SSB	SST
Basket	300	300	300
Silo	100*	100**	100**
Storage Chamber			200
Storage Building		100	
Processing Building***	30	30	30

Notes

* The service life for the out door silos represents a best case figure based upon a pro-active preventative maintenance routine.

** The figure for the covered storage silo reflects concern over the concrete/steel interface, which may preferentially corrode the storage tubes within the silo structures, and ultimately defeat the secondary containment.

*** The Processing Building is not required during initial facility operations, it will be required for repackaging operations.