CONCEPTUAL DESIGN OF A USED FUEL PACKAGING PLANT

Kristina Gillin
Candesco
Toronto, Ontario, Canada

Anders Nyström
SKB International AB
Stockholm, Sweden

Alan Murchison
Nuclear Waste Management Organization
Toronto, Ontario, Canada

ABSTRACT

As part of implementing Adaptive Phased Management for the long-term care of Canada's used nuclear fuel, the Nuclear Waste Management Organization has developed a conceptual design of a used fuel packaging plant. The purpose of the packaging plant is to receive and repackage the used fuel in corrosion-resistant containers before placement in a deep geological repository. It is assumed that the packaging plant will be located on the same site as the repository.

The packaging plant encompasses all necessary areas and equipment for receiving empty containers, receiving used fuel, loading the fuel into the containers – and sealing, inspecting and dispatching filled containers for transfer to the repository. There are also provisions for cutting open and emptying any containers that do not fulfill specified requirements. To ensure reliable delivery of containers to the deep geological repository, the plant includes surge storage for used fuel, empty containers and filled containers.

Most of the processing steps in the packaging plant are remotely operated and performed inside shielded areas. With a container capacity of 360 used CANDU® fuel bundles, the required throughput of the plant is 333 containers per year, which is achieved with a single processing line – except handling of fuel, which requires parallel processing equipment.

The used fuel packaging plant is an important step in the process of transferring Canada's used fuel from interim storage to a deep geological repository. In addition to ensuring safety during operation, the packaging plant must produce containers that fulfill requirements for long-term safety – without frequent or lengthy production stops that would jeopardize the rate of placement in the repository.

To meet all such requirements, further development of the packaging plant design is essential. In particular, methods for transfer of fuel bundles and technologies for fabrication, sealing and non-destructive testing of containers will be evaluated and demonstrated during the coming years. The detailed design and optimization of the packaging plant will be determined once the repository site has been selected and the container design has been finalized. At this conceptual stage of implementing Adaptive Phased Management, this packaging plant design serves as an important stepping stone for future design development and optimization projects.

1. INTRODUCTION

The Nuclear Waste Management Organization (NWMO) is responsible for implementing Adaptive Phased Management, the selected approach for the long-term management of Canada's used nuclear fuel. In this approach, the used fuel will be safely and securely contained and isolated from people and the environment in a deep geological repository in a suitable rock formation using a multiple-barrier system [1]. The repository will be constructed at a depth of approximately 500 metres and will consist of a network of placement rooms for the used fuel [1], see Figure 1.

One of the barriers in the system is a corrosion-resistant container in which the used fuel will be packaged before placement in the repository [1]. Packaging of the used fuel will take place in a dedicated used fuel packaging plant, which is to be built on the surface above the repository, and at this stage of the implementation process, a conceptual design of the packaging plant has been defined. In order to benefit from experience in developing a similar plant in Sweden, NWMO contracted SKB International AB to review and update a previous conceptual design of the packaging plant. In this paper, the updated packaging plant design is presented.

The optimal design of the packaging plant is dependent on the design of the used fuel container, and in the coming years, NWMO will perform further studies to optimize the container design with regards to material, capacity and fabrication. The packaging plant design described in this paper is based on a used fuel container of copper and steel, with capacity for 360 used CANDU®[1] fuel bundles.

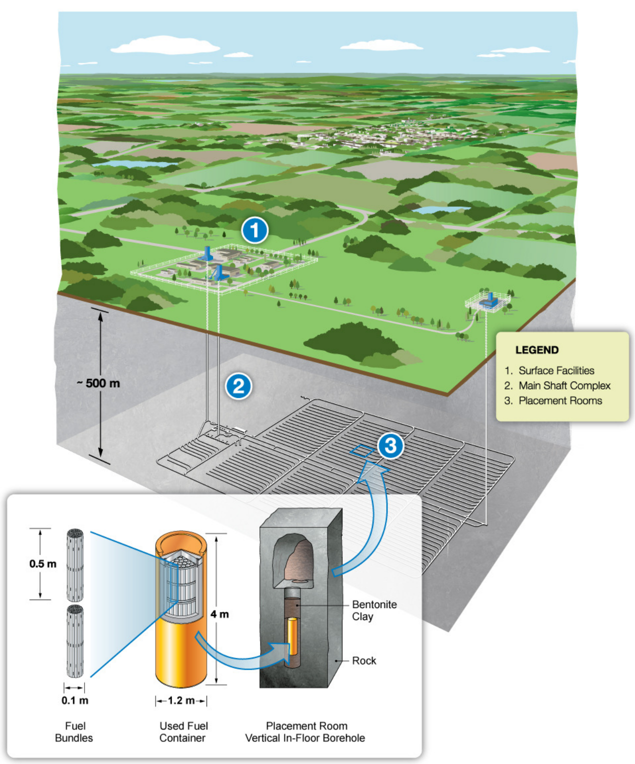

Figure 1. Illustration of a deep geological repository in crystalline rock.

[1] CANDU® is a registered trademark of Atomic Energy of Canada Limited.

2. USED FUEL CONTAINER

The purpose of the used fuel container is to act as one of the barriers in the deep geological repository to safely contain and isolate the used fuel for a very long period of time [1], and several design options are being considered. In this conceptual design of the packaging plant, the container is assumed to have capacity for 360 fuel bundles and consist of the following main components, see Figure 2:

- An outer copper vessel that comprises a cylindrical tube with a welded copper bottom and lid. The copper shell's function is to provide a corrosion-resistant barrier that will ensure long-term integrity of the container in the repository environment.
- An inner vessel of steel that consists of a cylindrical tube with a welded bottom and a bolted lid. The wall thickness of the inner vessel is sufficient to withstand the mechanical stresses that may be present at repository depth.
- Three baskets stacked in a row inside the inner vessel; one basket consists of 60 steel tubes that each holds two fuel bundles. The baskets' function is to facilitate loading of the fuel bundles into the container.

The total length of the container in this conceptual design is approximately 4 metres, and the diameter is 1.2 metres. The weight of the container, including fuel bundles, is approximately 27 tonnes.

It is assumed that the container components are fabricated off-site and transported to the packaging plant by road. Before shipment, the bottoms are welded, the steel lid is bolted and the steel vessel is assembled into the copper shell. The copper lid – which is welded as part of processing in the packaging plant – is matched and transported together with the container assembly. Baskets are fabricated and shipped to the packaging plant separately.

As part of NWMO's future plans, the technology for fabrication, sealing and non-destructive testing (NDT) of the container will be developed, evaluated and demonstrated in detail. For the conceptual design presented in this paper, it is assumed that sealing and testing of the steel and copper lids are similar to the technologies developed for encapsulation of used fuel in Sweden.

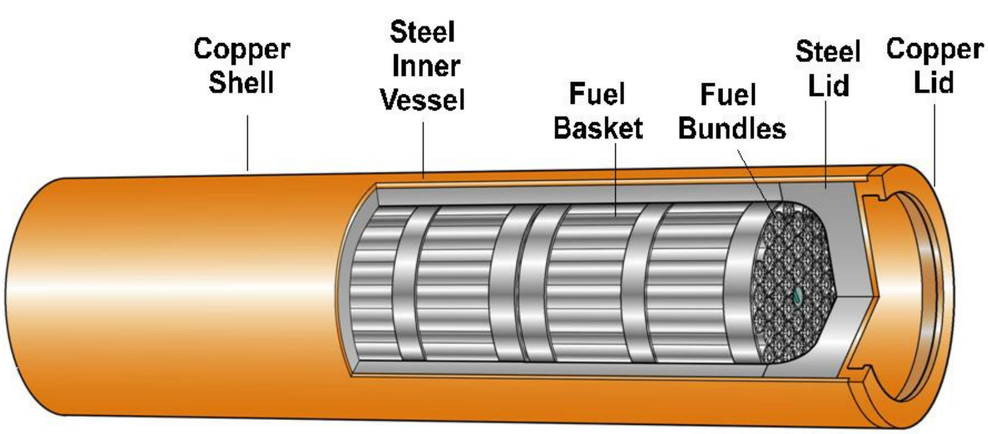

Figure 2. Conceptual design of a used fuel container of copper and steel.

3. PACKAGING PLANT

3.1 Key assumptions and requirements

The used fuel packaging plant is assumed to be located on the same site as the deep geological repository [1]. Used fuel will be transported to the packaging plant by road, rail, water or a combination of modes, depending on the location of the packaging plant and other factors.
In this conceptual design, it is assumed that the used fuel is transported by road in purpose-built transport casks that hold 192 bundles in two storage modules, as illustrated in Figure 3. Empty used fuel containers are also transported to the plant by road, and filled containers are dispatched to the deep geological repository in shielded casks on rails.

The packaging plant is a reinforced concrete structure that measures approximately 125 metres by 65 metres. It is designed with a nominal capacity for packaging 120,000 used fuel bundles per year for delivery to the repository; with the assumed 360-bundle container design, the required packaging plant throughput is 333 containers per year. The plant is designed to enable simultaneous processing in the various stations, and a high-level logistics study has confirmed that the specified throughput can be achieved with the presented packaging plant design.

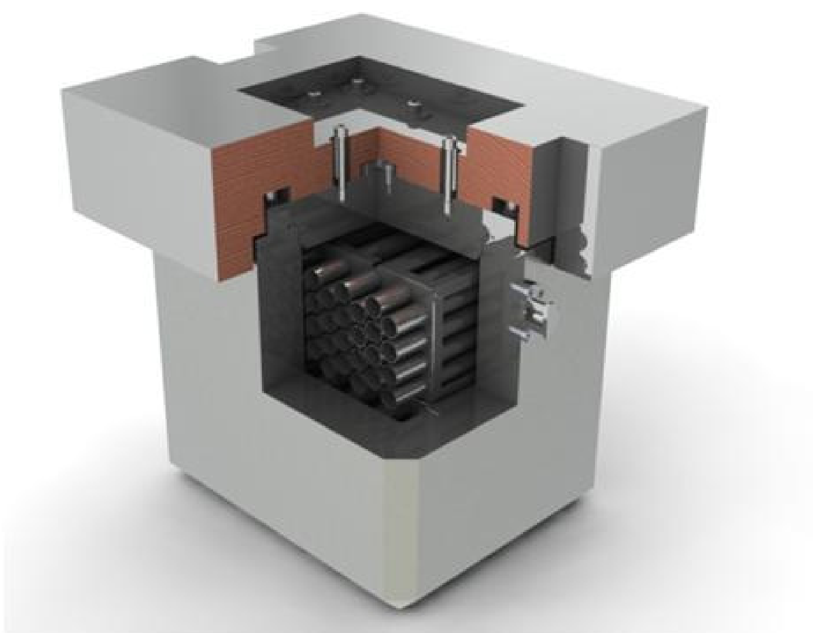

Figure 3. Irradiated fuel transport cask for two storage modules.

The packaging plant must encompass all necessary provisions for receiving empty containers, receiving used fuel, loading the fuel into the containers – and sealing, inspecting and dispatching filled containers to the repository. It must also be possible to reverse the packaging process and unload filled containers – in the event that containers contain defects or are returned from the deep geological repository as part of the Adaptive Phased Management approach. A conceptual layout of the used fuel packaging plant is shown in Figure 4.

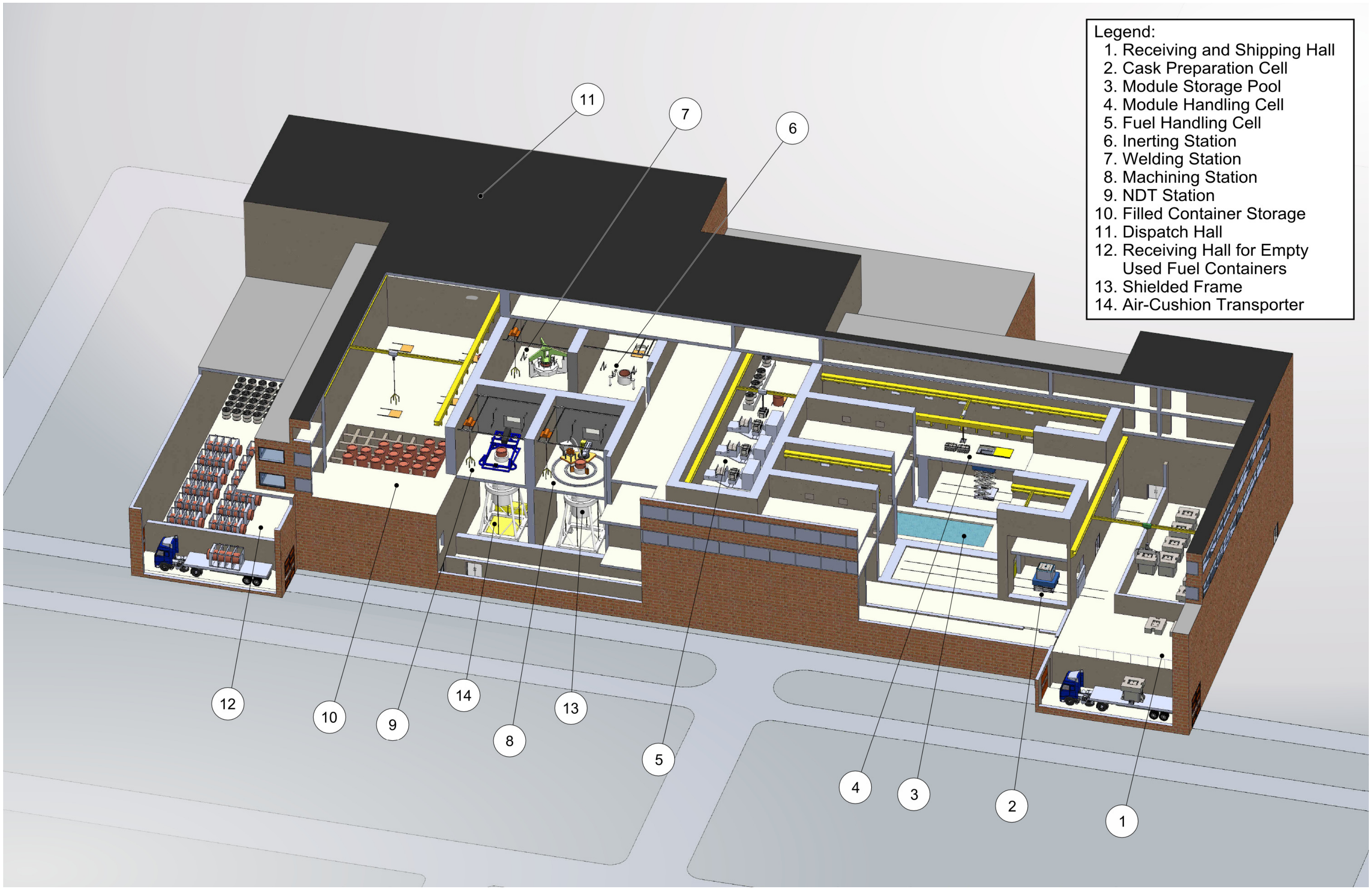

Figure 4. Conceptual layout of the used fuel packaging plant.

To ensure reliability in delivery of filled containers to the repository, the plant must contain surge storage for used fuel, empty containers and filled containers. The optimal capacity of the surge storage will depend on the location of the plant and mode of transport selected for the used fuel and empty containers. In this conceptual design, the selected surge capacity for used fuel is equivalent to 12 weeks' production, and for empty and filled containers, there is sufficient capacity for six weeks' production. It is further assumed that the surge storage for used fuel will be in water-filled pools, but dry storage options will be considered in future design stages.

Areas and equipment in which used fuel bundles and filled containers are handled are radiation shielded, and most of the handling in the plant is remotely operated. All applicable areas are equipped with overhead travelling cranes, and hot cells contain in-cell cranes, master slave manipulators and other equipment for remote handling as required.

The packaging plant contains three main areas for processing of used fuel and containers, as outlined in the following sub-sections. Areas for personnel, radiation protection, waste handling, etc., and systems for control, ventilation and other auxiliary services are also provided but are not included in this conceptual design description.

3.2 Area for transport cask receipt and unloading

For receipt and unloading of used fuel in transport casks, the packaging plant comprises the following:

- *A receiving and shipping hall for transport casks*, including 12 storage positions for empty or filled casks. The hall is accessed from the outside through a port that leads into a transport airlock where transport trailers are parked for loading and unloading.
- *Two parallel processing lines for preparation of casks* for unloading of fuel, including pallets on rails for transfer of transport casks from the receiving and shipping hall for further processing.
- *Two parallel module handling cells* for unloading of modules from a transport cask and transfer of modules to an adjacent fuel handling cell. Each module handling cell contains provisions for drying of fuel and a rail cart for transfer of modules from the cell.
- *A fuel handling cell*, which contains three parallel fuel handling machines for horizontal transfer of fuel bundles from storage modules to fuel baskets. The fuel handling cell is connected to the two module handling cells by vertical ports that are used for transfer of a module on a rail cart. The floor of the fuel handling cell contains one port for lowering of emptied modules for waste treatment and one port for docking of used fuel containers.
- *A module storage pool* for 300 modules, located between the two module handling cells. The storage pool is not used during normal processing but is available as surge storage for used fuel.

3.3 Area for used fuel container loading and sealing

For receiving, loading and sealing of used fuel containers, the packaging plant is designed to include the following:

- *A receiving hall for empty used fuel containers*, including surge storage for 40 empty containers and 120 baskets. The hall also contains a transport airlock for trailers and a working platform for inspection and preparation of empty containers.

- *Seven shielded frames*, which enable radiation-shielded transfer of filled used fuel containers in vertical position within the plant. Each shielded frame consists of a transport platform with two telescopic, shielded sections that are vertically mounted on the platform. The bottom section can be raised and lowered by screw jacks for docking of the container with the various stations.
- *Two air-cushion transporters* for transferring of shielded frames. Each transporter consists of a pallet with air cushions mounted on the bottom. The air cushions are shaped like inner tubes of a tire, with the centre of each tube connected to air supply. To move the transporter, air is pumped into the centre of each tube, creating an overpressure – which in turn creates an air film between the tube and the floor. The transporter is equipped with steering wheels that remain in contact with the floor, also when it is in the raised position. The air-cushion transporter can be controlled either manually or remotely.
- *A container transfer area*, which is a dedicated area for moving containers in shielded frames between the different container processing stations. The transfer area is located below the fuel handling cell and subsequent stations for container processing, and it includes two parking positions for shielded frames and one for air-cushion transporters.
- *Four radiation-shielded stations for sealing and final processing of the container lids*. Each station contains a port down to the container transfer area, and containers are docked from below by raising the lower section of the shielded frame, see Figure 5 for a conceptual illustration of one of the stations. The four container processing stations are:
  - *The "inerting" station*, which contains provisions for bolting the steel lid and for removing the air inside the container and refilling it with inert gas, e.g., argon. The inerting station is further equipped with a hatch and other equipment for importing a copper lid and placing it on a docked container.

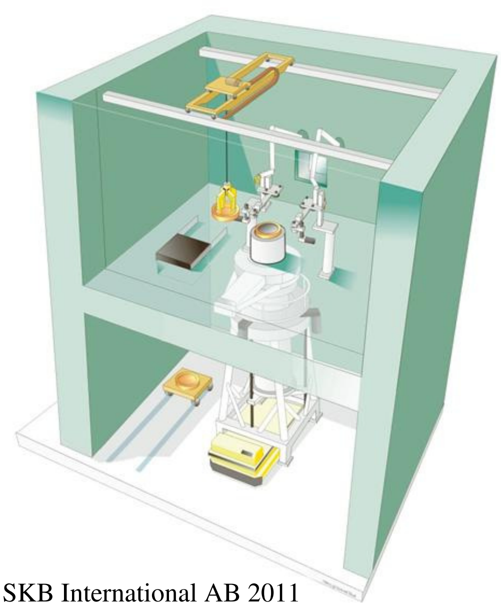

Figure 5. Processing station with a docked shielded frame and container.

- *The welding station*, which contains equipment for welding of the copper lid. In this conceptual design, the copper vessel is assumed to be seal welded using friction stir welding. In friction stir welding, a rotating welding tool is inserted and moved along the weld joint, and with the heat generated by the friction, the components are joined together while remaining in a solid state.
- *The machining station*, which houses a milling machine for machining of the weld area. Machining down to a smooth surface is required to perform NDT and to meet the requirements for placement in the repository. The milling machine can also be equipped with a special tool for cutting open defective containers.
- *The NDT station* for inspection of the copper lid weld, to ensure that the container does not contain any defects that could jeopardize long-term safety in the repository. It is assumed that both radiographic examination and ultrasonic testing are required.

3.4 Area for filled used fuel container storage and dispatch

For storage and dispatch of filled used fuel containers, the packaging plant includes:

- *A shielded container storage* for 40 filled used fuel containers. Containers are stored vertically and each storage position is covered by a shielded plug. The container storage is connected to the container transfer area by a port through which containers are transferred from a docked shielded frame.
- *A shielded cell for radiation monitoring and visual inspection of filled containers*. This cell also contains provisions for decontamination of containers, although decontamination is not normally required.
- *A dispatch hall* for loading of filled containers into shielded casks for transfer to the deep geological repository. The dispatch hall is connected to the container storage through a port, under which a shielded transfer cask is positioned for loading of a container. The hall also contains a working platform for cask operations and an airlock in which transfer casks arrive and depart on a rail wagon.

4. PACKAGING PROCESS

The used fuel packaging plant is designed for four main processes, as described in the following sub-sections.

4.1 Receiving and handling of empty used fuel containers

An empty used fuel container arrives to the packaging plant in a transport frame that is horizontally placed on a transport trailer. The trailer is parked in the transport airlock, and the transport frame with container is tilted to a vertical position and transferred to the working platform for visual inspection and preparation for processing. The container may also be transferred to a storage position for subsequent handling. The copper lid is transferred by pallet and hoisted into the inerting station prior to welding. Fuel baskets are transported and received at the packaging plant separately.

At the working platform, the steel lid is unbolted and removed, three empty baskets are lowered into the container, and the steel lid is placed back onto the inner vessel with the bolts left loose. The container is then lifted and installed in an empty shielded frame in the container transfer area. Using an air-cushion transporter, the shielded frame with container is transferred and docked with the fuel handling cell. A similar frame and transporter is used for development of encapsulation technology in SKB's Canister Laboratory in Oskarshamn, Sweden, see Figure 6.

At the fuel handling cell, the steel lid and empty baskets are lifted into the cell, leaving the docked container ready for loading of filled baskets.

Figure 6. Transport frame and air-cushion transporter at SKB's Canister Laboratory.

4.2 Receiving and unloading of transport casks

Transport casks with used fuel are assumed to be transported to the packaging plant by road on transport trailers. When receiving a transport cask, the trailer is parked in the transport airlock, from where the cask is lifted to an awaiting cask pallet – or to an empty storage position for transfer to a cask pallet at a later time.

After inspection and removal of its impact limiter, the transport cask is transferred and docked with a module handling cell from below. The cask lid is lifted into the cell, together with a cell containment door. The storage modules with fuel are then lifted up into the cell and over to the rail cart for transfer through the port into the fuel handling cell. Storage modules may also be transferred to the module storage pool for subsequent processing.

Once inside the fuel handling cell, the module is transferred from the rail cart to one of the fuel handling machines, along with an empty basket with the basket's tubes in horizontal position. In the fuel handling machine, two bundles at a time are pushed from the module to the basket. During the transfer operation, visual inspection and measurements are performed to verify the fuel's identity for safeguard purposes.

When filled with 120 fuel bundles, the fuel basket is turned to a vertical position and lowered into a docked container. After three baskets have been loaded, the steel lid is placed on top of the inner vessel and the container is undocked from the fuel handling cell for transfer to the inerting station.

When a module has been emptied of fuel, it is lifted out of the fuel handling machine and transferred to the waste treatment area below the cell for decontamination and compaction.

4.3 Sealing, inspection and dispatch of used fuel containers

Once used fuel has been loaded into the container at the fuel handling cell, the container – in its shielded frame – is lowered and transferred by an air-cushion transporter to the four consecutive stations for sealing and final processing of the container lids. At each station, the container is docked by parking it below a port in the station floor and raising the shielded frame to specified heights.

At the inerting station, the steel lid is bolted, and vacuum pumps and inert gas supply are connected to a valve in the lid. The air inside the inner vessel is evacuated and then replaced with inert gas. This process is repeated and the gas content measured to determine if the inner atmosphere fulfills specified requirements or if further gas exchanges are required. When the inerting process is completed, the connection to the valve is removed, and the copper lid is placed on the container before undocking from the station.

At the welding station, the container is docked and raised until the top section of the container is inside the station. The container is fixed into position, and a hole is drilled in the top flange of the lid for the welding tool. Using friction stir welding, the copper lid is then seal welded onto the copper vessel, see Figure 7.

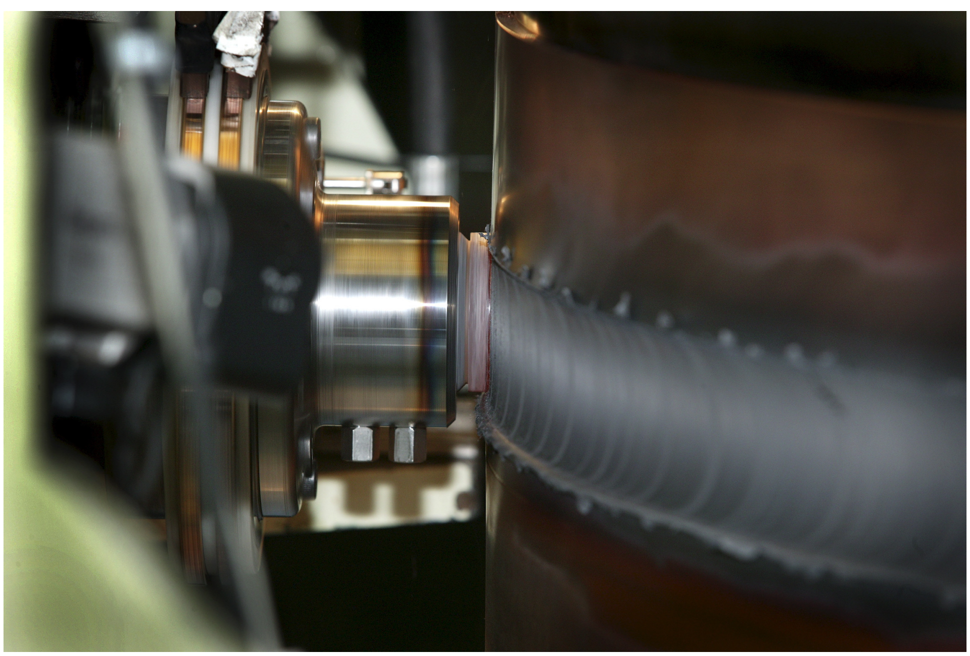

Figure 7. Friction stir welding of a copper lid at SKB's Canister Laboratory.

At the machining station, the container is docked and positioned so that the copper lid weld area can be accessed by the station’s milling machine. The top of the copper lid flange is cut off (to remove the area required for entry and exit of the welding tool) and the weld area machined to a smooth surface.

When sufficient time has passed to allow the container to cool, the copper lid weld is inspected in the NDT station using radiographic examination and ultrasonic equipment.

After passing inspection in the NDT station, the container is transferred to a docking position and lifted out of the shielded frame into the container storage area. In a dedicated cell, the container is swiped for contamination and, if necessary, decontaminated. The container is also visually inspected to ensure that it has not been mechanically damaged during handling in the plant.

Next, the container is transferred either to one of the storage positions for filled containers – or directly to a docked shielded transfer cask. Before dispatch, the loaded transfer cask is inspected and the cask lid secured at the working platform in the dispatch hall. Finally, the transfer cask is lifted to an awaiting rail wagon in the transport airlock for transfer to the deep geological repository.

4.4 Handling of defective containers

If NDT or visual inspection identify defects that are not acceptable for placing the container in the deep geological repository, the container is parked in one of the parking positions for shielded frames for subsequent handling. Since friction stir welding requires extra material for entry and exit of the welding tool, and the top of the lid flange has been cut off, it is not possible to re-weld a defective container.

To re-open a defective container, the milling machine in the machining station is first fitted with a special tool for cutting open copper lids. The container is transferred to the machining station, and the copper lid is cut open but left loose on top of the copper vessel. The container is then transferred to the inerting station where the copper lid is lifted off and the steel lid unbolted. Next, the container is transferred to the fuel handling cell where the steel lid is removed and the baskets lifted into the fuel handling cell. Once emptied, the container is decontaminated and sent off-site for recycling.

When the packaging process can resume, a new used fuel container is docked to the fuel handling cell. The three filled baskets – from previous unloading of the defective container – are loaded into the new container for normal processing.

5. CONCLUSIONS

In implementing Adaptive Phased Management, the used fuel packaging plant is an important step in the process of transferring Canada’s used fuel from interim storage to a deep geological repository. In addition to ensuring safety during operation, the packaging plant must produce containers that fulfill requirements for long-term safety – without frequent or lengthy production stops that would jeopardize the rate of placement in the repository.

To meet all such requirements, further development of the packaging plant design is essential. In particular, methods for transfer of fuel bundles and technologies for fabrication, sealing and NDT of containers will be evaluated and demonstrated during the coming years.

The detailed design and optimization of the packaging plant will be determined once the repository site has been selected and the container design has been finalized. At this conceptual stage of implementing Adaptive Phased Management, the described conceptual design serves as an important stepping stone for future design development and optimization projects.

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