Management of Legacy Spent Nuclear Fuel Wastes at the Chalk River Laboratories: The Challenges and Innovative Solutions Implemented - 13301

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ABSTRACT

AECL's Fuel Packaging and Storage (FPS) Project was initiated in 2004 to retrieve, transfer, and stabilize an identified inventory of degraded research reactor fuel that had been emplaced within in-ground "Tile Hole" structures in Chalk River Laboratories' Waste Management Area in the 1950s and 60s. Ongoing monitoring of the legacy fuel storage conditions had identified that moisture present in the storage structures had contributed to corrosion of both the fuel and the storage containers. This prompted the initiation of the FPS Project which has as its objective to design, construct, and commission equipment and systems that would allow for the ongoing safe storage of this fuel until a final long-term management, or disposition, pathway was available.

The FPS Project provides systems and technologies to retrieve and transfer the fuel from the Waste Management Area to a new facility that will repackage, dry, safely store and monitor the fuel for a period of 50 years. All equipment and the new storage facility are designed and constructed to meet the requirements for Class 1 Nuclear Facilities in Canada.

INTRODUCTION

AECL has operated research reactors at the Chalk River Laboratories (CRL) site since 1947, for the purposes of nuclear energy and scientific research, and for the production of radioisotopes. During the 1950s and 60s, a variety of spent nuclear fuel wastes were produced by irradiating metallic uranium and other prototype fuels. These legacy waste fuels were initially stored in water-filled fuel storage bays for a period of several years before they were placed in storage containers and transferred to the CRL Waste Management Area (WMA), where it has since been stored in below-grade, vertical cylindrical steel and concrete structures called "Tile Holes."

Background/Challenges

The legacy fuels that were emplaced into Tile Hole storage amount to about 22 tonnes of material, primarily metallic uranium and uranium dioxide, both clad in aluminum, and having less corrosion resistance than modern alloy-clad uranium oxide fuels.

Moisture is known to be present in some of the fuel storage containers. In some cases, this moisture resulted from incomplete water removal when the storage cans were taken out of the original water-filled fuel storage bays. There has also been ingress of surface water into some Tile Holes. Another source of moisture has been environmental humidity entering the Tile Holes through a pumping process due to atmospheric pressure changes. The net result is that the current fuel storage conditions are not dry, and this contributes to corrosion of the fuel and storage containers.

The safety concern with the long-term storage of uranium metal fuels in damp Tile Holes is such that:

- Damp conditions promote corrosion of the uranium metal fuels on fuel cladding that has been damaged producing a contamination hazard from uranium oxide, generating hydrogen gas and uranium hydrides; as well, corrosion could lead to the fuel slumping which is a potential hazard from a criticality perspective; and
- Those fuels clad with aluminium will also undergo cladding corrosion that produces hydrogen gas. The corrosion products create hazards since hydrogen gas is highly flammable and uranium hydrides, if formed, may ignite when exposed to air.

Continued storage will likely lead to further degradation of the fuels resulting in more complex and costly retrieval and fuel repackaging processes, and increased contamination of Tile Holes and higher tile hole remediation costs.

PROJECT SCOPE

The FPS Project was launched to remediate these legacy fuels. The FPS Project is to design, build, and cold commission equipment and systems, that can be used to retrieve, transfer, and stabilize degraded legacy fuels emplaced within specific Tile Hole Arrays in CRL's WMA. All aspects of the FPS Project are required to meet Canadian Nuclear Standards.

The FPS Project's Scope includes:

- Engineering of retrieval and transfer equipment, fuel packaging and fuel conditioning process equipment, a dry storage vault and associated building;
- Regulatory work comprising of licensing and safety analyses, completion of an Environmental Assessment (EA), radiation safety analysis, criticality safety analysis, and licensing approvals for modification to the WMA;
- Procurement of fuel retrieval and transfer equipment, and a fuel packaging and drying system;
- Construction of a fuel packaging and storage building containing a dry storage vault, and civil modifications to the existing WMA, as needed to retrieve the spent fuel; and
- Fabrication, installation, and cold commissioning of the equipment and systems.

FPS Facility

The FPS Building will house two Fuel Packaging and Drying Stations, the Fuel Transfer System, and the Fuel Storage Block. The FPS Building shell is of steel frame panel-clad construction and provides a weather shield for the Fuel Packaging and Drying Stations and the Storage Block. The one-story building is an above-ground structure with a footprint of approximately 20 m by 30 m.

One half of the FPS Building consists of a Reception Bay and two identical packaging and drying stations. Duplication of the packaging and drying stations improves operational efficiencies. The Fuel Storage Block is built on bedrock and is a concrete structure covering approximately half of the building footprint. The Storage Block is designed to provide shielding for operational personnel inside the building, and any personnel outside the building.

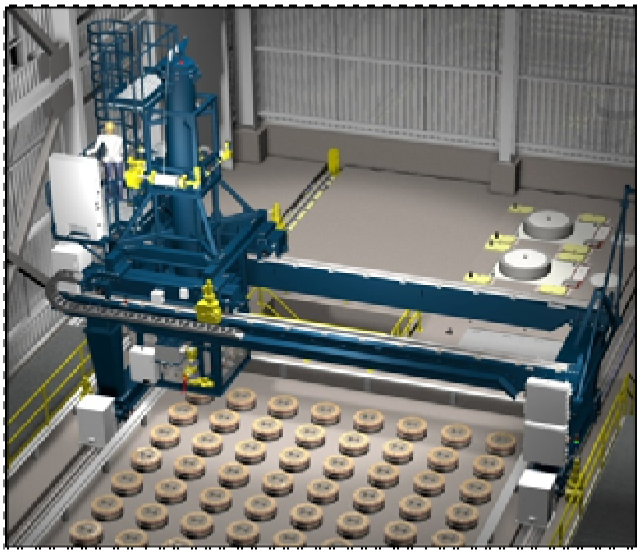

Fig. 1. FPS Building Storage Block©[1]

The Storage Block contains 112 Storage Wells positioned in an 8 x 14 array. A stainless steel Storage Tube is located in each of these Storage Wells and the legacy fuel will be placed in a Storage Container within each Storage Tube. The top of the Storage Tube is provided with a gas-tight copper gasket. Each Storage Tube is provided with a Storage Tube Shield Plug to maintain the necessary level of shielding and to provide the clamping force to ensure a gas tight seal between the copper gasket and the Storage Tube.

The Fuel Transfer System is used to move vertically orientated fuel between the Fuel Drying Stations in the Reception Bay and Storage Locations in the Storage Block.

MAJOR EQUIPMENT – FPS BUILDING

FPS Building – FPS Transfer System

The FPS Transfer System is a permanently installed overhead gantry style crane structure that incorporates a fully shielded flask into its trolley system. The system provides a 2000 kg capacity hoist integrated into the shielded flask for handling new, empty and loaded Storage Containers and a secondary 431 kg external hoist for handling Storage Tube Shield Plugs.

Two on-board radiation-hardened cameras provide an external view for fine positioning of the system over the target holes and an internal view observation camera to confirm items being hoisted in the flask.

[1] The design for the FPS Facility and all systems located therein are copyright protected by Rolls-Royce PLC.

Fig. 2. FPS Transfer System Assembly©[2]

The 4500 kg Shielded Collar translates vertically from the shielded flask to create a radiological barrier at the target hole for personnel protection during Storage Container Transfers.

Through a combination of local and remote controls the system moves throughout the FPS Building to accurately position the Shielded Flask at all 112 Storage Wells and the two Packaging and Drying Stations.

FPS Building – Vacuum Drying System

The Vacuum Drying System provides a safe and reliable means for argon purging and cold vacuum drying of the retrieved legacy fuel storage containers prior to transferring the re-packaged and dried container to its new storage location in the FPS Building.

Fig. 3. Vacuum Drying System©[3]

[2] The design of the FPS Transfer System Assembly is copyright protected by Rolls-Royce PLC.
[3] The design of the Vacuum Drying System is copyright protected by Rolls-Royce PLC.

Two identical and interconnected process systems each contain a Vacuum Vessel Module, Electrical Heating Jackets (EHJ), piping systems, HEPA filters, Process Vacuum Pump, Residual Gas Analyser (RGA), and instrumentation. Both systems are independently operated from a common remote control console and provide redundant or simultaneous operation.

The Vacuum Vessel Modules resemble a leak tight cylindrical vessel capped with a gate valve. The gate valve is featured with a roughing port through which the vessels are connected to the Vacuum Process Systems via a sintered metal HEPA filter. Each module is also featured with Programmable Logic Controller (PLC) controlled EHJs to maintain the desired temperature of the module throughout the drying process.

The Vacuum Process System enables the fuel drying process by purging the vessel of its initial air-argon content, providing vacuum to intensify moisture evaporation, supplying dry helium to speed up the vacuum drying process and argon for blanketing the new storage container prior to transferring the dried fuel to the new permanent storage location.

The automated control of the vacuum drying operation is based on pressure measurements in the Vacuum Vessels to indicate evaporation and removal of the water content, along with other process events, and determine fuel dryness and the end of the drying process. A fixed temperature set point on the external surface of the vessel maintains heat flux to its wet content and prevents overheating of the content above +75 °C.

FPS Building – Packaging Station

Located directly above each Vacuum Drying Vessels, the two Packaging Stations provide a safe and reliable means to assist the loading process of retrieved legacy fuel into the new storage containers while also providing radiological shielding to personnel during the drying process.

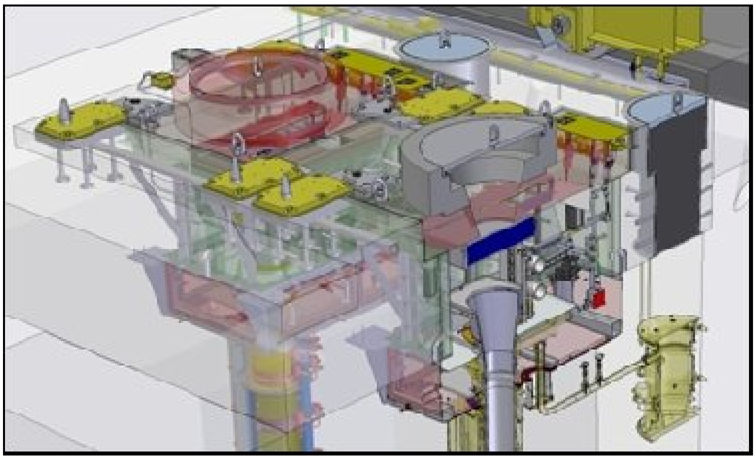

Fig. 4. Packaging Station©[4]

[4] The design of the Packaging Station is copyright protected by Rolls-Royce PLC.

With portions of the station embedded into the concrete floor of the FPS Building, the stations provide the interface to both the FPS Transfer System for placing a new clean storage container into the Vacuum Drying System and the interface for the FPS Retrieval and Transfer System Retrieval Flask to deposit the legacy fuel container into the awaiting new storage container.

The mechanically operated shielding door and Vacuum Vessel Gate Valve are opened and the Debris Guide is positioned to "funnel" the legacy fuel container and any residual liquid, sludge and debris into the new storage container. To control the spread of contamination within the Packaging Station, a Disposable Debris Guide Liner is pre-installed into the Debris Guide prior to the arrival of the Retrieval Flask.

Externally accessible view ports are provided for video scopes to remotely monitor these internal operations.

The Packaging Station also includes an independent Shielded Capping Tool, operated from a small overhead crane mounted in the FPS Building. The Capping Tool provides shielding for the operators and includes a zero weight balance design to ensure reliable capping and uncapping activities. The tool is positioned as required over either Packaging Station and deployed to remove the lid from the new storage container for preparation of legacy fuel container insertion.

MAJOR EQUIPMENT – LEGACY FUEL TILE HOLES

FPS Retrieval and Transfer System

The FPS Retrieval and Transfer System provides the means to safely extract legacy fuel containers from the historical Tile Holes, transport the fuel to the FPS Building, and deposit the legacy fuel into the new storage containers.

Fig. 5. FPS Retrieval and Transfer System – Retrieval Flask, Bridge and Trolley©[5]

[5] The designs for the FPS Retrieval and Transfer System (i.e. Retrieval Flask, Bridge and Trolley) are copyright protected by Rolls-Royce PLC.

Through a combination of wireless local and remote controls the Retrieval System can be moved around the Tile Array to accurately position the Retrieval Flask at all the target Tile Holes.

The system consists of 4 major sub-systems: Shielded Retrieval Flask, Tile Hole Array Bridge and Trolley, Flask Transfer Unit and Flask Rotating Unit.

Similar to the FPS Transfer System, the Retrieval System consists of a gantry style crane structure that incorporates a fully shielded flask into its trolley system. Unlike the indoor Transfer System, the Retrieval System is a temporarily installed modular outdoor system that can be moved to various Tile Hole Arrays.

Tile Hole Array Bridge and Trolley

The Tile Hole Array Bridge is mounted onto a crane rail system running the length of the historical Tile Hole Array. The 20 Tonne, 1.5 m x 4.5 m x 12 m Bridge can be removed as a single module or split into multiple sub-assemblies for re-installation at another Tile Array.

The 25 Tonne, 3.5 m x 4 m x 5.5 m Tile Hole Array Trolley, including the 5500 kg, Shielded Collar, can also be transferred as a single module and subsequently placed onto the Bridge. Two on-board radiation-hardened cameras provide an external view for fine positioning of the system over the target holes and an internal view observation camera to confirm engagement of the flask internal liner into the target Tile Hole.

The 5500 kg, 1 m diameter Shielded Collar translates vertically from the Trolley to create a radiological barrier for personnel protection during legacy fuel container retrievals and provide an argon seal at the target hole during Tile Hole purging operations. A 377 kg capacity external hoist is mounted on the side of the Trolley for handling Tile Hole Shield Plugs.

Retrieval Flask

The 40 Tonne, 2.25 m x 3 m x 6.6 m Retrieval Flask is removed from the Bridge and Trolley as a single unit.

When installed on the Trolley, the Retrieval Flask on-board Argon Gas Purge System purges the interior of the Retrieval Flask, Tile Hole Array Fixed and Moving Shield Collars, and the Tile Hole down to an oxygen content of < 2%. The Argon Purge System operates continuously during retrieval and transfer operations and has an Uninterruptible Power Supply (UPS) battery backup capable of continuous alarm monitoring for at least eight hours. The system also includes HEPA filtration and oxygen monitoring instrumentation.

The Retrieval Flask provides a 5000 kg capacity six-drop hoist integrated into the Shielded Flask for retrieving the historical legacy fuel containers. Due to the long period of storage and the potential impact of corrosion developed on the container, the hoist required additional load capacity to ensure a jammed or stuck container could be safely retrieved.

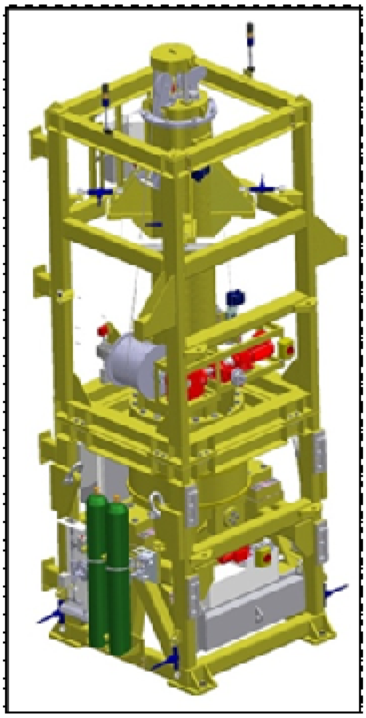

Fig. 6. Retrieval Flask©[6]

Once retrieved into the flask, a horizontally translating 340 kg lead filled steel gate is positioned below the retrieved container to provide complete radiological containment and retention of collateral liquids and solids during transfer of the flask to the FPS Building.

Flask Transfer Unit

The 41 Tonne capacity Flask Transfer Unit removes the Retrieval Flask from the outdoor Tile Hole Bridge and Trolley and safely transports the flask to the FPS Building. The unit positions the flask onto the Packaging Station, similar to the Trolley, for transfer of the retrieved legacy fuel container.

With a 5.8 m mast height, total length of 9 m and a gross mass of 53 Tonne, the large commercial unit can carry the Retrieval Flask in both a vertical and horizontal orientation as required for on-site handling.

Flask Rotating Unit

Located in a separate building adjacent to the FPS Building, the 41 Tonne capacity hydraulically operated unit rotates the Retrieval Flask 90° to horizontal or vertical as required.

[6] The design for the Retrieval Flask is copyright protected by Rolls-Royce PLC.

The flask is required to be vertical during normal operations and horizontal for maintenance activities.

The flask is delivered vertically onto the system by the Transfer Unit, interfacing similar to the Tile Array Trolley. The Transfer Unit can also remove a horizontal Retrieval Flask.

Fig. 7. Flask Rotating Unit©[7]

CHALLENGES AND INNOVATIVE SOLUTIONS

Drying Used Nuclear Fuel

Drying legacy nuclear fuel is a relatively new technology with no extensive standard practices. Only generic details are available on the container contents, physical state and chemical composition, the exact amount of expected liquid in the container is also unknown.

The drying of this particular legacy fuel required a system that does not use a high temperature drying process (less than 75 °C) and required a remote process due to the unknown time required for drying.

To develop an innovative solution, extensive analysis, prototyping, testing and instrumentation trials were performed for the complex heat transfers, gas exchanges, heating cycles and monitoring and control systems.

The developed remote Vacuum Drying Process initially purges the Vacuum Vessel (containing the retrieved legacy fuel canister inside a new storage container) of its initial inert environment with argon. A batch process is initiated applying heat at a low temperature under a low pressure vacuum using alternating heating cycles to remove the water vapour until the contents are dry. The vacuum pressure and heating process are controlled and monitored to avoid freezing of the water and maintain controlled evaporation rates. Dry helium is introduced to accelerate the

[7] The design for the Flask Rotating Unit is copyright protected by Rolls-Royce PLC.

vacuum drying process and a final argon supply blankets over the newly dried container prior to removal for storage. Helium has very good thermal conductivity properties and can transmit the heat through indirect paths.

Controlling Radioactive Contamination in a New Building

The retrieval of the legacy nuclear fuel from the Tile Holes includes loose collateral liquid and solids that will be brought into the Retrieval Flask along with the retrieved fuel container. Once the Retrieval Flask is over the Packaging Station, the flask gate will be opened and all the residual waste will flow down through the clean Packaging Station and into the new clean storage container. Instantly the entire area exposed to this process will become contaminated.

To develop an innovative solution, an understanding of the flow characteristics of the residual waste and a means to contain the waste to protect the internal components of the Packaging Station required analysis, prototyping, testing and manufacturing trials.

A robust, disposable, thin walled, funnel type Disposable Debris Guide Liner was developed to be pre-positioned in the Packaging Station prior to every container transfer. The thin walled design allows the funnel to be pushed through the station by the legacy fuel container and compacted at the bottom of the new container below the legacy container, consuming less than 25 mm of height to ensure capping of the new container is not compromised.

Argon Containment Environment at Tile Hole

Prior to commencing any retrieval operations at the legacy Tile Holes, the hole must first be purged of potentially explosive hydrogen gas build-up. Argon is used to purge the Tile Hole and Retrieval Flask to maintain less than 2% oxygen levels during retrieval operations. An extensive supply of argon is required to first purge the large volume of the Tile Hole and Flask and then maintain the required oxygen levels.

A sealing system is essential to minimize the required argon supply for both the initial purge and maintaining the set environment while also controlling its rate of flow.

Any sealing method between the 5500 kg Shielded Collar and the remediated historical concrete surface of the Tile Array must minimize the load transferred to the concrete surface and result in a known and repeatable contact pressure.

To develop an innovative solution to seal the Tile Hole and Retrieval Flask, extensive analysis of argon supply systems, flow rate calculations, prototyping, testing, manufacturing and assembly techniques were performed.

A low-permeability foam type disposable gasket was developed that could be pre-positioned over the target Tile Hole and provide a known and repeatable rate of argon flow along with minimizing the contact pressure to the concrete surface to less than 21 kPa.

Wire rope penetrations required development and analysis of commercially available wire ropes along with potential encapsulation methods and materials. The selected combination of encapsulated wire rope along with wire brushes for cleaning the rope prior to exiting a penetration and packing being retained under known forces with spring washers provided a known and repeatable sealing method to control the argon flow while also protecting the wire rope and retaining debris inside the Retrieval Flask.

Instrument and actuation rod penetrations, through the shielded walls of the Retrieval Flask, are similarly sealed with a combination of packing being retained under known forces with spring washers.

CONCLUSION

The current status of Project activities is such that:

- Overall completion of the construction of the FPS Facility and all the civil works in the WMA to enable installation of the fuel retrieval systems have been completed;
- Installation of the major equipment within the FPS Facility will be completed by spring of 2013;
- Inactive commissioning activities have begun and will be completed by 2013 June; and
- The Final Safety Analysis Report supporting the FPS operations has been prepared and submitted to AECL's internal safety review committee.

Operational turnover of the FPS Facility is scheduled for 2013 and fuel retrieval, operations are planned to commence immediately thereafter. Approximately 22 tonnes of fuel located in five areas within the WMA is planned to be removed and safely stored over a five year period. The fuel will be stored in the FPS Facility until a national repository for high-level waste is built in Canada.

The FPS Project is funded by the Government of Canada, as part of the Nuclear Legacy Liabilities Program (NLLP).