NWMO CANADIAN USED NUCLEAR FUEL REPOSITORY - 16314

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Abstract: A brief introduction to Canada's Used Fuel Repository Plan, including the status of site selection and the conceptual design.

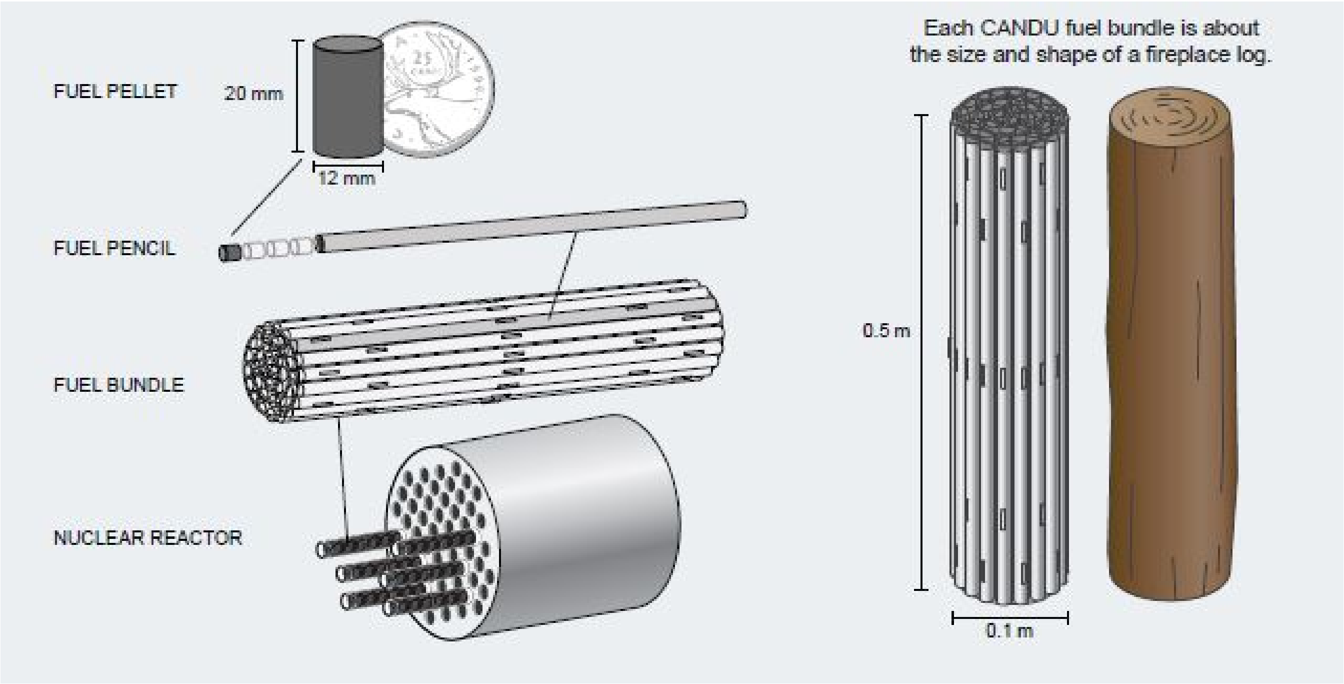

Figure 1: Relative size of a CANDU Fuel Bundle

For decades, Canadians have been using electricity generated by CANDU nuclear power reactors in Ontario, Quebec and New Brunswick. As of June 30, 2014, Canada's commercial nuclear reactors have produced about 3,100 terawatt hours of electricity and just over 2.5 million used fuel bundles. In addition, there are small quantities of used research and development fuels in storage at Atomic Energy of Canada Limited's Chalk River Laboratory. If used nuclear fuel bundles could be stacked like cordwood, all of Canada's used nuclear fuel could fit into about seven hockey rinks, reaching from the ice surface to the top of the boards.

CANDU nuclear fuel consists of uranium dioxide (UO2) made from naturally occurring uranium, see Figure 1. During fabrication, UO2 powder is pressed into solid pellets and then baked into a ceramic form. The ceramic pellets are placed inside a tube made of a zirconium-tin alloy, with the completed assembly called a fuel element or fuel pencil. A CANDU fuel bundle consists of a cylindrical array of 28 or 37 of these fuel elements mounted together to form a bundle. Each CANDU fuel bundle has a length of about 0.5 metre, a diameter of about 0.10 metre, contains about 20 kilograms of uranium and has a total mass of about 24 kilograms.

HOW MUCH USED NUCLEAR FUEL WILL BE MANAGED?

The *Nuclear Fuel Waste Act*, which was passed by the Government of Canada in 2002, requires the Nuclear Waste Management Organization (NWMO) to manage all used nuclear fuel produced in Canada.

Currently, Canadian reactors produce about 90,000 used CANDU fuel bundles per year. If Canada’s existing reactors operate to the end of their planned current lives, including planned refurbishments, the inventory of used fuel that will need to be managed in the facility could be about 4.6 million bundles, depending on future operating experience. The repository will need to be large enough to contain and isolate the inventory of used fuel from nuclear plants in Canada. Canada’s plan was developed for managing Canada’s used nuclear fuel. No foreign used fuel will be placed in the APM repository.

For design and safety assessment purposes, NWMO has assumed a reference used fuel inventory of 4.6 million used CANDU fuel bundles from the existing nuclear reactor fleet in Canada.

COMPONENTS OF CANADA’S PLAN

Canada’s plan for the long-term care of used nuclear fuel is known as Adaptive Phased Management (APM). It emerged from dialogue with Canadians and experts and best meets the key priorities considered important by citizens. The Federal Government selected APM as Canada’s plan in June 2007.

The plan is consistent with the long-term management approach adopted by other countries with nuclear power programs, such as Finland, Sweden, Switzerland, the United Kingdom and France.

Canada’s plan is both a technical method and a management system.

PHASED IMPLEMENTATION

Canada’s plan for long-term management of used nuclear fuel is designed with a risk management approach of deliberate stages and periodic decision points. It will meet rigorous safety and security standards throughout its design and implementation process to ensure health and safety of people and the environment. It has been designed to be flexible to allow for new learning and social priorities, and to be adaptable to other changes that may be encountered along the way.

The project will only proceed with the interested community, First Nation and Métis communities in the area and the surrounding communities working together to implement it.

Canada’s plan for used nuclear fuel is a multi-generational project that will be implemented through a number of phases. These include:

Site Selection
Site Preparation and Construction
Operations
Extended Monitoring
Decommissioning and Closure
Postclosure Monitoring

The NWMO initiated the site selection process in May 2010. Site selection may take about 15 years or more to complete, followed by a 10-year period to prepare the site and construct the facility. Used fuel transportation, handling and placement operations in the repository will occur over a period of about 40 years or more, depending on the inventory of used fuel to be managed. After that, the repository will be monitored for an extended period of time before decommissioning, closure and postclosure monitoring.

REPOSITORY PROJECT PHASES

The project is designed to be implemented in phases over many decades. New learning and social priorities will be incorporated into Canada’s plan for the long-term management of used nuclear fuel, driving refinement and adaptation of the plan throughout its implementation.

The NWMO will have to demonstrate that the project meets or exceeds strict regulatory requirements to protect the health, safety and security of Canadians as well as the environment, while also respecting Canada’s international commitments on the peaceful use of nuclear energy. Requirements set by regulatory authorities for this project will be addressed in the criteria used to assess the suitability of potential sites. The project will proceed only after all appropriate regulatory approvals are obtained at each phase of the project.

More details on the required approvals throughout the project are described in the Regulatory Oversight section.

The major phases for the APM project are described below.

Timelines provided are estimates that were developed for planning purposes only. Actual timelines will be driven by a variety of factors, including the time it takes to identify a suitable site with an informed and willing host; the time required to assess technical safety; and time required to obtain regulatory approvals.

Flexibility in the pace and manner of implementation is key to meaningful engagement of communities and demonstration of safety. The NWMO has committed that it will take the time necessary to do it right.

SITE SELECTION PHASE

The site selection process is designed to ensure safety, security and protection of people and the environment. Through a collaborative process in 2008 and 2009, the NWMO worked with interested Canadians to develop the decision-making framework for selecting a site for the project. The site selection process is built on a set of principles that reflects the values and priorities of Canadians on this issue. The process is laid out in the NWMO's May 2010 document *Moving Forward Together: Process for Selecting a Site for Canada's Deep Geological Repository for Used Nuclear Fuel*, available online at www.nwmo.ca.

The siting process includes a series of steps and is designed to be flexible and adaptive. Individual communities will proceed through the process at a pace and in a manner that reflect their needs and preferences. At each step, the NWMO will share the findings of assessments with the community. As studies become progressively more detailed and more information is known about the area, the NWMO will focus its studies on areas with strong potential to meet project requirements and where communities continue to be interested in exploring the project.

In Step 1, the NWMO initiated the siting process with a broad program to provide information, answer questions and build awareness among Canadians about the project and process for implementing it.

In Step 2, communities identified their interest in learning more. The NWMO conducts an initial screening to evaluate potential suitability of the community and vicinity against a list of initial screening criteria.

In Step 3, preliminary assessments of potential suitability are conducted at the request of the interested communities. The NWMO conducts these feasibility studies collaboratively with communities to determine whether a site has the potential to meet detailed project requirements. Preliminary assessments are conducted in two phases:

- The first phase preliminary assessment involves desktop studies to explore potential to meet safety requirements. These assessments include studies of engineering, geoscientific suitability, environment and safety, and transportation. This phase also involves the interested community learning more about the project, and engagement and reflection on its potential to foster well-being in the area and fit with the community's long-term vision.

- The second phase preliminary assessment is conducted with a smaller number of areas selected based on the outcome of Phase 1. Phase 2 activities focus on evaluating specific geoscientific uncertainties and provide additional information that can be used to assess and compare potential suitability of the communities. Technical studies and field investigations in this phase include activities such as geophysical surveys, geological mapping, environmental surveys, and borehole drilling and testing to better characterize and understand the specific natural environment. Phase 2 also involves more detailed exploration of the potential to foster well-being and sustainability in the community and the broader area. This phase also involves exploring the potential for partnership with the interested community, First Nation and Métis communities in the area, and surrounding communities.

  Involvement of First Nation and Métis communities in the area and surrounding communities is a key component in planning and implementing these detailed technical studies and field investigations. Aspects of this work will need to be aligned with community input, including involvement of First Nation and Métis communities, to help identify socially acceptable study areas. It will be important to integrate Aboriginal Traditional Knowledge into this work.

  At the completion of these preliminary assessments, a preferred site will be selected for more detailed site characterization.

The preferred site must meet robust technical requirements focused on safety. In order to select the preferred location for the repository, the NWMO would need to have a sufficient degree of confidence that:

- A deep geological repository can be developed with a strong technical safety case at that location;
- A safe, secure and socially acceptable transportation plan can be developed to transport used nuclear fuel to that location; and
- A strong partnership can be developed with the interested community, First Nation and Métis communities in the area and surrounding communities.

More work on two sites may be required to develop sufficient confidence to select a single preferred site. The NWMO would complete any additional work before identifying the preferred location.

In Step 4, the centre of expertise will be established in or near the selected community, as determined with the community, and detailed site characterization activities will begin. Initially, the centre of expertise will include an engineering test facility for developing container laser welding, copper coating, shaping bentonite clay buffer materials and container placement equipment. Detailed surface and subsurface investigations would be similar to those carried out during geological investigation stages of typical mining projects and would include further drilling and testing of boreholes, and environmental studies. Detailed investigations could require roughing in access corridors to the candidate site. These activities may result in environmental effects associated with noise, vegetation clearing for site access, drilling and increased traffic. An environmental management plan would be implemented to reduce the effects through proper mitigation measures. Input from the interested community and First Nation and Métis communities would also be sought to aid in minimizing effects.

The site selection phase will also see further engineering design activity to support future construction of surface facilities and the underground repository in subsequent phases.

For planning purposes, the NWMO has assumed the site selection phase could take about 15 years or more to complete.

DESCRIPTION OF THE FACILITIES

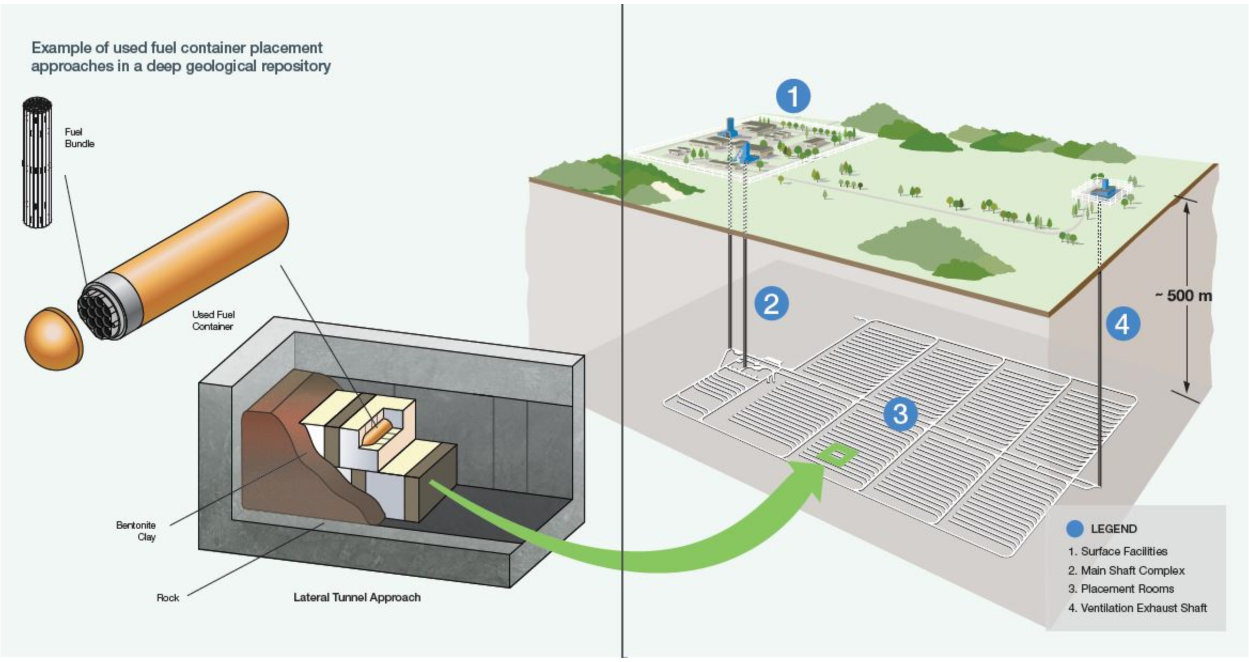

Figure 2: Overview of a Used Fuel Container Placement approach in a Deep Geological Repository

OVERVIEW

Adaptive Phased Management (APM) facilities include a centre of expertise, a number of surface facilities and a deep geological repository for the long-term management of Canada’s used nuclear fuel, see Figure 2.

The **centre of expertise** will be home to an active technical and social research and technology demonstration program involving scientists and other experts in a wide variety of disciplines, including geoscience, engineering, and environmental, socioeconomic and cultural impact assessment.

The **surface facilities** will process approximately 120,000 used CANDU fuel bundles per year. Their primary function is to receive used fuel shipped from interim storage facilities, repackage the used fuel bundles into durable, corrosion-resistant used fuel containers, and transfer the containers underground for placement in the deep geological repository. The surface facilities require a dedicated surface area of about 650 metres by 550 metres for the main buildings and about 100 metres by 100 metres for the ventilation exhaust shaft.

The **deep geological repository** is a multiple-barrier system designed to safely contain and isolate used nuclear fuel over the long term. Based on the current reference design, it will be constructed at a depth of approximately 500 metres, depending upon the specific geology and detailed characteristics of the site. It will consist of a network of placement rooms for the used fuel containers and clay-based sealing systems, as well as a series of access tunnels and shafts to ensure accessibility and monitoring. The layout of the underground repository will depend on a number of factors, including the characteristics of the rock types underground, refinements made to the final design of the engineered barrier system, final safety considerations and the inventory of used fuel to be managed. A conceptual layout for a repository would require an underground footprint of about two kilometres by three kilometres (about 600 hectares or 1,480 acres).

Used fuel containers are an important component of the multi-barrier system, which is designed to safely contain and isolate used nuclear fuel over the long term. For the expected, normal evolution of the repository, used fuel containers will remain intact and the radionuclides in the used fuel will remain inside the container. Safety studies have been prepared to examine other possible future events or “what-if” scenarios where used fuel containers and sealing systems deviate from their expected evolution in the repository. These studies are used to help demonstrate that the repository will meet the requirements of the Canadian Nuclear Safety Commission to protect members of the public

Following placement of used fuel in the repository, the facility will continue to be monitored and the used fuel will be retrievable for an extended period of time. The NWMO will have to demonstrate that safety requirements have been met during the extended monitoring period. The duration of this monitoring period will be decided many decades from now in collaboration with the community and regulatory authorities.

Once a decision has been made to close the facility, the NWMO will need to seek the appropriate regulatory approvals prior to decommissioning. Any remaining equipment will be removed and then the access tunnels and shafts will be backfilled and sealed. The NWMO will have to demonstrate that safety requirements will be met after closure of the facility. The nature and duration of any postclosure monitoring will be decided in collaboration with the community and surrounding areas several decades into the future.

CENTRE OF EXPERTISE

A centre of expertise will be established in the community selected for detailed site evaluation, see Figure 3. The centre will be located in or near the community, as determined with people who live in the area. Its purpose will be to support the multi-year testing and assessment of the site on technical safety and community well-being related dimensions, which are key components of the site selection process. The centre of expertise will be home to an active technical and social research and technology demonstration program during this period, involving scientists and other specialists in a wide variety of disciplines, including geoscience, engineering, and environmental, socioeconomic and cultural impact assessment.

An engineering test facility will be located within the centre of expertise. Activities in the engineering test facility will include container laser welding and copper coating development, bentonite clay buffer shaping and forming development, as well as the development of container placement equipment for the underground repository. The engineering test facility will also house production demonstration equipment to show the complete repository packaging and container placement process.

The centre of expertise could be expanded to support construction and operation of the deep geological repository. The centre will become a hub for knowledge sharing across Canada and internationally. It may also serve as a training centre to prepare personnel to work on various aspects of project implementation.

Design details of the centre of expertise will be developed with the interested community, First Nation and Métis communities in the area and surrounding municipalities with their preferences in mind. Discussion of design details also provides an important opportunity for involvement of youth. The centre of expertise could be designed as a focus for engaging members of the community to learn more about the project, and to view scientific and engineering work involved in site assessment, through public viewing galleries and interactive displays. The centre could highlight and demonstrate the science and technology being used to determine whether the site is suitable and to encourage youth science literacy and capacity development. It may be developed as a meeting place and learning centre for the community, and as a destination that welcomes interested visitors from the region and beyond. There may be an opportunity to explore whether technologies and monitoring processes involved in operating a deep geological repository may be of interest and have applications in the community beyond the repository.

Should the First Nation and Métis communities in the area desire, the centre of expertise could feature a learning and demonstration area focused on how Aboriginal Traditional Knowledge is being applied to the project.

As with some other aspects of the project, the exterior design of facilities and the way they are incorporated into the surrounding landscape will be a subject of discussion and shared planning with those living in the area.

Figure 3: A possible design for the Centre of Expertise

SURFACE FACILITIES

Surface facilities provide processes and equipment for receiving, inspecting, repackaging and moving used fuel to the main shaft for transfer underground and placement in the repository, see Figure 4.

The administration building would be the first building that visitors and most staff encounter when arriving at the facility.

For security purposes, certain areas of the surface will have restricted access. These restricted areas include the used fuel packaging plant, main shaft complex, service shaft complex and ventilation shaft complex.

Other surface areas outside the restricted area would include the administration building, sealing material compaction plant and concrete batch plant. A management area for excavated rock from the underground repository would also be required. Its location (on-site or off-site) and footprint would be determined in collaboration with the community.

The surface facilities require a dedicated surface area of about 650 metres by 550 metres for the main buildings and about 100 metres by 100 metres for the ventilation exhaust shaft, which will be located approximately 2 km away from the main buildings. The ventilation shaft location supports oneway ventilation flow from the main shaft through the underground repository and exhausting through the ventilation shaft. NWMO expects that land above the underground footprint that is not required for surface facilities or to meet regulatory requirements would be available for other uses. The NWMO will have to demonstrate that regulatory or other requirements for safety that could limit those activities in the immediate area surrounding the surface facilities have been met.

A portion of excavated rock from the repository may be used in backfilling and sealing operations. The remaining rock may have a public or commercial use as aggregate for construction. The excavated rock management area is currently assumed to be located off-site; its size and location will be determined in collaboration with the community and surrounding area.

An excavated rock management area could require a surface area of about 460 metres by 380 metres, with a height of 15 metres. The footprint, height and location(s) of excavated rock could be planned in a way that takes into account community preferences. The area will include a storm water management pond to collect and manage surface water. Surface water run-off from the excavated rock management area will be controlled, monitored and if required, treated to meet provincial water quality standards prior to discharge.

The concrete batch plant will produce the concrete mixes needed for specific functions in the repository, including the low-heat, high-performance concrete required for the bulkheads to be placed at the entrance of the filled container placement rooms and for other repository seals. At the sealing material compaction plant, raw aggregate materials and clay will be mixed to produce dense backfill blocks, light backfill, compacted bentonite blocks and gapfill material required for used fuel container placement and for sealing of the placement rooms.

Water supply to the facility is assumed to be sourced locally and is expected to be about 130 cubic metres per day. It will be treated, if required, to provide potable water.

The total electrical power demand for the APM facility is estimated to be about 20 megawatts (MW). The site will be supported by several three-MW diesel emergency power generators and related equipment for use in the event of main line power failure.

During the 10-year construction phase, accommodation will be required for construction personnel. These workers could be housed in the community and surrounding area, or there could be a need to develop temporary infrastructure outside the main complex to provide sleeping quarters, kitchen, dining, laundry, medical and recreation facilities. The NWMO will work with the community and surrounding area to plan for and contribute to development of community infrastructure required during construction and operation to house and integrate personnel into the area. Community preferences will be an important consideration in development of implementation plans that will meet the needs of communities.

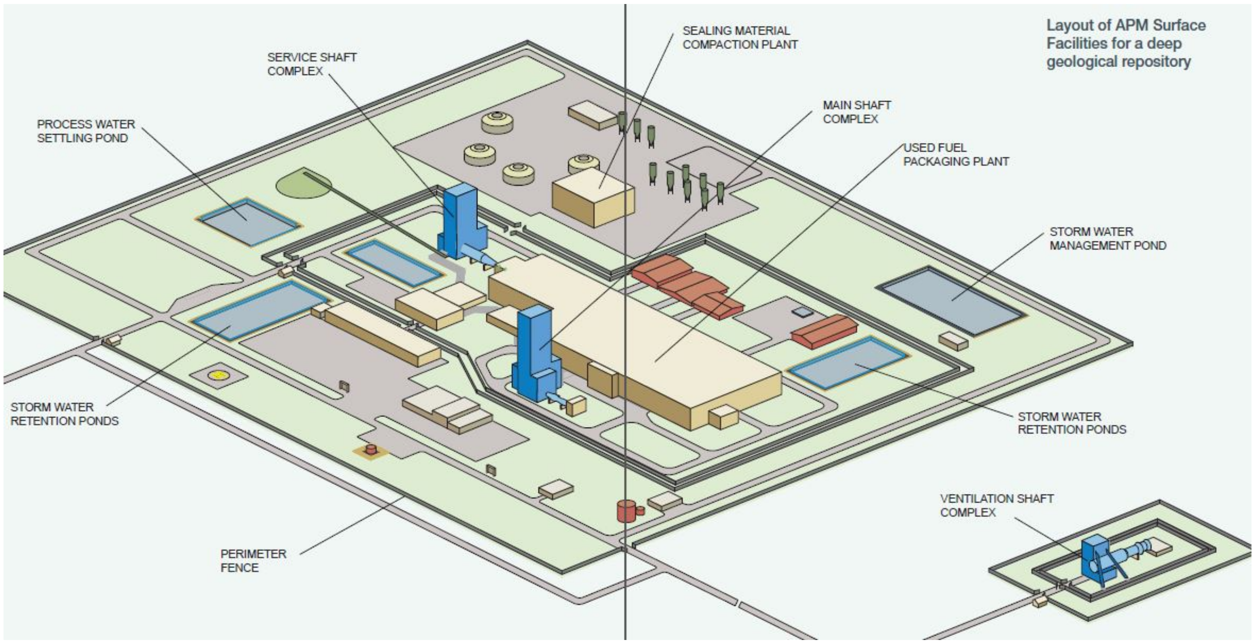

Figure 4: Example of a layout for the Surface Facilities

USED FUEL CONTAINER AND CONTAINER FACTORY

The used fuel container is one of the principal engineered barriers in a multi-barrier deep geological repository. The important features of the design are corrosion resistance, mechanical strength, geometry, capacity and compatibility with surrounding sealing materials.

The used fuel container consists of an outer corrosion-resistant material and an inner supporting material. The container is designed to withstand mechanical and hydraulic pressures up to 45 megapascals (MPa). This means the container could withstand pressures at repository depth due to swelling of the bentonite clay buffer surrounding the container, from the rock surrounding the repository, and from three kilometers of ice above the site during a future ice age.

The NWMO examined several used fuel container designs and capacities for the deep geological repository, see Figure 5. These particular container designs use steel for strength and copper for corrosion resistance. Due to the nature and size of CANDU fuel bundles, there are a number of options available in terms of container dimensions, capacity for used fuel, and placement configuration in the repository.

NWMO’s current conceptual design is for a used fuel container with horizontal placement in the repository. This particular container, with a length of 2.5 metres, is illustrated in Figure 6 below. The container holds 48 used CANDU fuel bundles (four layers of 12 bundles) in a steel basket within a standard carbon steel pipe which is protected by a copper-coated, corrosion-resistant outer layer. The carbon steel pipe and copper coating technology for this container design are based on proven technology that is readily available in Canada. For a facility handling 120,000 fuel bundles per year, approximately 2,500 of these used fuel containers would be required per year of operation.

The used fuel container and supporting components will be manufactured and assembled at a container manufacturing plant which could potentially be located in the host community or surrounding region, depending on interest.

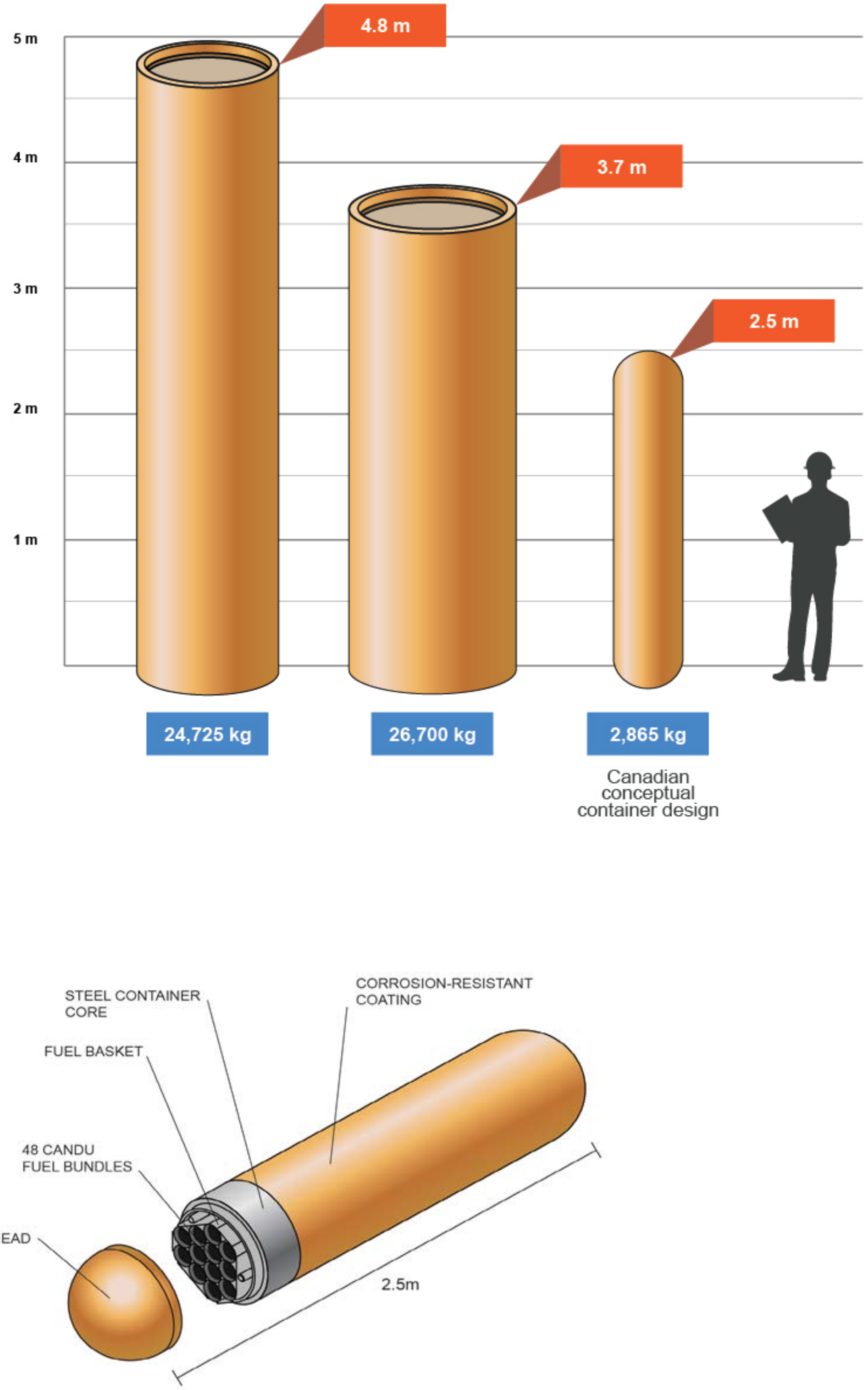

Figure 5: Various designs for Used Fuel Containers

Figure 6: A Prototype Container being developed

USED FUEL PACKAGING PLANT

The used fuel packaging plant is an important component in the process of transferring Canada's used nuclear fuel from interim storage to a deep geological repository. It will be designed to receive and repackage used nuclear fuel into long-lived, corrosion-resistant containers for placement in the repository, see Figure 7. The used fuel packaging plant encompasses all necessary areas and equipment for:

- receiving used fuel transportation packages from interim storage sites,
- receiving empty used fuel storage containers,
- loading used fuel into storage containers, and
- sealing, inspecting and dispatching filled containers for underground transfer and placement in the deep repository.

There are also provisions for opening and repackaging fuel from any containers that may be rejected as unsatisfactory following non-destructive testing and examination.

To ensure continuing reliable delivery of used fuel containers to the deep geological repository, the plant includes warehouse storage areas for used fuel transportation containers, empty used fuel storage containers and filled used fuel storage containers. It is intended that used nuclear fuel will be packaged and placed in the repository as it is received. As a result, there will only be minimal storage required for used fuel on the surface.

A conceptual layout of a used fuel packaging plant has been developed for planning and cost estimating purposes. The used fuel packaging plant will be a reinforced concrete structure that measures about 255 metres by 88 metres. It will have the capacity to package approximately 120,000 used fuel bundles per year into long-lived corrosion-resistant containers.

The packaging plant includes the following key features:

- A transport package handling area to receive used fuel transportation packages;
- A module handling area to unload fuel modules from the transport container;
- A fuel transfer cell to transfer the used fuel into the used fuel containers to be used underground;
- Processing stations to weld the lid and perform non-destructive testing of the filled container;
- A buffer box assembly area to place bentonite around the container prior to transfer underground; and
- Storage cells for empty and filled containers.

If non-destructive testing or visual inspection of a container identifies any defects or features that cannot be repaired, the rejected container would be transferred back to the processing stations for retrieval and repackaging of the used fuel. The rejected container would be decontaminated as required and sent off-site for recycling.

Provisions would be put in place for safe handling and storage of wastes generated during the used fuel packaging process.

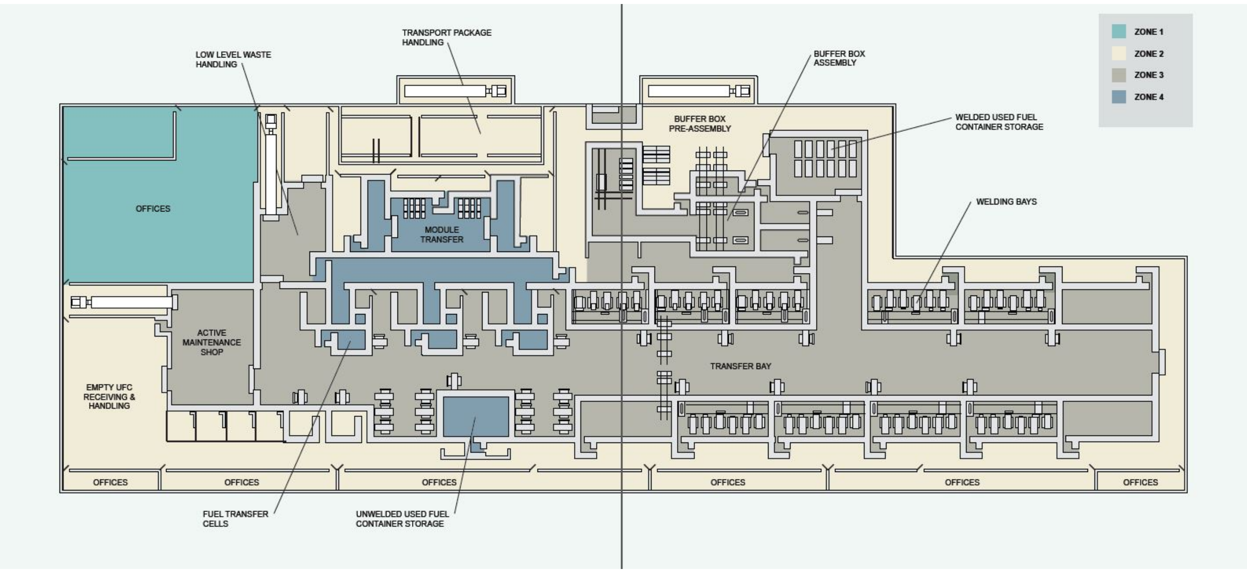

Figure 7: Example of a layout for a Used Fuel Packaging Plant

SEALING MATERIAL COMPACTION PLANT / CONCRETE BATCH PLANT

The sealing material compaction plant and the concrete batch plant provide materials for clay-based and cement-based engineered barriers in the repository. These barriers will be used to backfill and seal excavation openings, and inhibit groundwater movement, microbial activity and movement of radionuclides in the area of the repository surrounding used fuel containers.

Sealing materials prepared at these plants could include:

- Highly compacted bentonite clay blocks, see Figure 8;
- Dense backfill composed of bentonite clay and aggregate;
- Light backfill composed of bentonite clay and sand;
- Gapfill composed of bentonite clay pellets;
- Shaft seal composed of bentonite clay and sand; and
- Low-heat high-performance concrete.

A portion of the excavated rock from the repository may be used to manufacture crushed rock and sand for the backfill and concrete. These products will be stockpiled and stored on site for use in the sealing material compaction plant where presses will be used to prepare dense backfill blocks and gapfill material.

Figure 8: Bentonite Bricks manufactured in Oakville, Ontario

SHAFTS AND HOISTS

The reference design for the facility includes three shafts with hoists to enable the transfer of used fuel containers, rock, material, equipment and personnel between surface facilities and the repository:

» The Main Shaft: Conveys used fuel containers within a shielded transfer cask;
» The Service Shaft: Conveys personnel, equipment, waste rock and sealing materials; and

- The Ventilation Shaft: Will handle the majority of the repository exhaust to surface and will be equipped with a hoist for emergency exit for personnel. The exhaust shaft will be equipped with monitors and filters.

Headframes for the three shafts will be durable and easily maintainable structures that provide a high level of protection against weather-related disturbances. All shafts will be concrete-lined to help control inflow of water and to provide a durable, easy-to-maintain surface.

Once all of Canada’s used nuclear fuel is placed in the repository and a decision has been made to decommission and close the facility, the shafts will be sealed and all headframes, liners and peripheral equipment will be removed.

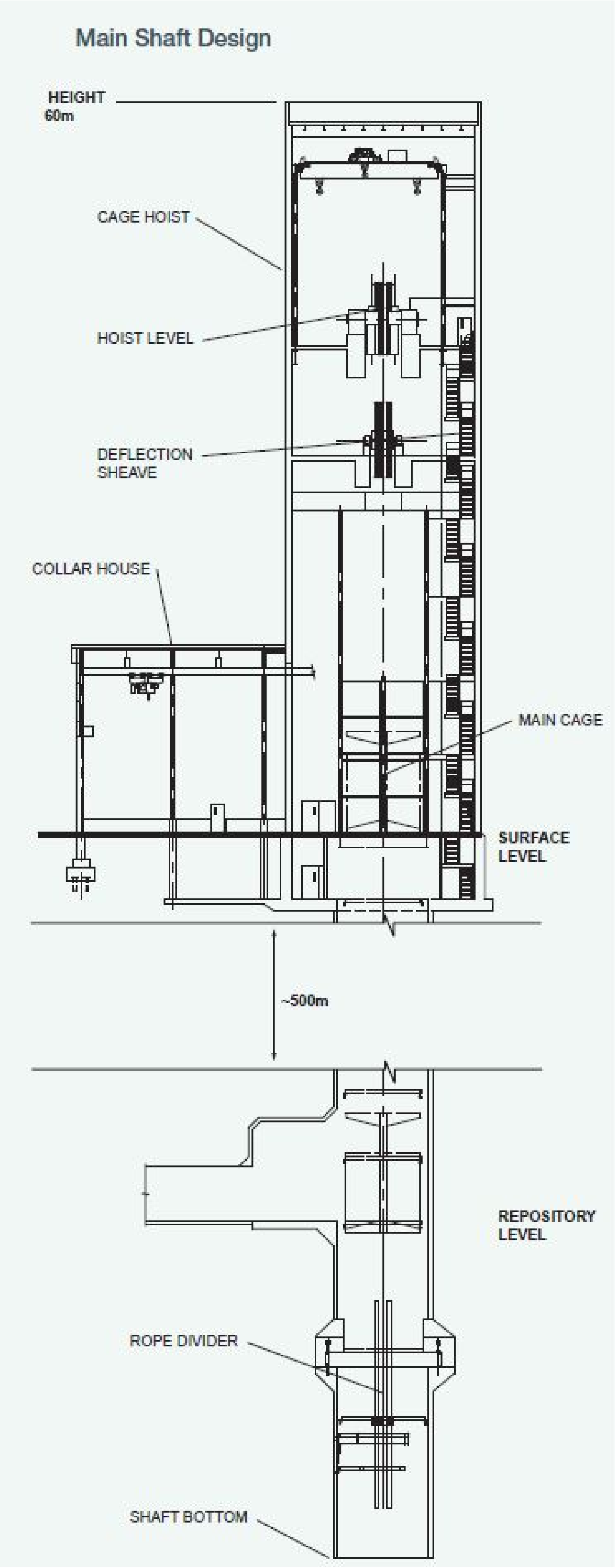

Figure 9: Example of a Main Shaft Layout

UNDERGROUND FACILITIES

The underground facilities consist of a deep geological repository and associated infrastructure, including provision for underground verification and demonstration activities.

DEEP GEOLOGICAL REPOSITORY

The deep geological repository is a network of tunnels and placement rooms for used fuel containers, see Figure 10. It will be constructed at a single elevation at a depth of about 500 metres below ground surface, depending on site-specific rock characteristics. Rock excavation would primarily be done using the controlled drill and blast method.

A conceptual layout for a repository would require an underground footprint of about two kilometres by three kilometres (about 600 hectares or 1,480 acres). The actual underground footprint at any particular site would depend on a number of factors, including the characteristics of the rock at the preferred site, the location of underground features in the rock, the final design of the repository and the total inventory of used fuel to be managed.

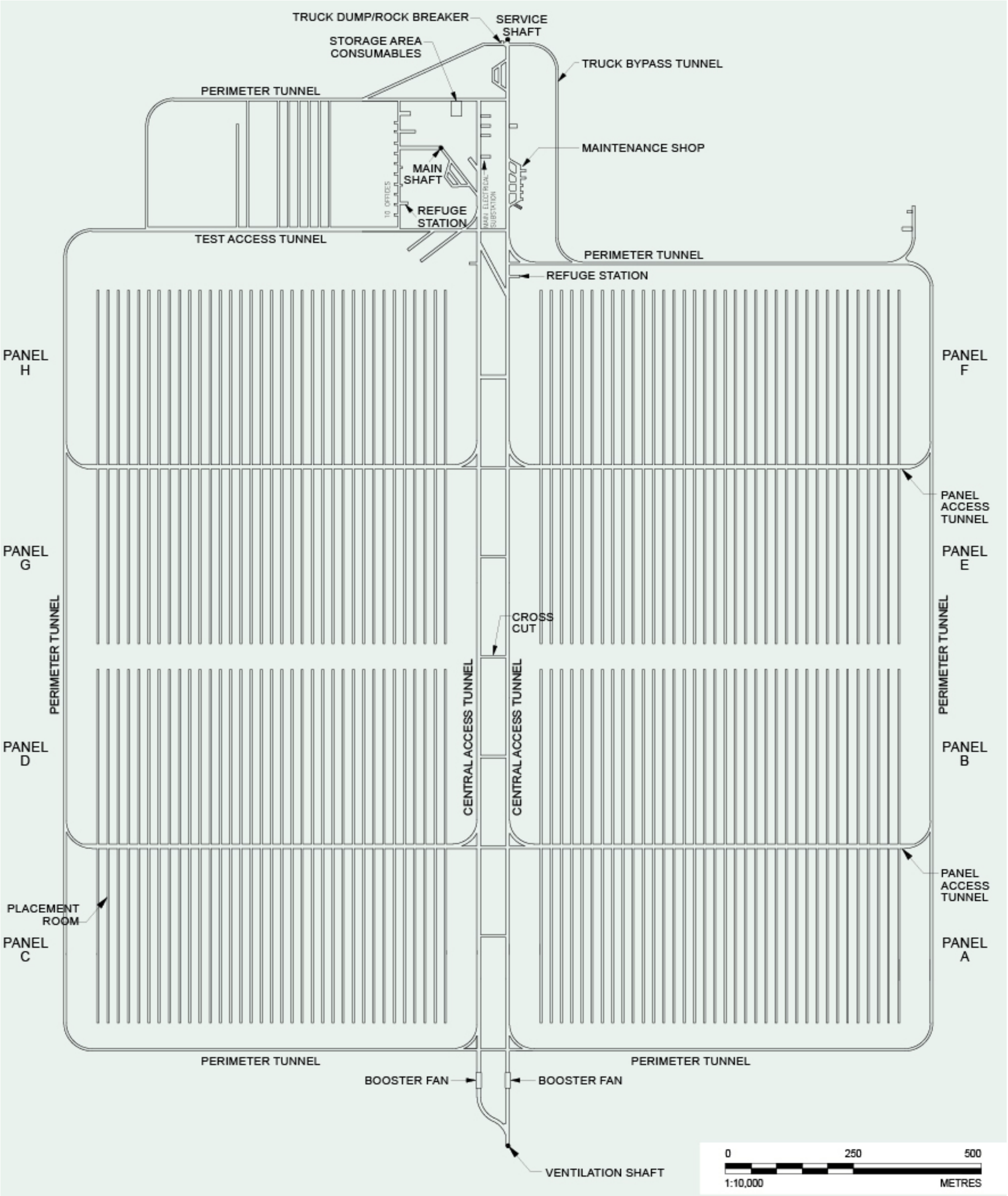

Figure 10: Example of an Underground Layout for a Deep Geological Repository

USED FUEL CONTAINER ROOMS

Within each placement room a used fuel container, encased in a bentonite clay buffer box, will be placed and separated from the next buffer box by bentonite clay spacer blocks, see Figure 11. Containers will be staggered and stacked in two rows in a retreating manner. Any void space will be backfilled with pneumatically placed bentonite clay pellets until the room is filled.

Each group of placement rooms, also known as a placement panel, would require about three to four years to develop. Each placement panel would be excavated in parallel with container placement operations in other panels of the repository.

A six-metre thick bentonite clay seal and a 10-metre thick concrete bulkhead will be used to seal the entrance to the placement rooms. Monitoring equipment will be installed to confirm the performance of the repository system during placement operations and during the extended monitoring period.

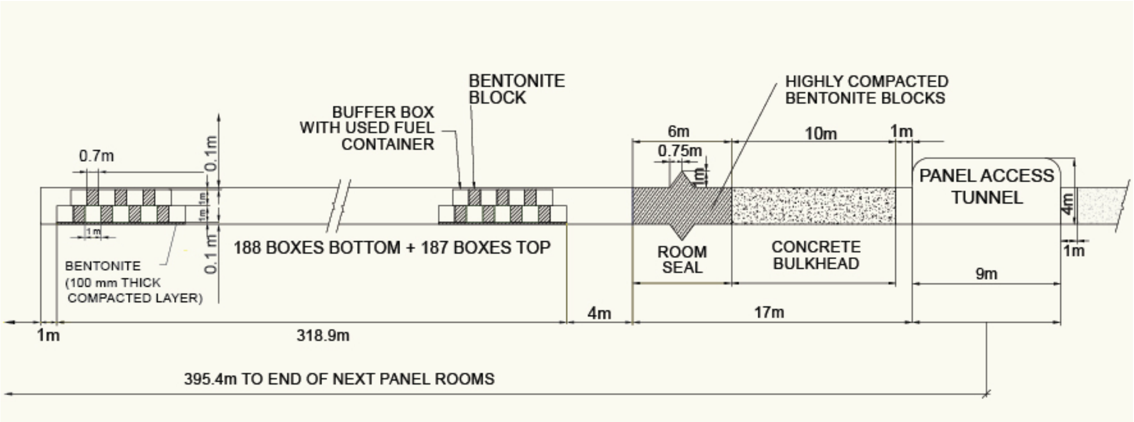

Figure 11: Example of a Placement Room for Used Fuel Containers

Reference: NWMO (2015) Deep Geological Repository Design Report Crystalline/Sedimentary Rock Environment Mark II Used Fuel Container, Document No. APM-REP-00440-0015-R00.