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MANAGEMENT OF LEGACY SPENT NUCLEAR FUEL WASTES AT THE CHALK RIVER LABORATORIES: OPERATING EXPERIENCE AND PROGRESS TOWARDS WASTE REMEDIATION

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ABSTRACT

AECL has been managing and storing a diversity of spent nuclear fuel, arising from operations at its Chalk River Laboratories (CRL) site over more than 50 years. A subset of about 22 tonnes of research reactor fuels, primarily metallic uranium, have been identified as a high priority for remediation, based on monitoring and inspection that has determined that these fuels and their storage containers are corroding. This paper describes the Fuel Packaging and Storage (FPS) project, which AECL has launched to retrieve these fuels from current storage, and to emplace them in a new above-ground dry storage system, as a prerequisite step to decommissioning some of the early-design waste storage structures at CRL. The retrieved fuels will be packaged in a new storage container, and subjected to a cold vacuum drying process that will remove moisture, and thereby reduce the extent of future corrosion and degradation. The FPS project will enable improved interim storage to be implemented for legacy fuels at CRL, until a decision is made on the ultimate disposition of legacy fuels in Canada.

I. INTRODUCTION AND BACKGROUND

AECL is an integrated nuclear technology company providing services to nuclear utilities worldwide. AECL's Commercial Operations include reactor development, design, engineering, special equipment manufacturing, project management and construction of CANada Deuterium Uranium (CANDU™) nuclear power plants, and provision of reactor services and technical support to operating CANDU reactors. AECL also operates Nuclear Laboratories (Chalk River Laboratories (CRL) and Whiteshell Laboratories (WL)) and performs research, produces isotopes used in nuclear medicine and other applications, stores and manages nuclear wastes, and decommissions nuclear facilities.

AECL's extensive waste management activities over several decades have included operation of waste management storage and processing facilities at CRL and WL; development of the concept and related technology for geological disposal of Canada's nuclear fuel waste;

development of the IRUS (Intrusion-Resistant Underground Structure) disposal concept for low-level nuclear waste; development of dry storage technology for interim storage of used fuel; development and assessment of waste processing technology for application in CANDU nuclear power plants and at CRL and WL. An overview of AECL's waste management activities was presented at the 2004 Pacific Basin Nuclear Conference [1].

AECL has recently launched two large decommissioning projects to remediate the highest priority legacy wastes at the CRL site [2]. The subject of this paper is the Fuel Packaging & Storage (FPS) Project, which will deal with the legacy fuels stored in tile holes. The Liquid Waste Transfer & Storage Project [3,4], will deal with intermediate and high-level radioactive liquid wastes. AECL is also proceeding with the phased decommissioning of the WL site, for which the Canadian Nuclear Safety Commission (CNSC) granted a six-year decommissioning license in early 2003 [5].

AECL has operated research reactors at the CRL site since 1947, for the purpose 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 being placed in storage containers and transferred to the CRL Waste Management Area-B (WMA-B), where they have since been stored in below-grade, vertical cylindrical steel and concrete structures called "tile holes" (Figure 1).

WMA-B was established in 1953, and continues to be operated as a licensed waste management facility at CRL. Various designs of tile holes have been used to store high level wastes, including irradiated fuel and hot cell wastes. Tile hole storage structures are engineered to shield the radioactivity of these wastes, and contain any contamination, and thereby prevent the spread of radioactivity into the environment. In this regard, their performance is being confirmed through an ongoing physical inspection program, and a Groundwater Monitoring Program. This program concentrates on radiological and non-radiological constituents in groundwater in the vicinity of the storage facilities, and since its full inception in 1997, has confirmed that the tile holes continue to meet their design intent.

Although the tile holes have not released contaminants to the environment, some of the fuel in early-design tile holes is known to be degrading due to ingress of moisture. Certain fuel types, in particular metallic uranium, are quite susceptible to degradation by moisture-induced corrosion. Monitoring and inspection of these older fuel types have shown that some of the fuel storage containers and the fuel itself are corroding. Although these fuels are stored safely, continued corrosion will increase the future costs and hazards for handling the fuel and decommissioning the CRL waste storage structures.

The remainder of this paper describes the operating experience that has been developed for storage of metallic uranium fuels in early-design tile holes, and the FPS Project, which will remediate those fuels by retrieving them and emplacing them in a new above-ground storage system. The new storage system is being designed for 50 years of operation, which covers an interim storage period, pending availability of a long-term high-level waste management/disposal concept for Canada.

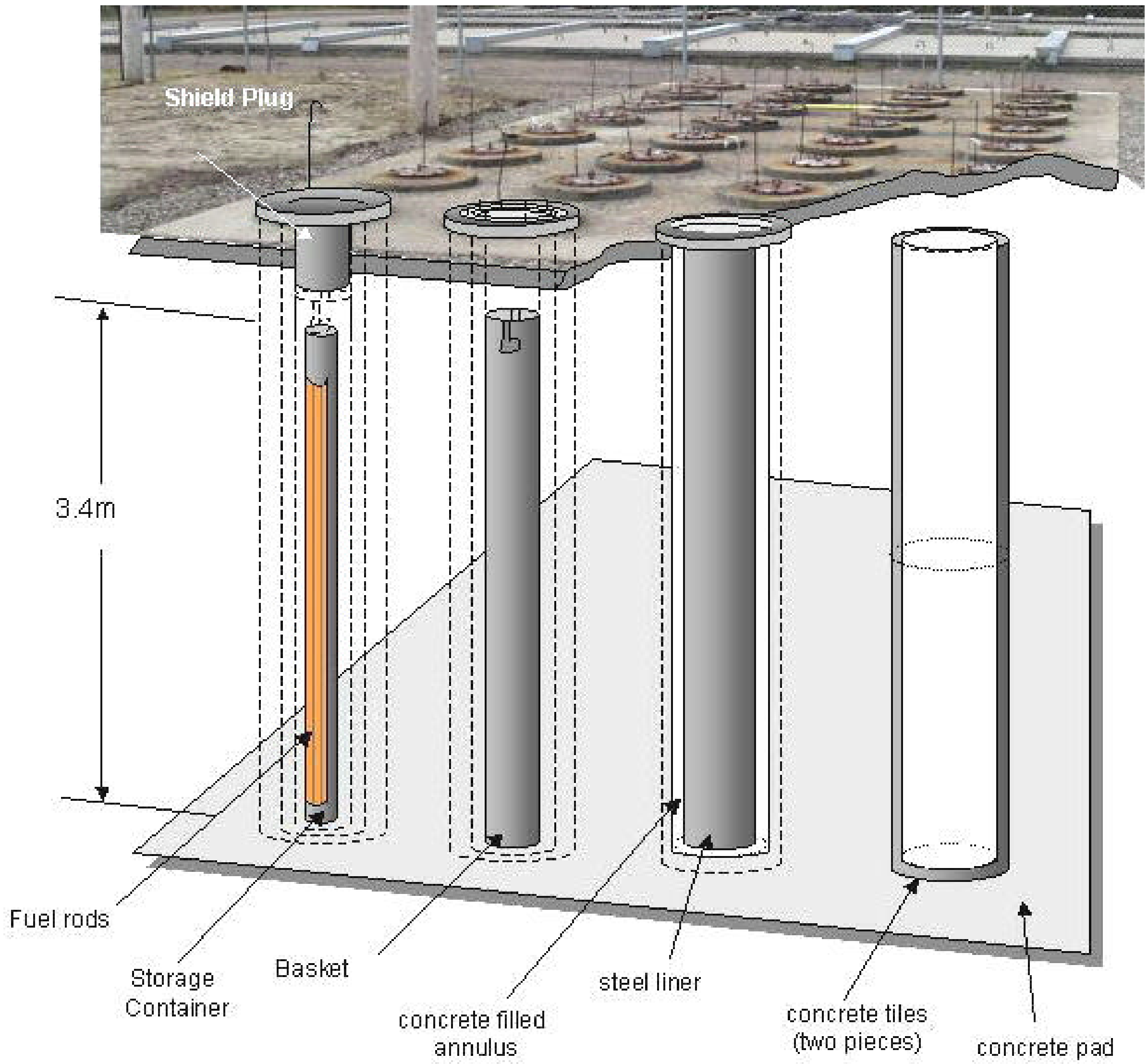

Figure 1. Tile Hole Construction. Tile Holes are constructed in arrays, on a concrete pad foundation, 4.6 m deep. Two concrete tiles are stacked vertically, and sealed at the joint. A mild steel liner with closed bottom is inserted, and the annulus backfilled with concrete. The liner tube has a gasket-sealed flange, which is closed by inserting a vented shield plug. The array structure is packed with sand between the tile holes, and capped with a concrete pad. The fuel rods (typically 3.4 m long) are contained in fuel storage containers, typically surrounded by baskets.

With the creation of the Nuclear Waste Management Organization (NWMO), Canada is progressing towards selecting and implementing an approach for the long-term management of Canada's nuclear fuel waste. The NWMO, established by the Canadian government in 2002 is mandated to make recommendations on long-term waste management concepts for Canada's used nuclear fuel in late 2005.

II. LEGACY FUELS

The term "legacy fuels" is used to describe spent nuclear fuels that were generated during the nuclear development program in Canada, primarily in the 1950s and 1960s. There are about 100 early-design tile holes containing legacy fuel in the form of long rods, 3.3 to 3.4 m in length, organized in five storage arrays in WMA-B. The fuels were irradiated in the 1950s, 60s and early 1970s, and were emplaced in tile hole storage beginning in 1963.

In total, this legacy fuel consists of about 700 rods (about 22 tonnes), primarily metallic uranium and uranium dioxide, clad in aluminum, and having less corrosion resistance than modern alloy-clad uranium oxide fuels. A small fraction of the legacy fuel also includes thorium metal, uranium-zirconium, thorium-uranium mixed oxides, uranium carbide and uranium-aluminum alloy rods. Table 1 provides a summary of the legacy fuel types and quantities.

Table 1: Legacy Fuels to be Remediated by the Fuel Packaging & Storage Project

Fuel Type	Percent of Total (22 tonnes)	Cladding Material
Uranium Metal (flat rods)	56	Aluminum
Uranium Dioxide Annular or Solid Rods	34	Aluminum
Thorium Metal	5.6	Aluminum
Uranium-Aluminum Alloy	<1	Aluminum
Uranium-Zirconium Alloy	2.5	Aluminum
Thorium-Uranium Mixed Oxide	1.5	Zircaloy
Uranium Carbide	<1	304 Stainless Steel

The rods vary in diameter from 44 to 76 mm. The burnup levels vary widely, with current decay heat of no more than about 4W per tile hole. The radiation levels also vary, up to approximately 1000 Rad/h for a fuel storage container, near contact.

Up to one quarter of the legacy tile holes contain quantities of bitumen (tar), which was poured into the tile hole after the fuel storage containers were first loaded, to assist sealing of the top closure.

III. OPERATING EXPERIENCE

AECL has been executing an ongoing monitoring, surveillance and inspection program, to ensure that the legacy fuel wastes remains in compliance with requirements, and that operational safety is maintained.

The monitoring program has confirmed that water is present inside some of the tile holes. In some cases this resulted from incomplete water removal when the storage containers were originally taken out of the water-filled fuel storage bay. There has also been ingress of water into some tile holes, through degraded flange gaskets. Another source of moisture has been environmental humidity entering the tile holes through a pumping process due to atmospheric pressure changes, with cooling of moist surface air drawn into the lower temperature regions inside the tile holes, resulting in condensation and a net accumulation of moisture over time. Through any of these processes, the result is that the current fuel storage conditions are not reliably dry, and this contributes to corrosion of the fuel and the storage containers.

Remedial action has been taken to remove water from the tile holes, and to limit further water ingress. A program to inspect and replace gaskets has been executed, and surface drainage around the concrete array caps has been improved. In recent years, a removable weather shield to shed precipitation has covered the arrays for the spring and winter seasons (Figure 2).

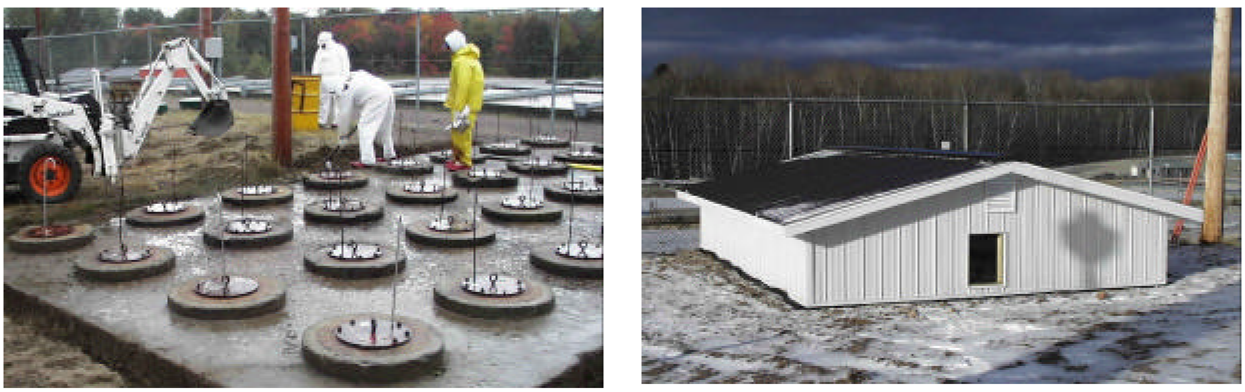

Figure 2. Remedial work to improve drainage and install weather shields over tile hole arrays.

The inspection program has included videoscope interrogation of the contents in many of the tile holes. The aim of these inspections was to determine the integrity of the storage containers and extent of corrosion of the fuel rods. Integrity of the mild steel storage containers has also been assessed by a program of measuring the friction while lifting the containers and weighing them when suspended a short distance above the bottom of the tile hole. These weight measurements were obtained using a custom-designed remote controlled hydraulic lifting system, with HEPA filtered ventilation, an inert gas purge system, and full containment during the operation (Figure 3).

Samples of the corrosion products (mainly oxides of uranium, thorium and aluminum) were also obtained and analyzed. A further detailed characterization of the fuel rods and storage container was conducted by removing these items from one tile hole and transferring them for destructive examinations in a shielded hot cell at CRL. This work was able to determine the extent of corrosion and confirmed that the corrosion was greater at the bottom of the fuel rods relative to the top, presumably due to moisture differences as a function of elevation in the tile holes. Segments of the retrieved fuel storage container, with enclosed sections of fuel rods, were cut and packaged into vessels that were humidified and subjected to vacuum drying tests, to determine the process parameters necessary to remove free water from the degraded fuel sections. The vacuum drying test program and results are described in [6].

Degradation of the stored wastes presents a challenge due to the potential for hydrogen build-up, resulting from corrosion and radiolysis processes in the closed storage containers. Equipment has been developed to ventilate these containers. The equipment has been designed and fabricated to remotely pierce the container, filter and vent any contained gases, and introduce oxidizing gases in a controlled manner to passivate the fuels that may contain hydrides of uranium. Piercing and passivation operations will be conducted before the fuel storage containers are retrieved and transferred by shielded flask to the new dry storage system.

Figure 3. Hydraulic lifting apparatus installed on tile hole.

IV. FUEL PACKAGING & STORAGE PROJECT

The Fuel Packaging & Storage (FPS) Project has been launched, to remediate the long-rod legacy fuels stored at CRL. The objective is to design, construct and commission the equipment and systems to:

- Retrieve the legacy long rod fuels from current storage in tile holes;
- Package and dry these fuels; and
- Store the packaged fuels in a new aboveground dry storage system.

The main construction will be a Fuel Packaging and Storage building (Figure 4) that will contain two Packaging and Drying Stations and a monolithic concrete Storage Block. The fuel will be retrieved in the existing storage containers, which will be placed in a new stainless steel container with a vented closure, and will then be dried before emplacement in the monitored Storage Block. Removing moisture and storing these fuels in a controlled atmosphere will stabilize deterioration, such that increases in the future hazards and costs of handling the fuel will be minimized.

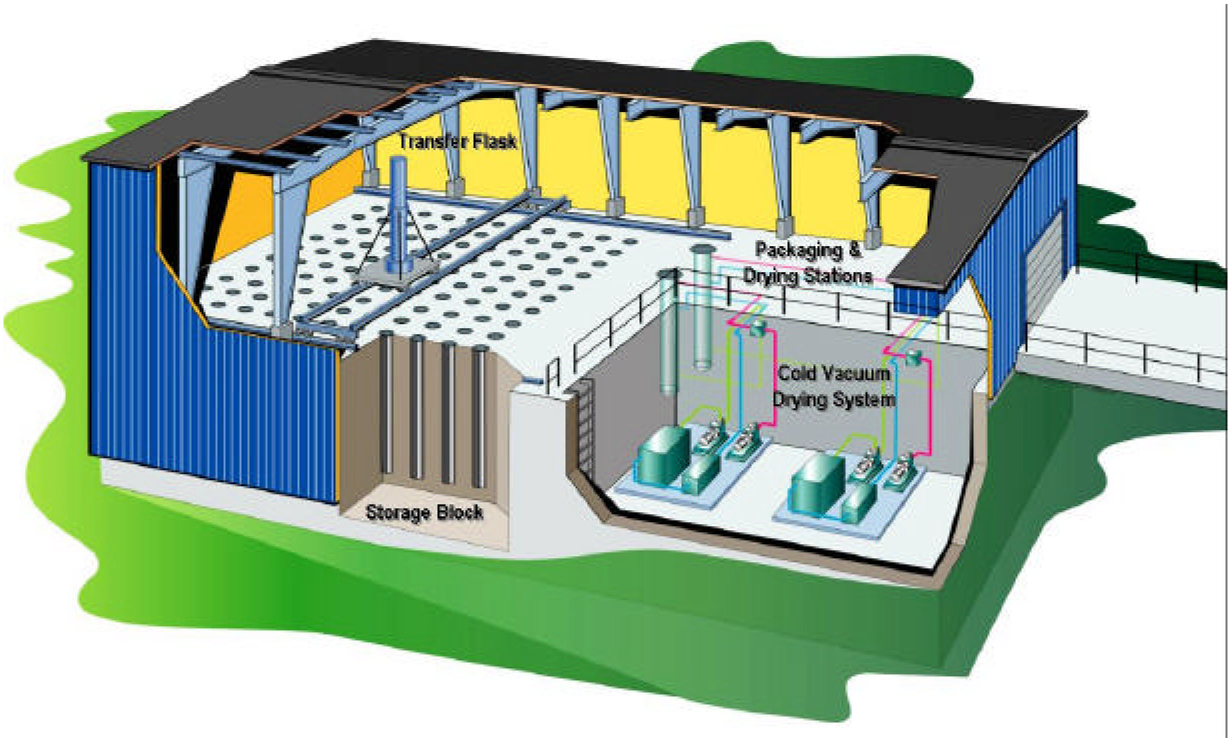

Figure 4. Conceptual view of the FPS Building.

The CRL site has a Nuclear Research and Test Establishment Operating Licence issued by the Canadian Nuclear Safety Commission (CNSC) pursuant to the Nuclear Safety and Control Act (NSCA). The Operating Licence defines conditions for operation and requirements to modify facilities listed in the licence. The FPS Project involves modifying the CRL Waste Management Areas, which is a license-listed facility, and must therefore comply with all relevant licence conditions and requirements.

AECL is an ISO 14001 environment-management-system-certified company. To ensure that workers, the public and the environment are protected during execution of the FPS Project, AECL operates established and approved Radiation Protection, Occupational Safety and Health and Environmental Protection programs that are in compliance with federal and provincial regulations, international standards and practises, and are approved by the CNSC. The CNSC staff review these programs and their effectiveness is assessed through audits conducted as part of the CNSC's compliance review processes. The effectiveness of these programs and their application during the FPS Project must be adequately demonstrated before regulatory approvals are granted.

The FPS Project is being executed under a quality management system that meets the requirements of the Canadian Standards Association (CSA) CAN3 N286.0-92, *Overall Quality Assurance Program Requirements for Nuclear Power Plants* and the International Standard ISO 9001:2000 *Quality Management Systems – Requirements.* A rigorous project management system is also being applied to control scope, schedule, cost, quality, risk, communications, procurement, and human resources.

The design of the FPS dry storage system has progressed to the detailed design stage. The design is being conducted to meet Canadian and international standards (e.g., CSA/N292.2 1996 *Dry Storage of Irradiated Fuels* and IAEA-116 *Design of Spent Fuel Storage Facilities*).

The CNSC has determined the need for a screening level federal Environmental Assessment (EA) under the Canadian Environmental Assessment Act (CEAA). The EA study report is currently being prepared, having completed the first phase of a public consultation process in communities surrounding the CRL site.

IV.A. Fuel Retrieval and Transfer System

The primary function of the Retrieval and Transfer System is to connect to the existing tile hole (Figure 5), recover fuel storage containers and transfer them to the FPS building. The main component is a Retrieval Flask, which will be positioned and supported above the tile hole by an Array Bridge and Trolley. A forklift truck will be used to move the Retrieval Flask from the tile hole array to the FPS building.

The Retrieval Flask will be designed to accept a 3.5 m long by 225 mm diameter mild steel storage container weighing up to 900 kg. It will consist of a shielded canister, a shield gate and an integral winch/grapple. An inert gas purge will be utilized during the retrieval operation to mitigate combustible gas hazards.

The Tile Hole Array Bridge and Trolley sub-system consists of four major components:

- Pilings supporting ground level rails and the Tile Hole Array Bridge;
- Tile Hole Array Trolley;
- Tile Hole Array Shielded Collar; and
- Hoist for raising and lowering the Tile hole Shield Plugs

The Retrieval Flask will consist of a shielded canister, a shield gate, an integral winch, a flask liner and a HEPA filtered cover gas system.

Any closed storage containers will have been pierced and vented several years prior to retrieval operations to passivate any uranium hydride that may currently be present.

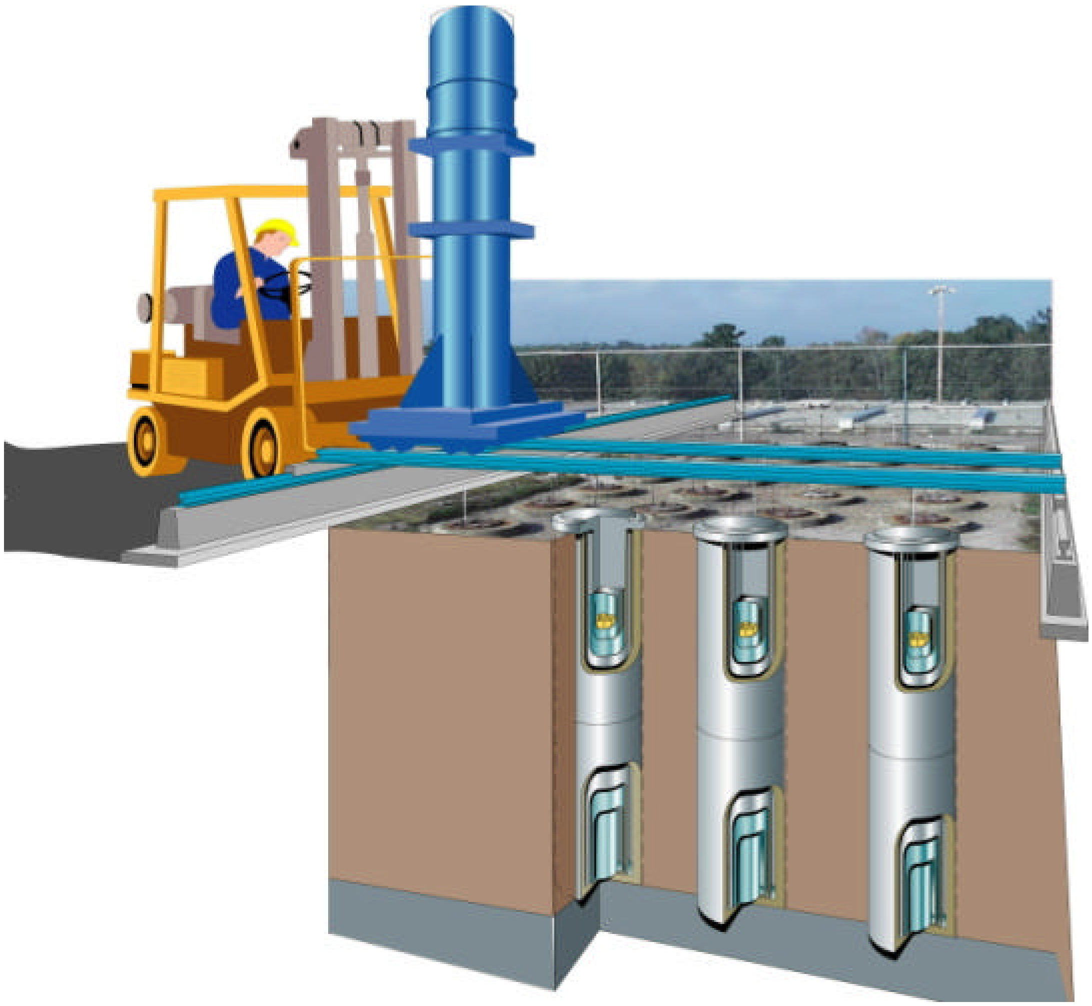

Figure 5. Concept view of the Array Bridge and FPS Retrieval Flask positioned above the tile holes array.

IV.B. Packaging and Drying System

Two Packaging and Drying Stations will be located within the FPS Building to receive storage containers transferred in the Retrieval Flask. The Retrieval Flask will be connected and sealed to the Packaging and Drying Station and the storage container will be unloaded into a new stainless steel storage container. A vented lid, with sintered metal filters, will be remotely applied to the new stainless steel container after the Retrieval Flask is disengaged and the Packaging and Drying Station is sealed. The vented lid will confine radioactive particulate while allowing atmospheric exchange between the inside and outside of the new container.

After applying the lid, a Cold Vacuum Drying (CVD) process will be performed, using a combination of cyclic evacuation and inert gas purges, followed by a pressure measurement test to determine completeness of the operation. This technology is widely employed, around the world, for drying of spent nuclear fuel. The intent of the CVD system is to remove residual free water from the storage container. Chemisorbed and physisorbed water are assumed to remain after the drying cycle is completed.

An extensive vacuum drying test program has been conducted at CRL, using degraded irradiated fuel rods retrieved from a tile hole, to provide information on the process parameter, such as temperature and pressure necessary to achieve the required level of moisture removal. The test program, which is described in detail in reference [6], indicates that a temperature of about 50ºC will be appropriate for processing the degraded metallic uranium fuel in the presence of bitumen. The CVD process will employ two skid-mounted vacuum heating/cooling systems, one for each Packaging and Drying Station. It is anticipated that up to one week will be required to complete the CVD process for each fuel storage container.

IV.C. Dry Storage System

AECL designs and builds CANDU spent fuel dry storage facilities worldwide. AECL has constructed eight large-scale above ground dry storage facilities for CANDU spent fuel in several countries. These projects add up to a constructed capacity in excess of 5,000 MTHM, which is a significant share of the total worldwide dry storage capacity.

The design for the new FPS dry storage system consists of a concrete block with an array of fuel storage tubes that will hold the new fuel storage containers. Conceptual designs considered many alternatives, including canisters and vault storage (Figure 6). The FPS storage structure will provide shielding and a secondary confinement boundary, and facilitate monitoring and inspection. The Storage Block design will utilize many features of AECL's Modular Air Cooled Storage (MACSTOR®) system [7].

A key feature of the FPS dry storage system is the capability to monitor the pressure, and hence storage performance of each individual storage volume. The design intent is to achieve a high level of dryness in the degraded fuels, through the CVD process, but it is recognized that there is uncertainty in the achievable level of moisture removal, particularly regarding chemisorbed and physisorbed water. For this reason, the new storage containers are designed to allow venting, through a sintered metal filter, into a sealed storage volume. The storage volume will be kept at a slight positive pressure, and will be monitored, to detect changes in pressure, due to leakage or due to gas evolution through ongoing corrosion processes.

Figure 6. Concrete Canister Storage (left) for spent CANDU fuels at CRL, and Modular Air Cooled Storage (MACSTOR®) module at the Gentilly-2 reactor site (right).

IV.D. Schedule

The FPS Project is being executed against a seven-year schedule, beginning 2003 April and concluding 2010 December. The project has completed the conceptual design phase. Preliminary engineering of the FPS building and associated systems will be completed in 2005, in parallel with the EA and development of the conceptual safety case. Detailed design of the dry storage system is proceeding now. A construction approval is anticipated in early 2008, and commissioning, with turnover to Operations, will be completed in 2010. Fuel retrieval, packaging and drying operations are planned to commence immediately thereafter, and be completed over a three-year period.

Although AECL is performing the detailed design of the dry storage system, the majority of design and construction activities for the other systems are planned to be contracted to qualified vendors on a competitive basis.

AECL expects to invite bids for design-build contracts for the retrieval and transfer system, and the CVD system in early 2006.

V. SUMMARY

AECL manages a diversity of spent nuclear fuels at the CRL site. Performance monitoring programs have identified the need to implement an improved storage system for some of these fuels, arising from the early period of nuclear development in Canada. About 22 tonnes of fuel, primarily metallic uranium, will be remediated by removing moisture and storing these fuels in a controlled atmosphere, in order to stabilize deterioration, such that increases in the future hazards and costs of handling the fuel will be minimized.

The Fuel Packaging and Storage (FPS) project will advance the safe, interim storage of research reactor fuel rods by transferring them from existing storage at the CRL site to a new Fuel Packaging and Storage building. The project will enable improved interim storage to be implemented until a decision is made on the ultimate disposition of legacy fuels in Canada.

VI. REFERENCES

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