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Material Handling in the Tritium Extraction Facility at Savannah River Site

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Abstract

One alternative for tritium production being considered by the United States Department of Energy is the irradiation of Tritium Producing Burnable Absorber Rods (TPBARs) in a Commercial Light Water Reactor (CLWR). The reference design for the TPBARs uses a stainless steel sheath to decrease tritium permeation during irradiation. The subsequent activation of the stainless steel poses unique radiation related challenges to the tritium extraction process. The design utilizes a combined bridge crane and robot, modules with master-slave manipulators, and a unique transporter to exclude oxygen from the extraction process. The preliminary design for the material handling for both tritium extraction and waste removal is presented.

Introduction

The Commercial Light Water Reactor option for production of tritium will irradiate TPBARs to produce tritium from lithium. The irradiated TPBARs will be shipped from the reactor to a new facility at the Savannah River Site. This new facility, the Tritium Extraction Facility (TEF) will receive the shipments from the reactor, store the TPBARs, prepare the TPBARs for tritium extraction, extract the tritium, and package the waste for disposal. The gamma radiation from the stainless steel sheath on the TPBAR will preclude direct human contact with the irradiated TPBARs.

Discussion

Description of Facility

The TEF will consist of two main buildings, and several support structures, as shown in Figure 1. The main buildings will be the Remote Handling Building and the Tritium Processing Building. Additional structures will include a support building, diesel generator building, chiller building, cooling tower, and gas cylinder shed. The Remote Handling Building will have a large remote handling area (RHA) and a smaller area for operators. The remote handling building features a below grade portion where the majority of the remote processes occur and an above grade portion for movement of material between process steps. A large bridge crane will be used for accomplishing the moves. The bridge will be equipped with hooks of various capacities, and a telescoping mast and robotic manipulator. An artist concept of the RHA is shown in Figure 2.

One unusual requirement for the TPBARs is that they should be stored and processed in an atmosphere with very low oxygen concentration. A nitrogen atmosphere will be used in the process modules, although argon or helium is also suitable. In order to preserve the nitrogen atmosphere, while allowing items to be moved between process modules, the TEF will use a nitrogen atmosphere transporter. The transporter is presented in greater detail in reference 1. The transporter will use a double door seal system to mitigate both oxygen intrusion into the nitrogen, and tritium or transferable contamination migration to the RHA general area. The transporter will have a hoist inside to raise and lower containers of TPBARs.

Receiving

Casks will be received on legal weight trucks in the truck bay. Inside the cask will be a collection of TPBARs that will have been consolidated prior to shipment by placing them into a grid structure. The grid structure, called an array, allows the TPBARs to be handled as a group. The array also maintains the spacing of the TPBARs so that they can be grasped individually when necessary. The cask will be removed from the truck and have transportation related items like tie downs and impact limiters removed. A hatch cover will be removed from the floor of the truck bay by the gantry crane. The cask will then be lifted to a vertical orientation and lowered through the hatch onto a trolley in the cask decon area.

Figure 1 - The Buildings of the Tritium Extraction Facility

The trolley will be used to move the cask from the cask decon area to the cask receiving area. A thick shielding door will separate the two areas. Operations in the cask receiving area will all be performed remotely. Prior to introducing the cask into the remote handling area, a number of contact operations will be performed. The cask exterior may require decontamination to prevent introduction of road dirt into the TEF remote handling area. The cask internal atmosphere will be sampled to verify that no tritium is present. In the event that tritium contamination is detected, the cask can be connected to a stripper system that will capture any free tritium in the cask atmosphere to minimize the airborne release when the cask is opened. One of the final contact operations will be to loosen or remove the cask lid retaining bolts to facilitate remote opening of the cask.

After the completion of contact operations with the cask, personnel will leave the cask decon area. The shielding door will then be opened, and the trolley will be used to move the cask into the cask receiving area. After the shield door is closed and secured, personnel will be able to re-enter the cask decon area.

In the cask receiving area, the cask lid will be removed by the overhead bridge crane and robot system. The cask lid will be placed in a fixture to prevent damage to the lid seals. The crane and robot will be used to remove the TPBAR array from the cask. The array will be placed into a container for storage and processing.

Figure 2 - Isometric View of the TEF Remote Handling Area. The Near Crane Rail is Removed for Clarity

The container is called a furnace basket, since it will eventually be placed inside the extraction furnace. The furnace basket will have two major pieces; the furnace basket bottom and the furnace basket lid. A flange will join the two pieces to each other. The furnace basket is shown in Figure 3. The furnace basket lid is planned to have a number of features. The inside of the lid will have a series of baffle plates and stainless steel media to provide surface area for condensation of volatiles released during extraction. The top of the furnace basket lid will have a flanged top on a short pipe. This provides a lifting surface for a grapple, as well as being the gas outlet from the basket. The basket is planned to also serve as an inerted storage container prior to extraction. To contain the inert environment, the flanged basket top will be blanked or plugged. The basket lid will also have a connector mounted on the side to allow for connection to an evacuation and backfill system that will establish the inert environment for storage. The flange which mates the basket lid to the basket bottom will have captive bolts installed in the basket lid flange. This will minimize loose parts in the remote area.

The TPBAR array will be placed in the furnace basket bottom by the crane and robot system. The furnace basket lid will then be retrieved and placed on the furnace basket. When the furnace basket lid is positioned on the basket bottom, the robot manipulator will use a tool to tighten the captive bolts. The basket at this point will contain the TPBAR array in an air atmosphere. The crane will use a grapple to lift the furnace basket by the flange on the basket lid to transport it to an inerting station. At the inerting station, the robot will install a jumper from the basket lid connection to the evacuation and backfill system. After several repetitions of the evacuate and backfill cycle, the basket will be inerted. The robot manipulator will remove the jumper, and the crane will grapple the furnace basket and transport it to a storage silo location.

The cask that contained the array will be empty. The cask lid will be retrieved from its holding fixture by the crane and placed on top of the cask. The cask decon area will be cleared of personnel, and the shield door opened. The trolley will then move the empty cask into the cask decon area. After the shield door is closed, personnel will enter the cask decon area to verify the cask exterior did not become contaminated during the array movement. If contamination is present, it will be removed to within permissible limits. The cask lid will be secured for shipment, and the cask removed through the same hatch it entered through. The empty cask will then be returned to the reactor.

Storage

Lag storage will be provided in the TEF to allow for receipt of several shipments from the reactor in a short period of time. Commercial power reactors operate for extended periods of time between refueling outages. This time period is on the order of one year. After the refueling outage is completed, it is anticipated that the consolidation of TPBARs into arrays will commence. It is desirable to ship the TPBAR arrays from the reactor to the TEF without undue delay. Thus, the TEF must provide storage capacity for approximately one year's worth of production.

Figure 3 - The Furnace Basket and Furnace Basket Lid, with the Array Shown in Phantom

Storage silos will be located in one room in the remote handling area. There will also be other storage locations and processing locations within this room. The room will be accessed from above, and will have concrete hatch covers to isolate the room from the remainder of the remote handling area. The storage area will have sufficient capacity to accommodate all high radiation sources in the TEF. This will allow the high radiation sources to be sequestered in the event manned entry into the remainder of the remote handling area is ever desired. The TPBAR arrays are stored in the sealed, inerted furnace baskets that are inserted into storage silos. No provision exists for routinely monitoring the integrity of the basket internal atmosphere.

Preparation for Extraction

Prior to placing the furnace basket into the extraction furnace, several operations must be performed. The preparation steps will be performed in a cell equipped with master-slave manipulators known as the Target Rod Preparation Module, or TRP. The TRP module has a nitrogen atmosphere that is connected to a tritium stripper system to recover any tritium that may be released during preparation steps. The nitrogen atmosphere also serves to exclude oxygen, so that formation of tritium oxide (tritiated water vapor) is minimized.

In order to preserve the integrity of the nitrogen atmosphere in the TRP module, the transporter will be used. The transporter is presented in greater detail in reference 1. It features a double door seal system on its lower end that will mate to docking doors on the inerted processing modules. The double door system operating principle is shown in Figure 4. The transporter will also have a true vertical lift hoist, which will grapple the furnace basket and raise it into the transporter payload section. The transporter's portion of the double door system will be passive. The transporter door will have to be mated to a module docking door to complete the double door seal system before the transporter can be opened.

The bridge crane will be used to remove a furnace basket from a storage silo and move it to the transporter inerting station. The transporter inerting station will have a docking door on the upper end that will mate to the transporter's bottom seal door. The door on the transporter inerting station will open to allow the bridge crane to lower the furnace basket assembly into the inerting station. After the furnace basket has been deposited in the transporter inerting station, the bridge crane will be used to retrieve a transporter from storage. The transporter will be mated to the docking door on the transporter inerting station to complete the double door seal system. The mated doors will then open as a pair to allow the transporter to grapple the furnace basket. A piping system connected to the transporter inerting station will be used to evacuate the air atmosphere and replace it with a nitrogen atmosphere.

Figure 4 - Cross Section of Double Door Sealing System. View A shows each door mated to its respective flange. In View B, the doors and flanges are mated to each other. View C shows the mated doors removed from the mated flanges.

After the atmosphere in the transporter and transporter inerting station has been exchanged for nitrogen, the double door system will be closed. The transporter will be detached from the transporter inerting station and moved by the bridge crane to the TRP module. The door mating and opening sequence will be repeated to introduce the furnace basket into the TRP module.

In the TRP module, the furnace basket will be opened to allow access to the TPBARs. The basket lid will be removed by unfastening the captive bolts in the basket flange. The lid will be prepared for extraction by removing a plug from the lid neck flange. This will provide the outlet path for the extracted gas stream. The inerting connection will also be removed from the lid, and a cap installed on the pipe stub so that the extracted gas does not exit the lid through this path. The master-slave manipulators will be used to perform these operations.

The TPBARs will be prepared for extraction by breaching the cladding to access the TPBAR internals. Each TPBAR must be assured to have a gas release path to prevent overpressurization of the TPBARs in the extraction furnace. A mechanical puncture of each TPBAR is the current baseline for this process, however alternative methods are being examined in conjunction with the Pacific Northwest National Laboratory. It is planned to have an automated system perform the breaching operation, with the master-slave manipulators being a backup.

When all of the TPBARs have been breached, the furnace basket lid will be reinstalled to complete the furnace basket assembly.

Extraction

After the TPBARs have been prepared for extraction, the assembled furnace basket will be moved to the extraction furnace. The basket will be carried in the transporter, which in turn will be moved by the bridge crane. The bridge crane will raise the transporter from the docking door on the TRP module and move it to one of two extraction furnace modules. The transporter will mate with the docking door on the furnace module, and the double doors will be opened.

The furnace module serves as a secondary confinement structure for the extraction furnace. The furnace will be a high temperature vacuum furnace with a cold wall. No credit is taken for tritium confinement by the furnace retort due to the permeability of tritium through metals at the high temperatures present in the furnace.

The furnace lid will be remotely opened by a dedicated actuator system. The hoist in the transporter will be used to lower the furnace basket into the furnace retort. The furnace lid will be closed and sealed. The double door system for the module to transporter seal will be closed and sealed. The transporter will be disconnected from the docking door on the furnace module, and moved to a storage location by the overhead bridge crane.

Once the transporter has been removed from the furnace module, the furnace cycle may begin. The extraction cycle will consist of a variety of steps to establish a good vacuum in the furnace retort, followed by a programmed heating recipe. During the furnace cycle, tritium will be liberated from the TPBARs and pumped to accountability tanks. The vacuum pumps and accountability tanks will not be located in the remote handling area since tritium is not an external radiation hazard. The piping, which will connect the extraction furnace to the vacuum pumps, will have a labyrinth path through the shielding wall to minimize radiation streaming.

After the tritium has been removed from the TPBARs, the furnace will be cooled down to allow for removal of the spent furnace basket. The transporter will be used to prevent introducing oxygen into the furnace module. The spent furnace basket will be moved to the waste packaging station.

Waste Packaging

In order to meet waste packaging requirements, the spent furnace basket must be placed in a waste overpack. The overpack is shown in Figure 5. A dedicated overpack station will be used to accomplish this. The station will have a docking door to allow the transported to mate to the overpack station and discharge the spent furnace basket. There is not a requirement for an inert atmosphere in the overpack, so the station will have an air atmosphere. The docking door will be mounted on a pair of rails to allow it to move to the side after the spent furnace basket has been placed in the overpack.

With the docking door out of the way, an overpack lid will be placed on the overpack by the bridge mounted robot manipulator. An automatic welder will be used to weld the lid to the overpack to assure integrity of the overpack container. The overpack will then be transported by the bridge crane to a staging area.

Waste Shipment

The waste shipment process will be similar to the receiving process. A shielded transport cask will be introduced into the cask decon area and moved with the trolley to the cask receiving area. The cask lid will be removed, the overpack placed in the cask, and the lid replaced on the cask. The loaded cask will then be moved by the trolley to the cask decon area, the cask will be surveyed, and then lifted out of the hatch to the truck bay. Permanent disposal of the overpack will be in the existing E-area vaults at Savannah River Site.

Figure 5 - Waste Overpack, shown with Furnace Basket and Array in Phantom

Maintenance

Equipment maintenance will be performed remotely. The design of the extraction furnace permits remote replacement of seals, thermocouples, electrical connections, vacuum piping jumpers, and heaters. The furnace design also provides for complete remote removal and replacement of the furnace.

Development Program

A multi-year development program is underway to reduce the risk associated with the remote handling operations. The transporter development is described in reference 1. Other development activities have examined seals and connectors for remote service, particularly the ability of remote connectors to meet the required vacuum leak rates for the furnace vacuum line. A full height robotic manipulator is planned for installation in a development and test facility. The robot will be used to mitigate operability concerns, and demonstrate remote maintenance capabilities.

A separate development effort is underway to design and fabricate a proof-of-principle extraction furnace. The furnace will be installed in the development facility and undergo operability testing. Remote maintenance issues will be addressed.

The TPBAR breaching apparatus that provides a vent path from each TPBAR is scheduled for development currently. The design of the lead test assembly (LTA) TPBARs used in the Watts Bar irradiation requires the breach to be made through the lithium aluminate ceramic pellets of the TPBAR. Modifications to the TPBARs are currently being proposed that may ease the breaching process.

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References

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