MANAGING RADIOACTIVE WASTE AT ATOMIC ENERGY OF CANADA LIMITED (AECL) - RECENT DEVELOPMENTS

W.C.H. Kupferschmidt
Atomic Energy of Canada Limited, Chalk River Laboratories
Chalk River, Ontario, Canada K0J 1J0

ABSTRACT

AECL continues to add to its over half-century history of contributing to the solution of nuclear waste management questions in Canada and internationally. This paper describes selected recent examples, which range from construction of used fuel storage facilities, to application of technology for environmental restoration, to the initial steps of decommissioning an entire complex nuclear research laboratories site.

AECL designs and builds CANDU used fuel dry storage facilities worldwide. AECL has constructed eight large-scale above ground dry storage facilities for used fuel from CANDU™ power reactors in Canada, Korea and Romania. These facilities represent a significant share of the total worldwide dry storage capacity for used fuel.

AECL is continuing its long-standing research effort on deep geological disposal of used nuclear fuel for the Canadian nuclear utilities, with a view to its possible future implementation in Canada. This contribution, through Ontario Power Generation’s Deep Geologic Repository Technology Program, builds on the experimental work at the Underground Research Laboratory (URL) near AECL’s Whiteshell Laboratories (WL) in Manitoba, as well as the experience gained over the last 60 years in operating AECL's Chalk River Laboratories (CRL) site in Ontario. Work continues on developing the technologies needed to characterize potential repository sites, geotechnical engineering to design and site a repository, modeling of the entire disposal system, and assessment of its future performance. AECL has collaborated with numerous radioactive waste management organizations in other countries for decades. The recent second phase of the Tunnel Sealing Experiment (TSX), funded by France and Japan, studied the effectiveness of clay and cement-based tunnel sealing systems.

AECL is also contributing to the U.S. Yucca Mountain project. Work completed by AECL includes risk analysis, radionuclide transport experiments, crevice corrosion and neutron stress analysis studies on metal alloys, and extensive independent reviews of scientific documentation on the suitability of the Yucca Mountain concept. As the Yucca Mountain Project moves closer to construction activities, AECL is now contributing its expertise in used fuel handling equipment.

AECL has a mandate to manage Canada's legacy radioactive wastes at AECL sites. AECL manages the wastes from its own nuclear R&D activities and medical isotope production. It also receives the low-level waste from hospitals, universities and industry across Canada for interim storage, and eventual processing, repackaging and disposal. AECL continually improves its waste management practices, and carries out applied R&D in support of advanced environmental remediation technologies.

Several projects are underway at CRL to address various legacy waste management issues from the early days of Canada's nuclear program. These currently include replacing early storage systems for research reactor fuel and liquid radioactive wastes. Technologies have also been developed and are now being deployed, for example, to trap and immobilize groundwater-borne contaminants in situ.

In recent years, AECL has decommissioned radiochemical laboratories, electron accelerators, heavy water plants and reactors, and currently manages prototype power reactors and nuclear facilities undergoing decommissioning at several sites. In the late-1990s, AECL began preparations to decommission its entire Whiteshell Laboratories (WL) site. In late 2002 the Canadian Nuclear Safety Commission issued to AECL a decommissioning licence authorizing the first planned phase of WL site decommissioning. The six-year WL licence was the first overall decommissioning license issued for a Canadian Nuclear Research and Test Establishment, and was the longest licence term ever granted for a nuclear installation of this complexity in Canada. The first phase of decommissioning is now in progress.

USED FUEL MANAGEMENT

Long-standing Canadian strategy for managing the used fuel from Canada's CANDU® nuclear power plants has been to provide safe interim storage at the reactor sites using a combination of pool and dry storage technology, and in parallel to develop the technology for direct disposal of the fuel.

Both pool and dry storage of fuel are fully proven, based on many years of successful, safe operating experience. AECL pioneered the dry storage concept in Canada, and has now completed dry storage facilities for both domestic and foreign utilities.

AECL has also developed a concept for the direct disposal of used fuel in plutonic rock of the Canadian Shield. While Canada is currently evaluating which approach it will adopt for long-term management of used fuel, AECL continues to carry out research to maintain and develop the disposal concept further under contract to Ontario Power Generation (OPG).

Interim Storage of Used CANDU Fuel

Typical CANDU fuel consists of a bundle of 37 fuel pins, each containing a series of natural uranium fuel pellets. The pins are welded to grid spacers to make up the bundle. Bundles are cylindrical, approximately 50-cm in length, 10-cm in diameter and weigh approximately 24 kg. When a fuel bundle is discharged from the reactor after 12-18 months of irradiation, it is moved to a pool system for interim storage. The water in the pool removes the residual heat produced by the used fuel and provides radiation shielding for workers. The compact design of the CANDU fuel bundle, and the impossibility of criticality occurring for CANDU natural uranium used fuel bundles in water pool storage, makes for extremely simple and economical pool storage. Fuel packing densities are determined by considerations such as heat transfer and shielding, and not by the need to avoid criticality accidents.

After used CANDU fuel has been out of the reactor for about six years, its radioactivity and rate of heat generation have decreased sufficiently to allow the fuel to be transferred to dry storage, if desired. Compared with wet storage, dry storage is considered to have several advantages: safe and passive storage conditions, ease of providing additional storage capacity, simplicity, and low construction and operating costs.

AECL started to study dry storage for used nuclear fuel in the early 1970s. Silo-like structures called concrete canisters were first developed for the storage of enriched uranium fuel from research reactors, and were then further developed for used CANDU natural uranium fuel. By 1989, concrete canisters were being used for safe and economical storage of all used fuel accumulated during the operation of AECL's decommissioned prototype reactors (see Table I). Each concrete canister contains a stack of nine used fuel baskets, with each basket holding up to 60 fuel bundles.

Table I. Dry Storage Facilities Using AECL's Technology

Location	Fuel Quantities (MgU)	Number of Concrete Canisters/Modules
Whiteshell Laboratories[(a)]	17[a, d]	11[b, d]
Gentilly-1[(a)]	67[a, d]	11[b, d]
Douglas Point[(a)]	298[a, d]	47[b, d]
Chalk River Laboratories (fuel is primarily from Nuclear Power Demonstration (NPD)[(a)])	75[a, d]	11[b, d]
Pt. Lepreau Nuclear Generating Station	1436[d] 2790[e]	140[b, d] 275[b, e]
Wolsong-1 Nuclear Power Plant	2052[d] 2790[e]	200[b, d] 275[b, e]
Gentilly-2 Nuclear Generating Station	1140[d] 2790[e]	5[c, d] 16[c, e]
Cernavoda 1-2 Nuclear Power Plants	228[d] 6156[e]	1[c, d] 27[c, e]

a) Site under Decommissioning
b) Concrete canisters
c) MACSTOR modules
d) As Built/Current Capacity
e) Lifetime Capacity

The same basic technology was then applied to on-site dry storage of used fuel generated by operating CANDU nuclear power generating plants. New Brunswick Power and Korea Electric Power Company selected AECL's concrete canister technology for their CANDU 6 nuclear generating stations at Point Lepreau (1989) and Wolsong 1 (1990) (see Table I).

In 1989, AECL began development of a monolithic, air-cooled concrete structure for dry storage, called MACSTOR (Figure 1). A full-scale test facility was built at AECL's WL that confirmed the efficient thermal performance. MACSTOR modules require less land area than concrete canisters for the same amount of used fuel and are suitable for storage of used fuel assemblies from CANDU reactors as well as other reactor types (PWR, BWR, VVER and RBMK). In 1995, Hydro-Québec built the first such system for dry storage at the Gentilly-2 CANDU 6 nuclear generating station (Figure 1) [1], and continues to add modules as needed.

Fig. 1. MACSTOR Dry Storage Modules at Gentilly-2 in 2003. Two further modules were added in 2004.

In 2000, *Societatea Nationala Nuclearelectrica S.A.* (SNN), the plant owner of the Cernavoda station in Romania, proceeded with an international invitation to bid for the supply of dry storage technology for used fuel from Unit 1 (and eventually Unit 2) of the Cernavoda CANDU 6 nuclear power plant. The MACSTOR system emerged as the most suitable and cost-effective technology. AECL has supplied the complete used fuel packaging system and dry storage structure, including one storage module. The project started in 2001 and was completed in 26 months; used fuel loading commenced in June 2003.

Since 2001, KHNP/NETEC's (K/N) and AECL have been jointly developing a higher-capacity dry storage structure based on the MACSTOR storage module concept for the Wolsong site. The proposed approach addresses the conditions that are specific to the Wolsong site: large yearly fuel throughput, space limitations, and the need for an economical dry storage structure that can store lifetime used fuel inventories expected from the four CANDU units. The selected configuration is a 4-row MACSTOR-like module with a capacity of 24,000 bundles stored in 400 baskets, each holding 60 used fuel bundles. The module is thus termed MACSTOR/KN-400, which would offer a storage density increase of about a factor of 3, compared to the concrete canisters that are presently in use [2].

Disposal of Fuel Waste

Current used fuel storage practices at CANDU sites have an excellent safety record, permit easy monitoring and retrieval, and could be continued for many years. Storage, while an extremely effective interim measure, is, however, not considered to be a permanent measure. There is general international consensus among waste management experts that the preferred method for long-term management of nuclear fuel waste is land-based geological disposal [3]. Canada and other countries with nuclear power programs have been developing the technology for the permanent disposal of nuclear fuel waste for many years.

In the 1980's and 1990's, AECL developed a concept for disposal of Canada's nuclear fuel waste based on deep geological disposal, similar to the disposal methods proposed in many other countries [4]. AECL proposed to use the rock of the very stable Canadian Shield. In common with the approach adopted in other countries, the disposal concept developed by AECL entails isolating the waste from the biosphere by a series of engineered and natural barriers. These barriers include the waste form itself (either used fuel or solidified high-level waste from reprocessing); the long-lived containers in which the waste is sealed; buffer materials to separate the containers from the surrounding rock and to control the movement of water to, and corrosion products away from, the containers; seals and backfill materials to close the various openings, tunnels, shafts and boreholes; and the rock mass in which the repository is located (the geosphere). The biosphere, although not a barrier per se, is an important part of the overall system. It needs to be studied as part of any waste management program, since it contains the pathways through which direct exposure of humans and other organisms to contaminants could occur.

The waste would be emplaced in a repository excavated in stable rock below the water table. Hence, the principal concern from the point of view of long-term safety is that groundwater could eventually become contaminated with radioactive or other hazardous materials, and ultimately make its way to the surface and pose a risk to future human health or the environment. The multi-barrier system consisting of the chemically stable waste form, the very long-lived container, the buffer and the rock, provides assurance that the effects will not be significant. Thus, human health and the environment will be protected, even in the very long term.

The concept underwent an extensive environmental review by an independent panel under the Government of Canada's Environmental Assessment and Review Process in the mid 1990's. This review included an in-depth technical review of the concept, probably the most extensive technical assessment review of any project advanced in Canada.

The panel concluded that from a technical perspective, the safety of the AECL concept had been on balance adequately demonstrated for a conceptual stage of development, but from a social perspective, it had not received demonstrated broad public support [5].

Recent Developments

In 2002, the Government of Canada approved the Nuclear Fuel Waste Act (NFWA) [6]. The legislation required electricity-generating companies which produce used nuclear fuel to establish a not-for-profit waste management organization to carry out the managerial, financial, and operational activities to implement long-term management of nuclear fuel waste. Accordingly, the Nuclear Waste Management Organization (NWMO) was established in late 2002. The NWMO will manage all the nuclear fuel waste of the utilities, universities, and other small owners in Canada.

The NFWA legislation also authorized the establishment of a trust fund by the owners of nuclear fuel waste in Canada to pay for the long-term management of the waste, with deposits to the fund made on an annual basis. The NWMO will only have access to this funding after the

Government of Canada has selected and approved a long-term management approach and has issued an appropriate license related to activities for implementation of the approach. In the meantime, Ontario Power Generation (OPG) has continued to provide financial support and technical direction to advance and optimize the disposal technology and to maintain key areas of technical expertise.

As its first major task, the NWMO was charged with studying the options and different approaches for the long-term management of nuclear fuel waste, including geological disposal based on the concept developed by AECL, storage at reactor sites, and centralized storage above or below ground.

In its first two years, the NWMO has:

- engaged in a series of conversations about expectations with stakeholders, technical experts, and interested Canadians;
- explored the fundamental issues involved in developing a strategy for long-term management of used nuclear fuel that safeguards the public in a way that is sustainable, ethically and socially acceptable, and respectful of the environment - now and in the future;
- commissioned a series of background papers to present factual information on the current status of nuclear fuel waste and the context for its long-term management; and
- issued an extensive assessment of the advantages and disadvantages of the various approaches.

The NWMO will propose to the Government of Canada by November 2005 one or more long-term used fuel management strategies for Canada based on a comprehensive, integrated, and economically sound approach. The NFWA legislation authorizes the Government of Canada to decide which approach will be adopted. The government's choice will then be implemented by the NWMO, subject to all of the necessary regulatory approvals. Extensive information on the progress of the NWMO is reported on its website: www.nwmo.ca.

Current AECL Activities In Deep Geological Disposal

In recent years AECL has continued performing R&D required to further refine the technology for deep geological disposal under OPG's Deep Geologic Repository Technology Program (DGRTP). The areas of AECL effort include geoscience and methods for site characterization, repository design and engineering, and long-term safety assessment.

AECL has carried out R&D on disposal in collaboration with the waste management organizations in a number of other countries, including Finland, France, Japan, Sweden, the United Kingdom and the United States over the past 20 years. AECL's Underground Research Laboratory (URL) near the Whiteshell Laboratories has been dedicated to the study of technologies related to the long-term management and deep geological disposal of nuclear fuel waste. For over ten years, a major experimental program has been undertaken in the URL to develop various technologies that form the basis of the deep geological disposal concept.

A recent achievement was the completion of the first phase of the Tunnel Sealing Experiment (TSX), co-sponsored by AECL, OPG, ANDRA (France), JNC (Japan) and the USDOE [7]. The

TSX was a large-scale demonstration of the design, construction and performance of concrete- and clay-based seals similar to those that would be used in a geological repository. Two bulkheads, one composed of high-performance concrete and the other of highly compacted sand-bentonite material, were constructed in a tunnel in unfractured granitic rock at the 420-m level in the URL. The chamber between the two bulkheads was pressurized to 4 MPa, a value representative of the ambient pore pressures in the rock at a depth of 420 m. Instrumentation in the experiment monitored the seepage through and around each bulkhead, as well as parameters that are important indicators of bulkhead performance. The results from the TSX have been used to characterize the performance of the two bulkheads under applied hydraulic pressures.

In the second phase of the TSX, supported by JNC and ANDRA, the performance of the two bulkheads was tested at higher temperatures, comparable to those expected in a geological repository. With the support of ANDRA and JNC, the second phase of the TSX is being completed, with TSX underground work having been completed in 2004.

With the conclusion of the TSX project, and in the absence of other on-going research and development programs in the URL, AECL is now proceeding with its closure.

AECL Supporting Work for the U.S. Yucca Mountain Project

In the United States, AECL has supported the USDOE during the site characterization phase for the construction of a geologic repository at Yucca Mountain, Nevada [8]. Recent AECL contributions include:

- experiments on unsaturated and saturated flow and transport of radionuclides in blocks of tuff excavated from Busted Butte,
- experiments to determine whether various combinations of metals and alloys would be susceptible to crevice corrosion;
- excavation by diamond wire saw of an undisturbed block of fragile volcanic tuff at Yucca Mountain for experiments at Lawrence Berkley National Laboratory to validate several models related to fracture networks; and
- extensive independent reviews of scientific documentation pertaining to the suitability of Yucca Mountain as a repository for the disposal of high-level nuclear waste.

MANAGEMENT OF LEGACY AND OPERATIONAL WASTES AT AECL SITES

As the Federal Crown Corporation charged with leading the development of peaceful applications of nuclear technology in Canada, AECL has a long history of managing radioactive wastes, beginning with the establishment of the Chalk River Laboratories in the mid-forties. Indeed, the first radioactive waste management area at the Chalk River site was established in 1946.

As is well recognized, radioactive wastes encompass a wide spectrum of characteristics, including physical properties (gases, solids, liquids), chemical properties (organics, in-organics), and radiological properties (radioactivity levels, radioactive half-lives). The management of such diverse wastes requires that management steps be tailored to the properties of the waste. Radioactive waste management needs to be planned and implemented as a continuum of activities that are integrated and that take account of the various steps in waste management. Thus, wastes need to be segregated and characterized so that they can be processed, packaged, stored, and eventually disposed of in an optimum manner, i.e., constraining costs while meeting the fundamental objectives of ensuring worker safety, and protecting public health and the environment, now and in the future, while at the same time minimizing the burden passed to future generations.

From the earliest days of radioactive waste management at AECL’s laboratories, the radiological hazards posed by radioactive wastes were well recognized (e.g., solid wastes were managed in segregated waste management areas, with a focus on characterizing and managing them on the basis of external radiation fields to ensure the radiation protection of workers). Thus, at CRL, very low activity liquids were originally directly discharged to the Ottawa River with appropriate monitoring to ensure releases were well below (typically <1% of) the regulatory limits. Higher activity liquid wastes were discharged to designated waste management areas. Still higher activity liquid wastes were processed to remove radioactive contamination, using techniques such as ion exchange, reverse osmosis, micro-filtration and evaporation. The highest activity liquid wastes arising from the processing of fuels were placed into storage in shielded tanks. Similarly, very low activity solid wastes were packaged and placed into sand-trench landfills; higher activity, but contact-handleable wastes were placed in lined trenches and concrete bunkers; and used reactor fuel and other highly active wastes were placed into below-grade, engineered tile holes. A tile hole consists of two stacked vertical concrete tiles, approximately 250-mm in diameter and 4.3-m in height, and mounted on a concrete pad. Typically 20 or more tile holes are constructed at a time in a rectangular array. Shielding is provided by the soil surrounding the tile holes and the transfer of wastes from shipping flasks into the tile holes is relatively straightforward.

Over time, these waste management practices have evolved as knowledge and technology have improved. Thus, at AECL’s WL, contact-handleable wastes have been stored in above-ground storage facilities for many years, and this practice has also been adopted at CRL for the solid wastes that were previously placed in-ground in designated waste management areas. Direct liquid discharge to waste management areas has been discontinued for several years at CRL, and low-level liquid wastes are now processed in an upgraded Waste Treatment Centre. At WL, above-ground dry storage technology has been used for the storage of research reactor and other fuels since the mid-70s, and a similar approach is being phased in at the CRL site.

Comprehensive 10-year waste management and decommissioning plans have been developed and are regularly updated for the CRL site; these plans identify the remaining gaps between current practices and best practices worldwide, and define the steps to be taken to address those gaps. Defining these needs, and assessing the options for their management, is the function of a centralized planning and assessment group, which also manages the decommissioning of AECL’s nuclear facilities. This planning and assessment group works closely with a centralized waste remediation and enhancements project management group that establishes and directs project teams that build or upgrade facilities needed to address waste management and decommissioning liabilities.

Over the course of the past few years, a series of major waste remediation and infrastructure upgrading projects have been undertaken at CRL. These include:

- the Liquid Waste Transfer and Storage (LWTS) Project to recover, condition and re-store in a modern, monitored stainless steel storage system a variety of intermediate and high-level liquid wastes that are currently stored in numerous aging waste storage tanks;
- the Fuel Packaging & Storage (FPS) Project to recover, condition and place into a new interim storage facility, problematic historic research reactor fuels now stored in steel-lined concrete standpipes;
- a project to further increase the reliability of the Waste Treatment Centre used to treat liquid process wastes generated from site operations;
- a project to upgrade the existing shielded facilities to better accommodate decommissioning activities;
- a project to put in place new long-term storage facilities for high activity solid wastes and permit phasing out the use of tile holes for interim storage of highly radioactive materials; and
- construction of a new Waste Analysis Facility (Figure 2) to be used for characterizing "likely clean" solid wastes and for verifying the suitability of this material for unconditional release to conventional landfill sites, thereby avoiding the use of expensive storage systems when it is unnecessary to do so.

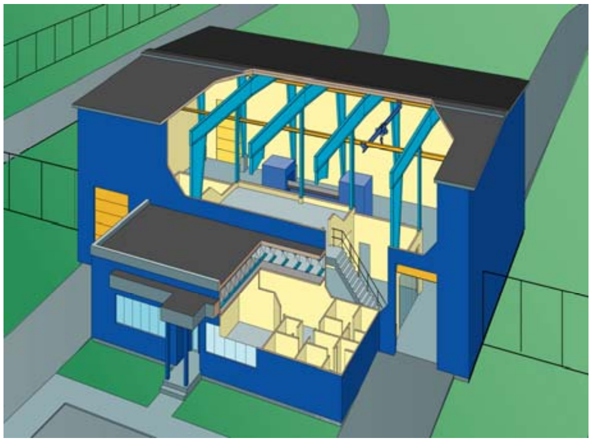

Fig. 2. Waste Analysis Facility.

The LWTS and FPS are the two largest projects, and are briefly described below.

Liquid Waste Transfer and Storage (LWTS) Project

The LWTS Project will provide equipment and facilities to retrieve liquids and sludges from historical storage tanks and transport them to a new consolidation facility for interim storage until processing facilities are available to solidify the wastes (Figure 3).

Fig. 3. LWTS Storage Facility.

The project involves retrieving approximately 300 m^3 of highly radioactive liquid radioactive waste that is currently stored in 21 tanks at several locations on the CRL site, transferring and consolidating it in a new storage system, and conditioning the waste for future solidification [9,10]. The wastes originated from research reactor operations, fuel reprocessing, and medical isotope production during more than 50 years of operations at CRL. The wastes are mixed, and contain radioisotopes (principally cobalt-60, cesium-137, strontium-90 and uranium) and non-radioactive hazardous materials (principally mercury, cadmium, acids and bases). The project will be a significant step towards a future long-term management solution for the wastes.

Wastes will be transferred to the new storage system by transfer pipelines or by shielded flasks on transport vehicles. The new storage tanks and associated equipment will be housed in a single building located within the developed area of the CRL site. The tanks will be placed within lined concrete vaults that are equipped with a leak detection system.

The storage system will have several advantages: fewer tanks in a single building, reduced waste surveillance costs, reduced doses to workers, enhanced safety features, including monitoring and retrieval systems, reduced criticality risk, and wastes chemically conditioned and stored in a form ready for solidification and that will minimize the future solid waste volume.

The project team has conducted extensive camera inspections of the tanks and vaults, sampled the wastes and done waste blending tests, assessed the hazards, possible technologies and their relative safety, built and tested mockups to develop and prove retrieval procedures, selected a site for the consolidation facility, and documented the chosen engineering concept. A request for proposals to design and build the new storage system is on schedule to be issued in March 2005. The project is targeted for completion by November 2008.

Fuel Packaging and Storage (FPS) Project

The FPS Project [11] will provide facilities to remove selected research reactor fuel rods from tile holes; transport the rods to a conditioning facility; dry and repackage the rods in new containers; and store the fuels in a monitored above-ground vault (Figure 4), pending the availability of a long-term waste management facility.

The FPS Project is focused on remediating some 22 tonnes of prototype research reactor fuel (approximately 700 fuel rods, each 3.4-m long) that was irradiated in the 1950’s, 60’s and early 70’s). The fuel was used in the experimental program to develop fuel for current CANDU reactors and AECL’s new Advanced CANDU reactor (ACR). Several fuel types are involved, including metallic uranium, uranium dioxide, uranium carbide, thorium, MOX, and HEU uranium alloys. The fuel is currently stored in approximately 100 tile holes.

Tile holes of early design were susceptible to ingress of water from surface run off, snowmelt and thermal cycling. Water entering some tile holes has promoted corrosion of uranium metal, leading to production and release of hydrogen gas. This water will be removed from the fuels via low-temperature vacuum drying technology. The passive monitoring system incorporated within the new storage vault will confirm that that the dried fuels remain stable.

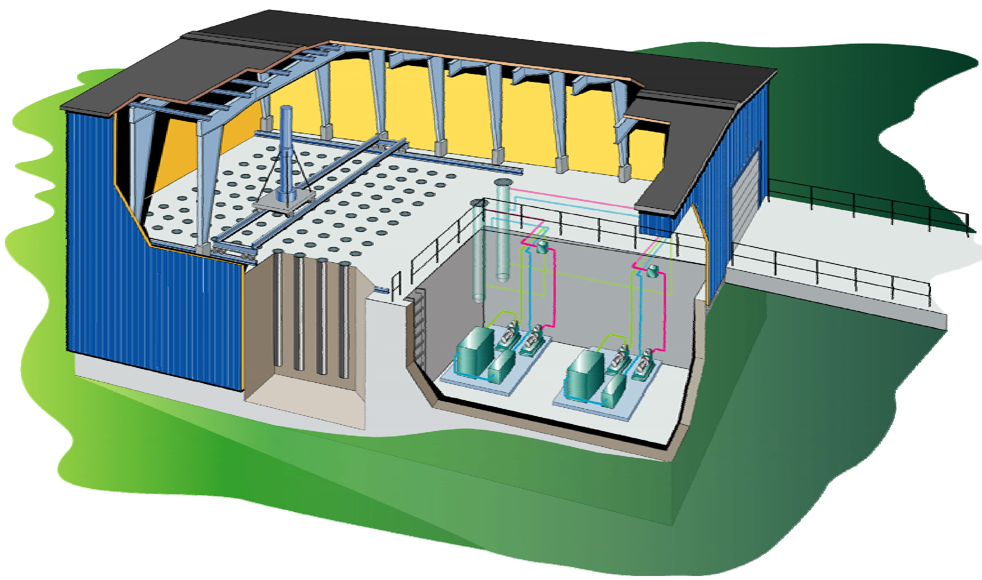

Fig. 4. FPS Fuel Conditioning and Storage Building.

The FPS Project team has confirmed the current waste and storage configurations, recovered a fuel sample and performed drying tests, assessed the relative risks to health, safety and the environment of the different types of fuel, evaluated alternative technologies for retrieval, drying and storage systems, and documented the recommended engineering concept. Detailed design work for the storage vault and equipment was recently initiated. The project is scheduled for completion in December 2010.

CHEMIC™ Groundwater Treatment

AECL developed the CHEMIC™ process as part of the company’s environmental remediation program [12,13]. The process is based on the direct-contact chemical treatment of wastewaters with suitable precipitants and powdered sorbents. Dissolved contaminants are transformed to a heterogeneous solid-liquid suspension. The contaminant-bearing solids are efficiently separated from the suspension using cross-flow microfiltration, and are further de-watered as necessary by using gravity settling or filter-press equipment. The de-watered secondary waste is either drummed directly or immobilized using a binder such as cement to produce a suitable waste form for storage and ultimate disposal. The majority of the process filtrate which meets the target water quality is discharged either directly or, if necessary, through a set of fixed-bed ion-exchange/adsorption columns to meet applicable release targets for treated water. The process utilizes the combined effects of contaminant precipitation, ion-scavenging, and ion sorption, together with synergistic use of chemicals in different parts of the process to provide the flexibility needed for mixed-waste solution treatment. In many respects, the process is an expanded and efficient version of a pre-treatment step that is generally required for reliable operation of processes such as fixed-bed ion exchange and reverse osmosis-evaporation.

Versions of the CHEMIC™ process for the removal of ^{90}Sr from groundwater have been implemented in remediating contaminated ground waters at two CRL locations. The process used in these applications involves a modified lime-soda treatment step combined with direct addition of a natural zeolite powder to enhance the removal of precipitates and sorbed suspended particles of ^{90}Sr, Ca and Fe by cross-flow microfiltration. Since 1994, the two facilities have treated in excess of 48 million litres (12.6 million US gallons) of Sr-90 contaminated waters (2000 too 3000 Bq/L) and reduced Sr-90 in the discharge waters by a factor in the range of 100 to 1000. The overall waste-volume reduction (volume of waste water to volume of stabilized secondary waste) has been in the range of 1000 to 3000.

The CHEMIC™ process is applicable to a wide range of contaminated groundwater, landfill leachate, and leachates from soil treatment and mine tailings. The process is flexible and can be used in applications involving a wide spectrum of contaminants and contaminant concentrations. The technology can be made portable for use in site remediation demonstrations and clean-up applications.

Wall and Curtain *In Situ* Remediation of Contaminated Groundwater

In the early 1950's, as part of a process system failure in a pilot facility at CRL for decomposing and volume reducing ammonium nitrate solutions, some of the solutions were released into the ground through pits lined with crushed limestone. Hydrogeological investigations performed by AECL staff later showed that the release of these solutions resulted in ^{90}Sr-contamination of a 400-metre long section of an aquifer and that, by the late 1990's, contaminated groundwater would be passing beneath a margin of wetland. Stopping or slowing the migration of ^{90}Sr was important because the introduction of ^{90}Sr to wetlands results in an accumulation in vegetation and soils.

A permeable reactive barrier was installed in December 1998 to prevent the subsurface strontium from contaminating the wetland. The goals were: 1) to halt the migration of the ^{90}Sr before it could reach the wetland, 2) to provide the same quality of flow and concentration monitoring that is possible with pump-and-treat technologies, such as the CHEMIC™ process, and 3) to do this with a low-cost, no-maintenance, passive technology. The barrier meets these goals and also allows flow and effluent concentrations to be measured directly and the width of the groundwater capture zone to be adjusted.

The permeable reactive barrier is called the Wall & Curtain, named for its two main components - a steel cut-off **wall** that extends into the ground 12 metres into till or to bedrock, and a **curtain** of reactive, granular zeolite through which the contaminated groundwater is directed (Figure 5). At the back of the curtain (and in front of the wall) there is perforated piping. The overflow elevation of water in this piping can be set (at the Level Control Manhole) so that the width of the in-coming groundwater plume is controlled.

Flow-rate and the size of capture zone are adjusted by setting the elevation of the effluent drain.

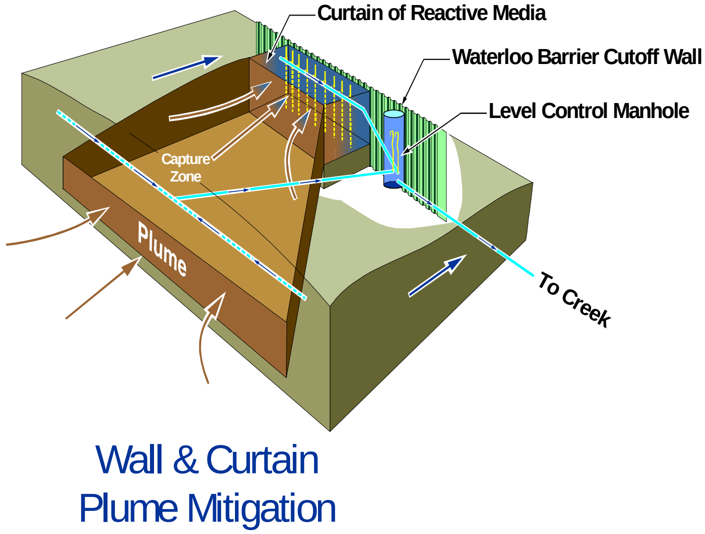

Fig. 5. Wall and Curtain Installation.

The system has continued to capture 99.5% of the ^{90}Sr that would otherwise have entered the wetland. Contaminated groundwater enters the treatment system with an average ^{90}Sr activity of 85 Bq/L and exits with 0.3 to 0.6 Bq/L. The drinking water standard is 5 Bq/L ^{90}Sr.

This facility currently treats 1.51 x 10^7 litres per year (7.6 gallons per minute). Since the first year of operation, the Wall and Curtain has prevented the discharge of 1.85 x 10^7 Bq of ^{90}Sr, maintained pristine conditions in the adjacent wetland and is predicted to do so for another 10 to 40 years.

The Wall and Curtain system continues to work very well, and plans to utilize this technology at other locations at CRL are well under way.

DECOMMISSIONING OF THE WHITESHELL LABORATORIES

AECL's Whiteshell Laboratories (WL), near Winnipeg, Manitoba has been in operation since the early 1960s. R&D facilities and programs carried out at WL include a 60 MW organic-cooled research reactor which operated from 1965 to 1985, reactor safety research, small reactor development, materials science, post irradiation examinations, chemistry, biophysics and radiation applications. The Canadian Nuclear Fuel Waste Management Program, which was focused on research in support of used fuel disposal concepts, continues to operate from this site.

In the late-1990s, AECL began to consolidate its research and development activities at CRL and began preparations to close and decommission WL. As a prerequisite to AECL's application for a decommissioning licence, an environmental assessment (EA) was carried out according to Canadian environmental assessment legislation. The EA process was concluded in 2002 April when the Federal Minister of the Environment published his decision that the decommissioning of WL was not likely to cause significant adverse environmental effects and that no further assessment by a review panel or mediation would be required.

In 2002 December, the Canadian Nuclear Safety Commission issued to AECL a 6-year decommissioning licence for WL. The licence authorized the first planned phase of site decommissioning as well as the continuation of selected research programs. The six-year licence for WL was the first overall decommissioning license issued for a Canadian Nuclear Research and Test Establishment and was the longest licence term ever granted for a nuclear installation of this complexity in Canada.

The first phase of decommissioning is now under way and focuses on decontamination and modifications to nuclear facilities, such as the shielded facilities, the main R&D laboratories and the associated service systems, to achieve a safe state of storage-with-surveillance by 2008 [14]. Later phases include waste management improvements for selected wastes already in storage, eventually followed by final decommissioning of facilities and infrastructure and removal of most wastes from the site.

CONCLUSION

AECL has maintained an active program in radioactive waste management since 1945, when the Canadian nuclear program commenced activities at CRL.

Waste management activities have included development of the concept and related technologies for geological disposal of Canada's nuclear fuel waste; development of dry storage technology for interim storage of used fuel; operation of waste management storage and processing facilities at CRL and WL; and the development and assessment of environmental remediation and waste processing technologies.

These activities continue today. In addition, AECL is: decommissioning the nuclear facilities at WL; in the initial stages of decommissioning the URL; carrying out a number of smaller decommissioning projects at CRL; putting in place projects to upgrade the low-level liquid waste processing capabilities of the CRL Waste Treatment Centre, recovering and processing highly active liquid wastes currently in storage; recovering, conditioning and improving the storage of selected fuel wastes currently stored in below-ground tile holes in the CRL waste management areas; and assessing options for additional remediation projects to improve the management of other wastes currently in storage and to address environmental contamination from historical practices.

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REFERENCES

1. F. PARÉ, “Dry Spent Fuel Storage with the MACSTOR System”, Proceedings of the 10th Pacific Basin Nuclear Conference, Kobe, Japan, (Vol. 2), (p. 1081), (Kobe, 1996).
2. M.M. COBANOGLU and P. PATTANTYUS, “Deployment of Advanced MACSTOR Dry Spent Fuel Storage Technology in Korea - A Joint Development Program,” Korea Atomic Industrial Forum, (2002).
3. OECD, “The Environmental and Ethical Basis of Geological Disposal of Long-lived Radioactive Wastes,” A Collective Opinion of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency, (1995).
4. AECL, “Environmental Impact Statement on the Concept for Disposal of Canada’s Nuclear Fuel Waste,” Atomic Energy of Canada Limited Report, AECL-10711, COG-93-1, (1994).
5. Canadian Environmental Assessment Agency, “Report of the Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel,” (1998).
6. Statutes of Canada 2002 Chapter 23, “An Act respecting the long-term management of nuclear fuel waste”.
7. N.A. CHANDLER, J.B. MARTINO and D.A. DIXON, “The Tunnel Sealing Experiment,” Proc. 6th Intl. Workshop on Design and Construction of Final Repositories, “Backfilling in Radioactive Waste Disposal,” Brussels, Belgium, 2002 March 11-13.
8. US DOE, “Final Environmental Impact Statement for a Geological Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye Country, Nevada,” (Vol. 1-4), (2000).
9. R.P. DENAULT, P. HEENEY, E. PLAICE, K. SCHRUDER, D. WILDER, and W. GRAHAM, “Stored Liquid Waste Remediation Program, Phase 1, at Chalk River Laboratories”, WM’05 Conference, Feb. 27-Mar. 03, 2005, Tucson, Arizona.
10. E.L. PLAICE, P.M. BREWSTER, R. PROKOPOWICZ, R. PONNAN, and R. THATIPAMALA, “Process Concept for the Stored Liquid Waste Remediation Program, Phase 1, at Chalk River Laboratories”, WM’05 Conference, Feb. 27-Mar. 03, 2005, Tucson, Arizona.
11. D.S. COX, I.B. BAINBRIDGE, and K.R. GREENFIELD, “Management of Legacy Spent Nuclear Fuel Wastes at the Chalk River Laboratories: Operating Experience and Progress Towards Waste Remediation”, WM’05 Conference, Feb. 27-Mar. 03, 2005, Tucson, Arizona.
12. S. VIJAYAN, “Experience with the Application of CHEMIC™ Technology for the Treatment of Ground/Surface Waters Containing Radiostrontium”, Proc. Waste Management WM’99 Conference, Feb.28-Mar. 04, 1999, Tucson, Arizona.
13. S. VIJAYAN, and C.F. WONG, “Uptake of Radiostrontium from Aqueous Solutions by Biomass and Natural Zeolites: Implications in the Treatment of Contaminated Waters by AECL’s CHEMIC™ Process”, Proc. Waste Management WM’01 Conference, Feb.25-Mar. 01, 2001, Tucson, Arizona.

14. G.W. KOROLL, “Site Decommissioning of AECL Whiteshell Laboratories”, WM’05 Conference, Feb. 27-Mar. 03, 2005, Tucson, Arizona.