Radioactive Materials Management

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

Alternatives for Hydro-Québec's Gentilly Reactor Site

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

April 2003

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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 RES alternatives for consideration at the Hydro-Québec Gentilly site. 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 the Gentilly 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 Atomic Energy of Canada Ltd [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 a technical description of the RES used fuel storage alternatives being considered for the Gentilly site. The alternatives under consideration within this report are:

- Vaults
- Surface Modular vault (SMV)
- Vaults in Shallow Trenches (VST)

The first two alternatives are above ground facilities. The VST is partially below ground and will be mounded over with an earthen cover. This will reduce the visual impact of the facility and provide increased protection against intrusion.

Vaults

Implementation of Vaults as the RES alternative represents a continuation of the current on site interim storage arrangements.
Five vaults currently exist and will provide available storage capacity until 2003. Additional vaults will begin to be constructed in 2004. Table 1 identifies the additional vault construction schedule and the assumed basket transfer rate from the wet bays into the storage vaults.
If the Vault alternative is selected, then the vault-loading schedule will continue until 2023, at this time all of the anticipated used fuel on the Hydro-Québec site will be dry stored within Vaults. The current vaults are located within an area that is capable of accommodating the total fuel inventory requirements of the Gentilly site (12 vaults).
Implementation of the Vaults alternative as the preferred RES solution will result in continued use of the current storage operations and facilities.
The used fuel from Atomic Energy of Canada Limited (AECL) Gentilly 1 reactor will be transferred from the silos in which it is currently stored into a vault after all Gentilly 2 fuel has been successfully transferred.

Surface Modular Vault (SMV)

Creation of a SMV as the preferred RES alternative will result in the construction of a single storage building, comprising 4 SMV vaults.
The 4 vaults provide adequate capacity for the total used fuel inventory. Each vault has a capacity of 600 baskets, housed within 60 tubes in a 5 x 12 tube array. The SMV is passively cooled with inlet and exhaust louvers integrated into the store and cover building design.

The interim storage facilities, which exist at the time of implementation of the SMV (Year 2020), will become redundant. The 9 existing vaults, which will contain 1,800 baskets, will be emptied and the fuel progressively transferred into the SMV. The empty vaults will be monitored and dismantled, with the waste material, steel and concrete, removed from site. The construction of the SMV vaults will be performed in a phased manner. The initial stage of construction will see the first SMV vault and the cover building constructed (in 2019), with the subsequent SMV vaults generated in-line with the construction sequence outlined in Table 2.

Vaults in Shallow Trenches (VST)

Implementation of the VST alternative will result in a vault array (12 vaults in total) being constructed longitudinally within two storage chambers. The chambers consist of two storage

bays. Each storage bay has provision for four vaults, three will be constructed with space for the fourth reserved for facility repeat operations.

The interim storage facilities that exist at the time of implementation of the VST (2020) will become redundant. The 9 existing vaults, which will contain 1,800 baskets, will be emptied, with the fuel transferred into the vaults generated for the VST alternative.

The empty vaults will be monitored and dismantled, with the waste material, steel and concrete, removed from site. The construction of the vaults within the shallow trench and the dismantling of the redundant surface vaults will be performed in a staged manner, in-line with the construction sequence outlined in Table 3.

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1. Introduction

1.1. Introduction and Background

The purpose of this report is to describe potential RES alternatives for the Gentilly site. The report first describes the current fuel storage methodology used by Hydro-Québec. Subsequent sections of the report describe the changes necessary at the Gentilly site in order to implement any of the RES alternatives under consideration.
The current or planned used fuel dry storage facilities at the Gentilly site will provide interim storage capability for used fuel owned by Hydro-Québec and AECL. Implementation of RES alternatives on the site 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 RES alternatives are being considered for Hydro-Québec's (HQ) Gentilly site:

- Vaults
- Surface Modular Vault (SMV)
- Vaults in Shallow Trenches (VST)

Currently all of the used fuel bundles (Refer Figure 1), contained on the HQ site are either in wet bays awaiting transfer into baskets (Refer Figure 2), or are already in baskets which are housed within vaults. The exception is the AECL Gentilly 1 used fuel. This fuel is currently housed in baskets, which are stored inside concrete canisters (silos). The silos have been constructed inside a redundant Gentilly 1 turbine building. The fuel within these concrete canisters although owned and controlled by AECL is assumed to be integrated into the alternatives under consideration for the HQ used fuel.
These three alternatives are described in detail in section 3 of this report. Each of the alternatives under consideration assumes used fuel will continue to be stored in stainless steel baskets.

1.2. Organisation of Document

The design report is organised into the following sections.

Section 1 Introduction and Background
This section provides an introduction to the report, background and context information, and definitions of key terms

Section 2 Current Used Fuel Storage Operations.
This section describes the current used fuel storage activities on the reactor site.

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

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

Section 5 References

1.3. Definitions

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, canister or vault. In this report it refers in particular to the type of fuel basket used by Hydro-Québec.

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.

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.

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 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.

Vault is a large monolithic reinforced concrete structure. It provides shielding and secondary containment for used fuel stored within baskets. The vault shield plug is welded to the vault liner after basket loading. Provision is made, via valved penetrations, for monitoring and sampling of the interspace between the baskets and the liner. Provision for IAEA safeguard seals over the top of the shield plug such that the plug can not be removed without breaking the seals are included.

2. Current Used Fuel Storage Operations

The Gentilly site is situated on the banks of the Saint Lawrence River, it is generally flat and open and is 15 km from the town of Trois-Rivières. The site is owned and operated by Hydro - Québec.

The Gentilly site houses two reactors, Gentilly 1, owned by AECL, which is awaiting decommissioning, and Hydro-Québec's Gentilly 2, which is operational and has a generating capacity of 675 megawatts (Refer Figure 3).

The Gentilly 1 reactor has been de-fuelled and is no longer operational. The total number of Gentilly 1 used fuel bundles currently held in dry storage on the HQ site is 3,213 bundles.

The used fuel is currently held within 85 baskets, which in turn are stored within an array of concrete canisters (silos) inside a redundant turbine building.

The baskets are stacked 9 high within the concrete canisters, and a total of 11 canisters have been constructed to house the Gentilly 1 used fuel. There are 38 fuel bundles in each Gentilly 1 fuel basket.

This used fuel is owned by AECL and is monitored and controlled within a compound for which AECL retain responsibility. The AECL 'compound' is within the general Hydro-Québec, Gentilly site. For the purposes of this study it is assumed that the Gentilly 1 fuel will remain on this site and will be integrated into whichever RES alternative is selected for implementation.

The fuel inventory for the current projected life of the Gentilly 2 reactor is 132,838 used fuel bundles. The Gentilly 2 reactor is currently scheduled to be shutdown in October 2013.

Fuel that has been discharged from the reactor will be held within the Irradiated Fuel Bay (IFB) for a minimum of 7 years prior to the fuel being transferred into fuel baskets.

After the cooling period in the IFB the used fuel is loaded into baskets. This operation is conducted within the IFB, with the basket submerged. When the used fuel is loaded into the basket body, (60 fuel bundles per basket), the basket cover is then placed onto the body. The loaded basket is then raised into a shielded workstation where the basket and fuel are dried by heated air. The cover is then seal welded to the basket base using automatic welding equipment. The dried and sealed basket is then ready for loading into the shielded flask, which in turn is loaded onto a transporter for the transfer to the concrete vault storage area.

The Gentilly 2 baskets are stored within concrete vaults. Each vault is designed to hold 200 baskets, (10 baskets per vault liner) these baskets will be stored in 20 liners.

Currently 5 basket concrete vaults have been constructed which house the fuel currently available for dry storage. The concrete vaults are constructed in the open and are passively cooled (Refer Figures 4 and 5).

The Gentilly 2 projected used fuel inventory, combined with the Gentilly 1 used fuel will require a total of 12 vaults to be constructed to house the combined fuel inventory.

3. Alternative Descriptions

3.1. Vault

3.1.1 General Description

The Vault concept comprises the storage of fuel baskets confined in concrete vaults. The vaults are constructed in the open on a concrete foundation slab.

Fuel baskets are transferred to the RES facility in the basket transfer flask. The basket transfer flask delivers the basket to the dedicated vault on a powered transporter.

Key features of the Vault extended storage concept include:

- The vaults accepts fuel in basket format
- Fuel is stored within sealed tubes in concrete vaults (each vault storage tube holds 10 baskets)
- Additional capacity provided by the construction of storage vaults on a rolling program
- Basket emplacement within vaults 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 vault for transfer of the baskets to the storage tubes in the vault
- Cooling and ventilation for the Vault is achieved by natural ventilation to regulate the basket temperature inside the Vault.

3.1.2 Fuel Retrievability

If the Vault storage system does not perform according to the specification, it is possible to easily retrieve the used fuel from the storage vault, so as to repair the vault or transfer the used nuclear fuel to a new storage facility.
The RES facility is 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 baskets are stored so that any individual basket can be retrieved at any time during the service life of the storage facility. The vault loading crane is maintained in an operational condition to provide recovery access to the fuel baskets.

To retrieve a used fuel basket from a specific vault liner 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.

3.1.3 Sequence of Operations

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

3.1.4 Basket Operations

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

3.1.5 Access

Access to the vaults is through a secondary security gate. Man access to the vault storage array is readily achieved. Routine monitoring and inspection of the integrity of each liner and the baskets within can be achieved utilising the valved lines that penetrate the shielding and allow the interspace to be monitored.

3.1.6 Cooling and ventilation

The vaults are constructed outdoors. Cooling and ventilation for the storage vaults will be provided by natural ventilation. The vaults have integral low level inlets, which follow a labyrinth type path to minimise the potential for radiation streaming (shine path) from the used fuel held within the vault liners. The air enters the vault at low level, picks up heat from the used fuel and exits at high level, thereby generating a natural cooling flow over the fuel basket storage liners.

3.1.7 Shielding

The shielding provided by the vaults 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.

3.1.8 Water Control

Water control is a function of site conditions and the implementation of specific construction design solutions. The surface around the vaults is graded, thus providing a surface run-off for rainwater and snowmelt. The vault liners are sealed, and the integrity of the liner can be monitored, using the network of pipes and valves which penetrate into the liner housings.

3.2. Surface Modular Vault (SMV)

3.2.1 General Description

The Surface Modular Vault concept (SMV) comprises the storage of fuel bundles confined in baskets and placed into an array of tubes in a series of engineered vaults within the storage buildings. The fuel baskets are placed in a series of vertical storage tubes within the vault, which ensures that they are correctly aligned and remain in place. The upper end of each storage tube is closed off with a closure shield plug unit. The fuel within the storage tubes is cooled by natural ventilation flow around and through the storage tube array. The modular vaults within a storage building are serviced by a basket-handling crane, which provides coverage to each array of storage tubes across a shielded charge hall floor. The basket handling crane can engage with each tube in the array (through an independent charge face gamma gate), remove the closure plug, and lower fuel baskets into the storage tube.

Key features of the SMV extended storage concept include:

- The SMV accepts fuel in basket format.
- 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’).
- Fuel is stored within storage tubes within the SMV vault modules.
- Additional capacity can be provided by construction of the SMV storage buildings on a rolling program.
- Fuel baskets are placed in storage (10 baskets per storage tube) vaults using transfer flask and a dedicated crane.

- Cooling is achieved by natural convection across the array of storage tubes from vents in the building structure.

3.2.2 Fuel Retrievability

If the SMV storage system does not perform according to the specification, it will be possible to retrieve the used fuel from storage so as to repair the storage system or transfer the used nuclear fuel to a new storage facility.
The RES facility will be designed to allow safe retrieval of used nuclear fuel from the storage vault at any point during the service life of the facility. The fuel basket handling crane provides recovery access to the fuel baskets.

3.2.3 Construction Materials

General
The concrete labyrinth arrangement of the inlet structure provides radiological shielding for the stored fuel. The pre-cast concrete collimators set into pockets in the structural walls of the vault improve the distribution of cooling air across the array of storage positions. The cooling air leaves the vault through a second set of concrete collimators and is exhausted to atmosphere through a concrete outlet duct.
A steel canopy mesh provided on the top of the outlet duct, prevents the ingress of rain, snow, birds etc. The ambient cooling air does not come into contact with the fuel baskets, which are seated in the storage tubes, ensuring the internal walls of the vault remain radiologically clean.
Walls
The internal and external walls of the vaults are 1.0m thick reinforced concrete. These walls provide shielding and accommodate the thermally imposed loads of the vault total heat output.
A 1.0m thick reinforced concrete charge face structure forms the roof of the vaults. Steel liners through the charge face provide location and access into the storage tubes. The charge face cover plates fitted over each storage tube provide a smooth floor for operator activities and basket transfer flask movements.
Roof
The vaults are covered by a continuous roof structure which provides a weather tight and illuminated enclosure for year round fuel loading, unloading and maintenance operations. This provides protection for the basket handling crane and gives considerable operating flexibility during adverse weather conditions and hours of darkness. The enclosure is constructed from a structural steel framework and cladding and is designed to remain weather tight for design base environmental conditions.

3.2.4 Modular Vaults

A Surface Modular Vault (SMV) facility provides a controlled environment for the safe storage and retrieval of spent nuclear fuel. High integrity vertical storage tubes provide a sealed secondary containment boundary for the fuel baskets. The individual storage positions allow access to individual baskets of irradiated fuel for monitoring, inspection or retrieval.
The storage building houses the fuel basket storage tubes. The roof enclosure above and between the vaults allows year-round transfer, storage, maintenance and monitoring operations, ensuring severe weather does not interrupt the availability of the system.
At any time during the storage period or for facility repeat operations, baskets can be removed from the storage tubes for inspection or transfer to newer vaults by simply reversing the loading procedure.

The design of the SMV facility is arranged to contain any potential contamination during operation and to facilitate its removal at the decommissioning stage ensuring existing vaults can be refurbished with minimal generation of radioactive waste.

3.2.5 Sequence of Operations

Basket Loading

The following sequences of operation cover the receipt, transfer and emplacement into store of sealed fuel baskets.

Basket Receipt

1. Receive the basket transfer flask on powered bogie from the existing site storage complex
2. Transfer basket transfer flask bogie below basket transfer flask hatch cover plate at store.

Before a fuel basket can be loaded into a storage tube from the basket transfer flask, the storage tube needs to be prepared. This involves manually removing the charge face cover plate and storage tube lid from the selected storage position. The storage tube shield plug is handled in a shielded housing and requires a temporary lifting ring attaching which replicates the basket lifting feature. Before the shield plug is removed an independent charge face gamma gate is positioned over the storage tube. This gamma gate provides shielding from the contents of the storage tube while the shield plug is absent.

Prepare a Basket Storage Tube for Loading

1. Remove storage tube cover plate using mobile crane
2. Remove storage tube lid using mobile crane
3. Fit temporary lifting feature to storage tube shield plug
4. Place independent charge face gamma gate over storage tube position
5. Place shielded housing onto charge face gamma gate
6. Open charge face gamma gates
7. Transfer shield plug to shielded housing
8. Close charge face gamma gates
9. Lift shielded housing away and place on charge face

With the storage tube ready to accept a basket, the basket-handling crane visits the basket transfer flask hatch positioned above the transfer tunnel. The cover plate over the hatch is manually removed before the crane is positioned. The basket bogie will have been previously loaded with a basket transfer flask containing a fuel basket at the receipt facility. The basket-handling crane lifts the loaded transfer flask into the charge hall above the transfer tunnel and storage vault.

Load a Basket in a Storage Tube

1. Remove basket transfer flask hatch cover plate using mobile crane
2. Position basket transfer flask with loaded basket below basket transfer flask hatch
3. Raise transfer flask using basket handling crane
4. Move transfer flask to storage position. Place onto charge face gamma gate
5. Open transfer flask and charge face gamma gates

6. Place loaded basket into storage tube.
7. Close transfer flask and charge face gamma gates
8. Return transfer flask to transfer trolley
9. Repeat steps 2 to 8 for nine further baskets

With the storage position fully loaded with 10 fuel baskets the storage tube can be closed and sealed. The shielded housing replaces the shield plug before the charge face gamma gate is removed from the storage position.

Close and Seal a Loaded Basket Storage Tube

1. Move shielded housing containing shield plug to storage position. Place on charge face gamma gate
2. Open charge face gamma gates
3. Replace shield plug in storage tube
4. Close charge face gamma gates
5. Move shielded housing away from storage tube
6. Move charge face gamma gate away from storage tube
7. Fit seal to storage tube lid
8. Place storage tube lid on storage tube. Torque tighten the storage tube bolts
9. Replace storage tube cover plate

3.2.6 Access

Fuel baskets will be transferred from the current storage area to the SMV in a basket transfer flask on a self powered transporter.
Man access onto the storage vault ‘charge face’ under normal operational conditions is considered to be standard operational practice. Store operating personnel will have open access to this area.

3.2.7 Cooling and Ventilation

Cooling of the fuel is by a totally passive system of heat removal. The fuel discharges its decay heat to the storage tube wall by thermal radiation. Cooling air enters each vault through an inlet duct and the natural buoyancy of warm air as it rises out of the outlet duct drives the cooling flow past the storage tube arrays removing the residual heat. This is a self-regulating system in that the hotter the fuel, the more airflow is driven through the vault, maintaining acceptable fuel and concrete temperatures.

Heat Transfer Path

Fuel decay heat removal is via a once through airflow, through the vault structure as it passes around the storage tube arrays. The vault airflow results from a buoyancy induced thermo-syphon. Cooling air enters each vault through a louvered opening that is provided with a mesh to prevent the ingress of birds, large debris, and vermin. The buoyancy head is created by the difference between the inlet and outlet air densities together with the height of the outlet duct. The pressure drops that result from the rate of airflow and the flow resistances created by the vault inlet duct arrangement, the storage tube bank array and the outlet duct arrangement balance this buoyancy head.

Heat Transfer for Fuel Baskets

The irradiated fuel bundle is stored vertically in positioning plates within sealed baskets. Part of the fuels heat load is transferred to the inside of the basket by conduction and natural convection in the atmosphere in the fuel basket. The positioning plates within the basket aid the heat transfer as they act as extended surfaces for the conduction process. The remaining heat is transferred by thermal radiation to the basket structure. Metal conductivity transfers the heat through the basket wall. This conduction, convection and radiation process is repeated to transfer the heat from basket to the storage tube. The heat is finally convected to the vault air and exhausted to atmosphere.

A steel canopy and mesh provided on the top of the outlet duct, prevents the ingress of rain, snow, and birds. The ambient cooling air does not come into contact with the fuel baskets, which are sealed in the storage tubes, ensuring the internal walls of the vault remain radiologically clean.

3.2.8 Containment

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

The vaults are covered by a continuous roof structure which provides a weather tight and illuminated enclosure for year round fuel loading, unloading and maintenance operations. This provides protection for the basket handling crane and gives considerable operating flexibility during adverse weather conditions and hours of darkness. The enclosure constructed from a structural steel framework and cladding is designed to remain weather tight for the design base environmental conditions.

A storage tube lid with ring seal is bolted to the top of the tube body sealing the storage tube. A sealed port in the lid provides a means to monitor the internal atmosphere of the storage tube during routine maintenance and inspection operations.

The storage tube assembly forms the secondary containment boundary for the fuel baskets. Provision for IAEA safeguards will be integrated into the design to allow duplicate seals to be applied to the filled storage tube. Duplicate seals are provided to ensure redundancy in case of accidental damage to either one, thereby reducing the probability of a need to re-verify the storage tube contents.

Temporary seals are applied to part-loaded canisters between each insertion of a spent fuel basket. The temporary seals are electronic and can be easily removed and replaced but only by an IAEA inspector. After the storage tube has been filled the permanent seals will be installed.

3.2.9 Shielding

The concrete walls and charge face above, provide the necessary radiation shielding during transfer and storage operations to maintain public and worker dose limits below those specified by the regulatory bodies.

The concrete and labyrinth arrangement of the inlet structure provides radiological shielding for the stored fuel.

The internal and external walls of the vaults are 1.0m thick reinforced concrete. These walls provide shielding and accommodate the thermally imposed loads of the vault total heat output.

A 1.0m thick reinforced concrete charge face structure forms the roof of the vaults. Steel liners through the charge face provide location and access into the storage tubes. The charge face cover plates fitted over each storage tube provide a smooth floor for operator activities and basket transfer flask movement.
A concrete filled shield plug sits in the top of each storage tube to complete the shielding of the charge face structure. The shield plug is handled by the grapple on the basket shield plug lifting housing, via a lifting ring bolted to the top of the shield plug to mimic the lifting feature on the fuel baskets.

3.2.10 Water Control

The storage vaults are engineered to ensure that the vault fabric is generally weather tight, the only exceptions to this are the cooling penetrations. The storage vaults are cooled by the flow of ambient air through inlet louvers. These inlet louvers are arranged at low level, with the exhaust discharged through a raiser at high level. Both the inlet and the exhaust are arranged, and engineered such that the potential for the ingress of rain or snow is minimised.

3.3. Vaults in Shallow Trenches (VST)

3.3.1 General Description

The Vaults in Shallow Trenches concept (VST) comprises the storage of fuel baskets, confined in vaults. The vaults will be housed in a series of parallel, modular chambers with concrete floors, walls and roofs constructed in a shallow trench and mounded over with earth cover. The chambers will be interconnected at both ends with corridors to form a complex accessible by a ramp from ground level. The earth cover will provide weather protection for the concrete chambers and added physical protection from sabotage and aircraft impact. The earth cover will also lessen the visual impact of the storage complex. 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.

Fuel baskets are delivered to the VST facility in the basket transfer flask. The basket transfer flask delivers the basket to the dedicated vault in the relevant storage chamber on a powered transporter.

Key features of the VST extended storage concept include:
- The receipt building accepts fuel in basket format.
- Fuel is stored within sealed tubes in concrete vaults.
- 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 vaults 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 vault for transfer of the baskets to the storage tubes in the vault.
- 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.

3.3.2 Storage Chambers

The design capacity of the storage chamber complex is based on the site inventory.
The vault inventory will be housed in storage chambers. Each chamber will be divided in two bays by a centre row of columns supporting the chamber roof. Each storage bay will contain an array of longitudinally positioned vaults serviced by a 30 tonne capacity electrically powered overhead gantry crane. The gantry crane will span the vault, and an aisle for the powered transfer flask bogie.
The vault storage chambers will be linked by access corridors on both ends of the store chambers. The storage chambers 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. 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.

3.3.3 Fuel Retrievability

If the VST storage system does not perform according to the specification, it will be possible to retrieve the used fuel from the storage vault, so as to repair the storage system or transfer the used nuclear fuel to a new storage facility.
The RES 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.
To retrieve a used fuel basket from a specific vault liner 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. Baskets, which are monitored and proven to require no further attention, will be transferred to the spare vault liner positions, thus permitting recovery access to a specific basket.

3.3.4 Interconnecting Corridors

The storage chambers will be linked to the grade level by an access tunnel. A rail track will be embedded in the access corridor floor to allow relocation of the gantry cranes. Once a storage chamber has reached capacity, the gantry crane will be transferred to a trolley to relocate it to the next chamber.
Air intake shafts will rise up to grade level from the storage chamber roof to air intake chambers, which will be constructed at grade level.
Vertical extract raisers will be constructed on the top of each storage chamber. These shafts will help to ensure natural ventilation (passive cooling). Escape ladders to grade level will be provided in the ventilation corridor for emergency exit.

3.3.5 Earthen Cover

The earthen cover above the storage chambers will be approximately 3.5m thick and will be crowned in the centre with a 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.

3.3.6 Sequence of Operations

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

3.3.7 Basket Operations

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

3.3.8 Access

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

3.3.9 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 vaults. Vertical raisers constructed on top of each 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. Air intake houses with weather louvers will be located at grade level above the access corridors, at both ends of the storage chamber, to allow ambient air to infiltrate the trench, due to the negative pressure generated within the chambers, created by the raiser effect.

The airflow through the storage chambers will be set manually by adjusting the dampers or openings located at the exhaust raiser on each chamber. The dampers or openings will be adjusted and locked in place to provide similar flows through each chamber.

During initial periods of storage and when personnel are conducting inspections of the storage facility, forced air ventilation systems located above the access corridors may be utilised to supplement the passive ventilation system. This will only be necessary before the storage chambers are fully loaded, as a partially loaded storage chamber may not provide enough energy to initiate the natural convection flow of air.

3.3.10 Shielding

The shielding provided by the vaults 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.

3.3.11 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 VST 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 Gentilly site:

- Vaults
- Surface Modular Vault (SMV)
- Vaults in Shallow Trench (CST)

Should there be decision made to implement reactor-site extended storage based on the Vault technology, then this alternative could be implemented immediately following the decison. HQ would continue to store fuel in vaults as is being done at the present time and new storage structures would be built as per the regulatory approvals already in hand. New approvals would be sought, as necessary, for refurbishment/replacement of the storage structures, periodic repackaging of the fuel and decommissioning of facilities.

Should there be decision made to implement either the SMV or VST technology, then additional time would be required following the decision to transition to a new dry storage system. Additional time would be required to locate a suitable site, to develop a site specific design, to gain all necessary approvals, and to construct and commission the new facility. Therefore, for the purposes of this study, it has been assumed that the earliest possible in-service date for a facility based on either SMV or VST technology would be January 2016. However taking into consideration the assumed availability of existing vault storage capacity (Refer to Tables 2 and 3) allows deferral of new technology implementation until January 2020. Following in-service, the new dry storage facility would operate indefinitely with refurbishment/replacement of the storage structures and periodic repackaging of the fuel. The new dry storage facility would accept fuel transferred directly from the wet bay and from existing storage vaults.

Tables 1, 2 and 3 provide details of the site-specific fuel inventories, assumed dates for constructing new storage facilities, assumed times periods over which used fuel would be transferred from the wet bay and old storage vaults to new storage structures (SMV and VST only), and assumed dates when vaults would be decommissioned after the fuel has been transferred. For the purpose of developing these tables it has been assumed that a decision to implement reactor-site extended storage would be made no sooner than July 2006. The following sections provide a more detailed description of the implementation of the Vault, SMV and VST dry storage systems on the Gentilly site.

4.1. Gentilly Site

4.1.1 Vaults

The RES Vaults alternative for Hydro-Québec is effectively a repetition of the current concrete vault interim storage structures.
The AECL owned Gentilly 1 fuel is stored in concrete canisters within the redundant Gentilly 1 turbine hall. This fuel will be removed and integrated into the storage Vaults for the Gentilly 2 fuel

baskets, after the Gentilly 2 fuel has been removed from the reactor, cooled sealed into baskets and transferred into Vault storage.

Implementation of the Vaults RES alternative will initially not require any changes to the current on site storage philosophy. Baskets will continue to be filled at the shielded workstation adjacent to the Irradiated Fuel Bay. The transfer and loading into the Vaults of the sealed baskets will remain unchanged.

Currently there are 5 operational vaults on the HQ site. (Refer Figures 4 and 6)

Each vault has a capacity of 200 fuel baskets, stored in 10 baskets per vault liner with 20 vault liners per vault (Refer Figure 8).

The annual basket production rate, the cumulative number of baskets in store and the phasing of the future construction of vaults is described in Table 1.

Table 1 also identifies the availability of vaults for use as an interim storage facility, prior to implementation of Vaults as a RES alternative.

Additional vaults will be constructed to match the rate fuel of used fuel production, inline with the schedule below:

Year	Additional Vaults	Total Vaults
2004	2	7
2009	1	8
2012	1	9
2016	1	10
2019	2	12

The total assumed Gentilly fuel inventory is:

Gentilly 1	3,213 fuel bundles	stored in 85 fuel baskets.
Gentilly 2	132,838 fuel bundles	stored in 2,214 fuel baskets
Total	136,051 fuel bundles	stored in 2,299 fuel baskets.

The total vault basket storage capability, after completion of all 12 vaults, will be 2,400 baskets, (Refer Figures 7 and 8).

As each Vault reach the end of its assumed design life (100 years), a repeat Vault will need to be constructed. This vault will be constructed as close as practical to the existing vault array. Transfer between the ‘old’ and ‘new’ vaults will utilise the conventional basket transfer methodology, section 4.3 outlines the facility repeat operations.

4.1.2 Surface Modular Vault (SMV)

The SMV facility at Gentilly will comprise a single storage building, comprising 4 vaults. Each storage vault has capacity for 600 fuel baskets (5 x 12 storage tubes x 10 baskets per storage tube).

The total Gentilly fuel inventory is:

Gentilly 2 132,838 fuel bundles, stored in 2214 fuel baskets

Gentilly 1 3,213 fuel bundles stored in 85 fuel baskets

This inventory will fill 231 storage tubes, which completely fills 3 storage vaults. The fourth vault will have 49 full storage tubes, with the remaining 9 tubes empty and spare (Refer Figures 9 and 10).

The Surface Modular Vault will have loading facilities which include a basket flask handling crane, capable of lifting a basket transfer flask, from a road transporter onto the charge face, and a storage tube gamma gate.
Implementation of the SMV RES alternative requires the creation of a SMV facility. Table 2 identifies the execution date for a SMV alternative as 2020. The table also identifies the amount of fuel that will be stored in vaults at the time of implementation of the SMV, and the phasing of the fuel transfer from the vaults to the SMV, as well as the SMV vault construction schedule.
Prior to the assumed SMV implementation date of 2020, baskets will continue to be stored in vaults. At the time of implementation of the SMV 9 storage vaults will be in service, these vaults will be decommissioned and dismantled.
The first phase of vault dismantling is scheduled to occur in 2026/2027. At this time 5 vaults will be dismantled.
Each vault comprises approximately 185 tonnes of steel and 700 cubic meters (1,680 tonnes) of concrete. The second phase of the vault decommissioning and dismantling is scheduled to take place in years 2030/2031, this second phase will see the dismantling of the final 4 vaults.
In parallel with the vault decommissioning and dismantling activities the SMV facility will be expanded. The first phase of construction will have taken place in 2019, with the second SMV vaults constructed in 2023, the third construction phase in 2025 with the final vaults constructed in 2027. Each SMV construction phase will see the generation of 3 vaults.
These activities are scheduled in Table 2.
Conversion to a SMV facility will require the transfer of all of the fuel baskets from the vaults into the SMV basket vault. The basket transfer will be accomplished using the conventional basket transfer flask. This flask will be used to retrieve the baskets from the vaults and will then interface with the SMV storage tube gamma gate. Sequenced operation of the storage tube gamma gate, the shielded transfer flask gamma gate and the flask hoist will enable basket transfers from the flask into the SMV storage tube.

When the SMV facility reaches the end of its 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 SMV loading operations. Transfer between the ‘old’ and ‘new’ surface modular vaults will utilise the conventional basket transfer methodology.
Section 4.3 outlines the operations related to repeat of the storage facilities.

4.1.3 Vaults in Shallow Trenches (VST)

The VST facility at Gentilly will comprise two storage chambers. Each storage chamber comprises two storage bays. Each storage bay has capacity for 4 storage vaults. This configuration allows the construction of a total capacity of 12 storage vaults in 2 storage chambers, with space for the construction of an additional 4 vaults, which will be utilised during facility repeat operations, see section 4.3.
The total Gentilly fuel inventory is:
Gentilly 2 132,838 fuel bundles, stored in 2214 fuel baskets
Gentilly 1 3,213 fuel bundles stored in 85 fuel baskets

This inventory will fill 231 storage tubes, which completely fills 11 storage vaults. The 12th vault will have 11 full storage tubes, with the remaining 9 tubes empty and spare, (Refer Figures 11 and 12).

Implementation of the RES VST alternative requires the creation of a series of storage vaults, housed within shallow trenches. Conversion to a VST facility will require the transfer of all of the fuel baskets from the original vault storage into vaults within a 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 vaults and will then interface with the gamma gate on the shallow trench vault. Sequenced operation of the vault gamma gate, the shielded transfer flask gamma gate and the flask hoist will enable basket transfers from the flask into the vault storage tube.

Table 3 identifies the implementation date for a VST alternative as 2020.

The table also identifies the amount of fuel that will be stored in interim storage in vaults at the time of implementation of the VST, phasing of the fuel transfer from the vaults to the VST, as well as the VST construction schedule.

Prior to the proposed VST implementation date of 2020, baskets will continue to be stored in vaults. At the time of implementation of the VST 9 storage vaults will be in service. These vaults will be emptied, decommissioned and dismantled as the VST facility is loaded and expanded.

The first phase of vault dismantling is scheduled to occur in 2026/2027. At this time 5 vaults will be dismantled.

Each vault comprises approximately 185 tonnes of steel and 700 cubic meters (1,680 tonnes) of concrete. The second phase of the vault decommissioning and dismantling is scheduled to take place in years 2030/2031, this second phase will require the dismantling of the final 4 vaults.

In parallel with the vault decommissioning and dismantling activities, the VST facility will be expanded. The first phase of construction take place in 2019, with the second VST vaults constructed in 2023, the third construction phase in 2025 with the final vaults constructed in 2027.

The activities are scheduled in Table 3.

When the VST vault reaches the end of its 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. There is adequate space within the shallow trench to enable replacement vaults to be constructed, without dismantling the trench structure, see section 4.3.

When the chamber 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. Once a storage trench has been cleared a replacement vault and trench can be constructed and the earthen cover restored.

4.2. 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.

4.2.1 Storage Structures

With particular respect to the VST, 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.

4.2.2 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 storage tube atmosphere.
With operating experience, it may be possible to extend the intervals between inspections.

During repackaging events, fuel will be withdrawn from 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 operations.

4.2.3 Vaults

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.
For vaults, a population of the storage tube inventory will be surveyed. This sample population will be interspersed amongst the total number of vault storage tubes in operation. Activities will include a radiation survey and internal storage tube atmospheric monitoring by connection to valved tapping points in each storage tube, which terminate at dedicated connection points on the vault outer walls.

4.2.4 SMV

For SMV basket stores a population of the storage tube inventory will be surveyed. This sample population will be interspersed amongst the total number of basket storage tubes in operation. Activities will include a radiation survey and atmospheric monitoring by connection to tappings on each storage tube plug. This monitoring of the interspace between the basket and the storage tube will allow the interspace gas to be assessed for early signs of basket leakage. The SMV basket flask crane provides the ability to transfer baskets from an in-service storage tube to a spare storage tube, should the storage tube internals require (remote) investigation.

4.2.5 VST

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.

For basket vaults, a population of the storage tube inventory will be surveyed. This sample population will be interspersed amongst the total number of vault storage tubes in operation. 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.

4.3. Operations – Facility Repeats

Storage facilities and principal containment structures have a finite life span. An estimate of the minimum service life of the various fuel containers and the structures used to house the fuel containers are presented in Table 4.
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.

4.3.1 Vault

When a storage vault requires replacement a new vault will be constructed. The fuel baskets will be transferred from the vault that has reached the end of its service life to the 'new' vault using a reversal of the vault loading operations.
The redundant vault will be monitored, decontaminated (if necessary) and dismantled. Each vault comprises approximately 185 tonnes of steel and 700 cubic meters (1,680 tonnes) of concrete.
The vacant location where the redundant vault has been removed will become the site for the next replacement vault. This system will allow the footprint for the vault storage array (12 vaults) plus a 13th position accommodate all of the facility repeat requirements.

4.3.2 SMV

When the SMV vault structure has reached the end of its service life it will be necessary to replace the whole vault. This will necessitate the construction of a new SMV, adjacent to the existing facility. The fuel baskets will be transferred out of the 'old' SMV and into the new using the basket flask crane and the basket flask. These operations are a reversal of the SMV loading sequences.
After removal of all of the fuel the redundant SMV will be monitored, if necessary decontaminated and dismantled. The dismantling of the SMV vaults will generate approximately 2,500 tonnes of steel and 21,900 tonnes of concrete.
Dismantling of the storage building superstructure from over the SMV vault will generate approximately 200 tonnes of scrap steel.
Subsequent repeats can utilise the position vacated by the original vault structure.

4.3.3 VST

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

Vaults

Facility repeats for Vaults as a part of the VST alternative will be a repeat of the sequence outlined above for vaults.

Storage Chambers

When the vault storage chamber reaches the end of its service life it will be necessary to remove all of the fuel from the vaults, in line with the procedure outlined above. The vaults 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 1,350 tonnes of steel and 26,000 tonnes of concrete. The concrete will be crushed and reinforcing bar removed for separate disposal.
Once a storage chamber has been cleared a replacement storage chamber can be constructed and the earthen cover restored.

4.4. Operations – Repackaging

4.4.1 General

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. The shielded facility will be housed within a larger building. The building will be capable of receiving baskets in shielded flasks, delivered on suitably powered transporter.
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.

4.4.2 Fuel Basket Repackaging

The fuel basket transfer operations will be performed in a dedicated shielded cell, the shielded cell will be within a processing building. 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. 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. (Atomic Energy of Canada Ltd) CTECH Report No: 1105/MD18084/REP/15 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: Vault Alternative – Assumed Annual Rate of Basket Transfers

Year	Bundles Transferred to Dry Storage	Vaults				
		Baskets Stored	Cum Baskets	Storage Capacity (Baskets)	Cum Capacity (Baskets)	Cum Vaults
31-Dec-01	48,000	800	800	1,000	1,000	5
2002			800		1,000	5
2003	9,600	160	960		1,000	5
2004			960	400	1,400	7
2005	9,600	160	1,120		1,400	7
2006			1,120		1,400	7
2007	6,000	100	1,220		1,400	7
2008	6,000	100	1,320		1,400	7
2009			1,320	200	1,600	8
2010	6,000	100	1,420		1,600	8
2011	6,000	100	1,520		1,600	8
2012			1,520	200	1,800	9
2013	9,600	160	1,680		1,800	9
2014			1,680		1,800	9
2015			1,680		1,800	9
2016			1,680	200	2,000	10
2017	6,000	100	1,780		2,000	10
2018	6,000	100	1,880		2,000	10
2019			1,880	400	2,400	12
2020	6,000	100	1,980			
2021	6,000	100	2,080			
2022	8,038	134	2,214			
2023	3,213	85	2,299			
Total	**136,051**	**2,299**		**2,400**		

Table 2: Surface Modular Vault (SMV) Alternative – Assumed Annual Rate of Basket Transfers

		Vault						Surface Modular Vault			
Year	Bundles Transferred to Dry Storage	Baskets Stored	Baskets Removed	Cum Baskets	Storage Capacity (Baskets)	Cum Capacity (Baskets)	Cum Vaults	Baskets Stored	Cum Baskets	SMV Capacity (Baskets)	Cum Capacity (Baskets)
31-Dec-01	48,000	800		800	1,000	1,000	5				
2002				800		1,000	5				
2003	9,600	160		960		1,000	5				
2004				960	400	1,400	7				
2005	9,600	160		1,120		1,400	7				
2006				1,120		1,400	7				
2007	6,000	100		1,220		1,400	7				
2008	6,000	100		1,320		1,400	7				
2009				1,320	200	1,600	8				
2010	6,000	100		1,420		1,600	8				
2011	6,000	100		1,520		1,600	8				
2012				1,520	200	1,800	9				
2013	9,600	160		1,680		1,800	9				
2014				1,680		1,800	9				
2015				1,680		1,800	9				
2016				1,680		1,800	9				
2017	6,000	100		1,780		1,800	9				
2018	6,000	100		1,880		1,800	9				
2019				1,880		1,800	9			600	600
2020	6,000			1,880		1,800	9	100	100		600
2021	6,000			1,880		1,800	9	100	200		600
2022	8,038			1,880		1,800	9	134	334		600
2023			-250	1,630		1,800	9	250	584	600	1200
2024			-250	1,380		1,800	9	250	834		1200
2025			-250	1,130		1,800	9	250	1,084	600	1800
2026			-250	880		1,800	9	250	1,334		1800
2027			-250	630	-1000	800	4	250	1,584	600	2400
2028			-250	380		800	4	250	1,834		
2029			-250	130		800	4	250	2,084		
2030			-130	-		800	4	130	2,214		
2031	3,213				-800	-	0	85	2,299		
Total	**136,051**	**1,880**	**- 1,880**		**-**			**2,299**		**2,400**	

Table 3: Vaults in Shallow Trench (VST) Alternative – Assumed Annual Rate of Basket Transfers

Year	Bundles Transferred to Dry Storage	Vault						Vaults in Shallow Trench			
		Baskets Stored	Baskets Removed	Cum Baskets	Storage Capacity (Baskets)	Cum Capacity (Baskets)	Cum Vaults	Baskets Stored	Cum Baskets	VST Capacity (Baskets)	Cum Capacity (Baskets)
31-Dec-01	48,000	800		800	1,000	1,000	5				
2002		-		800		1,000	5				
2003	9,600	160		960		1,000	5				
2004		-		960	400	1,400	7				
2005	9,600	160		1,120		1,400	7				
2006		-		1,120		1,400	7				
2007	6,000	100		1,220		1,400	7				
2008	6,000	100		1,320		1,400	7				
2009		-		1,320	200	1,600	8				
2010	6,000	100		1,420		1,600	8				
2011	6,000	100		1,520		1,600	8				
2012		-		1,520	200	1,800	9				
2013	9,600	160		1,680		1,800	9				
2014		-		1,680		1,800	9				
2015		-		1,680		1,800	9				
2016		-		1,680		1,800	9				
2017	6,000	100		1,780		1,800	9				
2018	6,000	100		1,880		1,800	9				
2019				1,880		1,800	9			600	600
2020	6,000			1,880		1,800	9	100	100		600
2021	6,000			1,880		1,800	9	100	200		600
2022	8,038			1,880		1,800	9	134	334		600
2023			-250	1,630		1,800	9	250	584	600	1200
2024			-250	1,380		1,800	9	250	834		1200
2025			-250	1,130		1,800	9	250	1,084	600	1800
2026			-250	880		1,800	9	250	1,334		1800
2027			-250	630	-1000	800	4	250	1,584	600	2400
2028			-250	380		800	4	250	1,834		
2029			-250	130		800	4	250	2,084		
2030			-130	-		800	4	130	2,214		
2031	3,213				-800	-	0	85	2,299		
Total	**136,051**	**1,880**	**- 1,880**		**-**			**2,299**		**2,400**	

Table 4:Assumed Service Lives for Facility Components

Component	Vaults	SMV	VST
Basket	300	300	300
Vault	100		100+**
Storage Vault		100	
Storage Chamber			200
Storage Building		100*	-
Processing Building	30	30	30

Notes

* This figure represents the assumed service life for the SMV above vault weatherproof structure. The roof/wall cladding comprises an inner and outer skin, with insulating material sandwiched within.
It is assumed that individual external cladding sheets are regularly inspected, and replaced, as and when they exhibit excessive corrosion or suffer mechanical damage.

** The figure for the underground storage vault reflects concern over the concrete/steel interface, which may preferentially corrode the storage tubes within the vault structures, and ultimately defeat the secondary containment. The assumed service life figure therefore differs from the underground concrete structure figure (Storage Chamber) for the VST alternative, but may approach the same, if atmospheric conditions within the VST alternative were favourable, and corrosion was minimised.