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Radiological Handling and Containment Considerations in Support of an American Medical Isotope Producer

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Abstract. This work will discuss evaluation and design of new and modified facility level radiological containment, transfer, and handling systems in support of the United States' American Medical Isotope Production Act. In the United States alone, Molybdenum-99 (Mo-99) is used as a precursor to locally generate its decay product, technetium-99m (Tc-99m), for use in approximately 40,000 medical procedures every day to detect cancer and heart disease. Currently, however, Mo-99 is primarily produced overseas and typically requires highly enriched uranium (HEU) which is classified as weapon-usable. This poses a serious security risk to the United States and, in 2012, Congress passed the American Medical Isotope ACT which aimed to cease all Mo-99 production that requires HEU and support American based companies who have found safer production methods. Through this effort, a system was designed and developed to access irradiated material in processing hot cells for ease of material introduction and removal in the confined area. The proposed solution uses a double-door design that allows for easy access to material while also providing shielding through a mechanically manipulated carousel. A system was also designed to transport irradiated materials from target reactors to a target receipt box using a rail guide system, pneumatic motor, and lead screw drive.

INTRODUCTION

Medical radioisotopes are imperative for detecting both cancer and heart disease in the United States, and technium-99m (Tc-99m) is used in two-thirds of all diagnostic medical procedures. Tc-99m is generated locally from its precursor, molybdenum-99 (Mo-99), which is primarily produced overseas in Australia, Belgium, Netherlands, and South Africa.[1] Mo-99 has been produced by irradiating a uranium-235 target in a nuclear reactor and then chemically separating the fission products. Once the Mo-99 has been separated, it is placed in a technetium generator and shipped around the world.[2] However, Mo-99 has a half-life of about 66 hours and its decay product, Tc-99m only has a half-life of about six hours. This means it is imperative that the entire supply be used within six days of production.[3] With about 20 million nuclear medical procedures being performed every year in the United States, producing these radioisotopes locally is a necessity.[4,5] Also, Mo-99 has been previously manufactured using highly enriched uranium (HEU), a material that is classified as weapon-usable. This poses a serious security threat to the United States as foreign adversaries could divert or steal the weapon-usable material.[2]

To combat these problems, Congress passed the American Medical Isotope Production ACT of 2012, which aimed to replace overseas producers with American based companies who have found safer production methods.[2] The National Nuclear Safety Administration (NNSA) has been directed to completely award five companies with a 50%/50% cost-shared agreement. As part of this agreement, the NNSA has also been directed to provide funding to Department of Energy National Laboratories who offer technical expertise and use of their facilities to these American Medical Isotope Producers (AMIPs).[1] Through this effort, Savannah River National Laboratory (SRNL) has assisted an AMIP on design considerations for a new Mo-99 production facility.

At the request of the AMIP, SRNL has designed three individual systems to transport, handle and access irradiated materials within the facility. The first system transports the target transport carrier from the nuclear reactor 35 feet to the end of the transfer canal. From this point, the second system transports the target transport carrier vertically 15 feet to the target receipt hot cell so processing can begin. Last, after decontamination has been completed, a system was designed to access the finalized Mo-99 from the hot cell so it can be packaged and shipped. Each system was designed with the primary objective to be simple as this is ideal for nuclear facilities. Each system was also developed with a focus on reducing total maintenance as this will yield lower downtimes for the AMIP and higher production rates.

TARGET TRANSPORT SYSTEM

The AMIP requested SRNL's guidance in developing a method for transporting targets from the reactor to the target receipt box. The AMIP specified that the transport system would be required to move the targets 35 feet horizontally across the canal and raise them 15 feet into the target receipt box while under 15 feet of water for radiological shielding purposes. These motions could be divided into two distinct systems that will be addressed separately. The target transport carrier will be constructed similarly to the target reactor with a few additions for locking and movement. From this information, SRNL designed two target transfer systems which would safely and securely move the target from the reactor to the target receipt box. Both systems consider potential fire hazards, points of failure, and necessary eventual maintenance.

Horizontal Transport System

The horizontal transfer system should be capable of moving linearly at low speeds to maintain safe operations when transporting targets. A simple cart-on-rails system was designed as shown in Fig 1. The cart would be driven by a lead screw that is powered by a pneumatic motor.[6] Pneumatic motors were selected based on their ability to stop and maintain balanced pressure when mechanically overloaded. Pneumatic motors are also explosion proof, fireproof, and commonly used in nuclear fuel transport.[7] The lead screw drive will be mounted outside the transfer canal to minimize the total amount of equipment and maintenance required within the canal. Linear rail guide systems were also chosen to minimize down time associated with maintenance. Round shaft linear rails were selected over profiled shafts based on their simple mounting mechanism and ability to operate in harsh environments.[8]

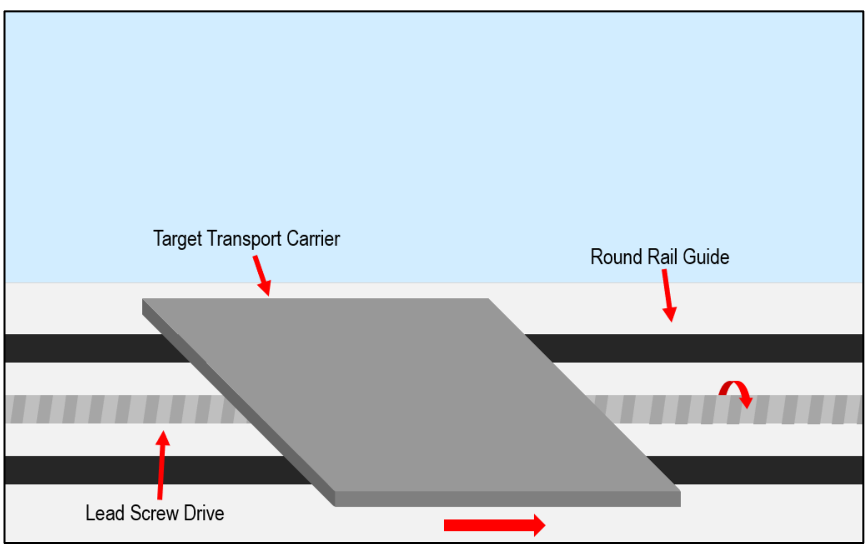

FIGURE 1. Horizontal target transport system

Vertical Transport System

Once the material is below the target transfer box, a system must be put in place capable of raising the target transport carrier 15 feet into the target receipt area, flush with the floor. Two designs were considered, with the first resembling a scissor lift or linear actuator. This lift or actuator would provide a force directly upward to the platform which is disconnected from the rail system as shown in Fig 2. While simple and effective, this design will not work with a lead screw drive due to the pass off of the transfer platform between horizontal and vertical movement. This could be solved by segmenting the leadscrew, but this would severely compromise its structural integrity and likely lead to misalignments, required manual attention to rectify.

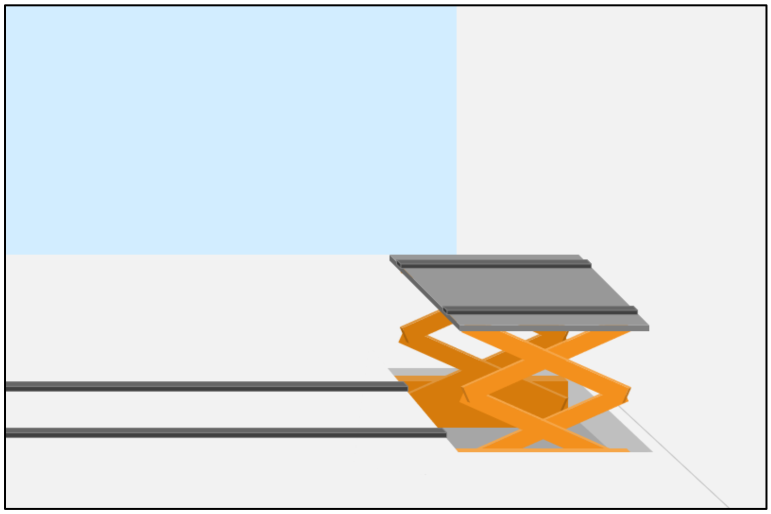

FIGURE 2. Initial vertical target transport system

The second design is made up of two lead screw drives that directly raise the basket into the receipt area (Fig 3). Forks slot into and secure the basket (not pictured) as it is transported. Lead screws were preferred over the belt or chain iterations as these can become less accurate over time and chains require a significant amount of lubrication. It also allows for better certainty in delivering the fuel to the target receipt box with a platform that can be ensured to be flush with the floor as requested by the AMIP.

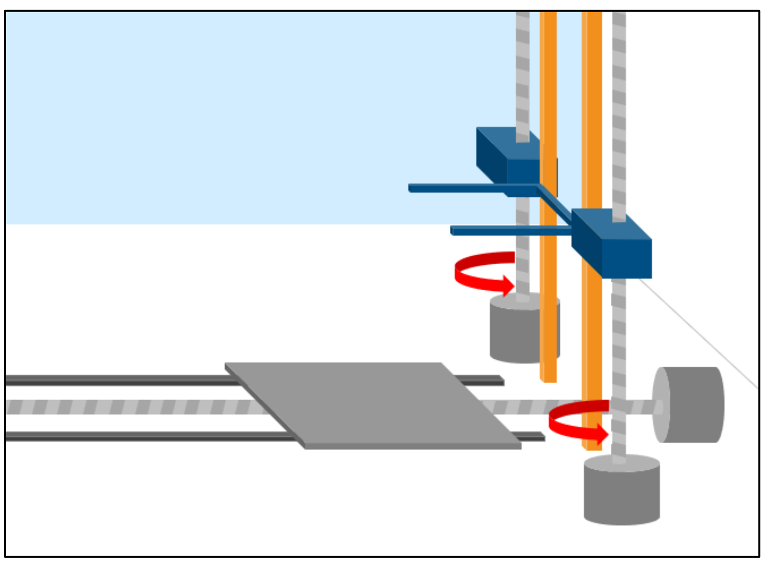

FIGURE 3. Vertical target transport system

IRRADIATED MATERIALS ACCESS SYSTEM

The AMIP also asked SRNL to design and develop a solution on how to access the irradiated materials from the target receipt and packaging hot cells. Initial considerations studied the design of a drawer system that would allow easy access of materials while maintaining a containment boundary. This design was later replaced with a much simpler antechamber-style double-door system.

Slide-out Drawer Access System

A drawer design was initially considered at the AMIP's request as it would provide simple movements and easy access to hot cells. The final iteration of this design concluded in a double seal drawer that opens from the top and slides out in the horizontal direction from outside the hot cell. As shown in Fig 4, The top door would open using a ninety-degree handle to allow easy maneuvering from a standard master-slave manipulator. The irradiated material would then be lowered into the drawer and the top door would close and latch. The drawer could be accessed from outside the hot cell by rotating the access handle and pulling the drawer out. The drawer design, although favorable economically and spatially, presents a contamination control issue. Any spills in the hot cell area would likely flow into the drawer resulting in a contaminated transfer drawer mechanism that cannot be opened into the personnel area. Access to this system also would take up valuable floor space that must either be kept clear of any other equipment or routinely cleared for removal of material that would pass through the transfer system. Furthermore, the irradiated material in the lead pig could be dropped while being lowered into the drawer. The ability to provide vertical force to ensure the integrity of the confinement boundary would also have required a significant amount of R&D, characterization, and federal review and approvals than a simpler antechamber design.

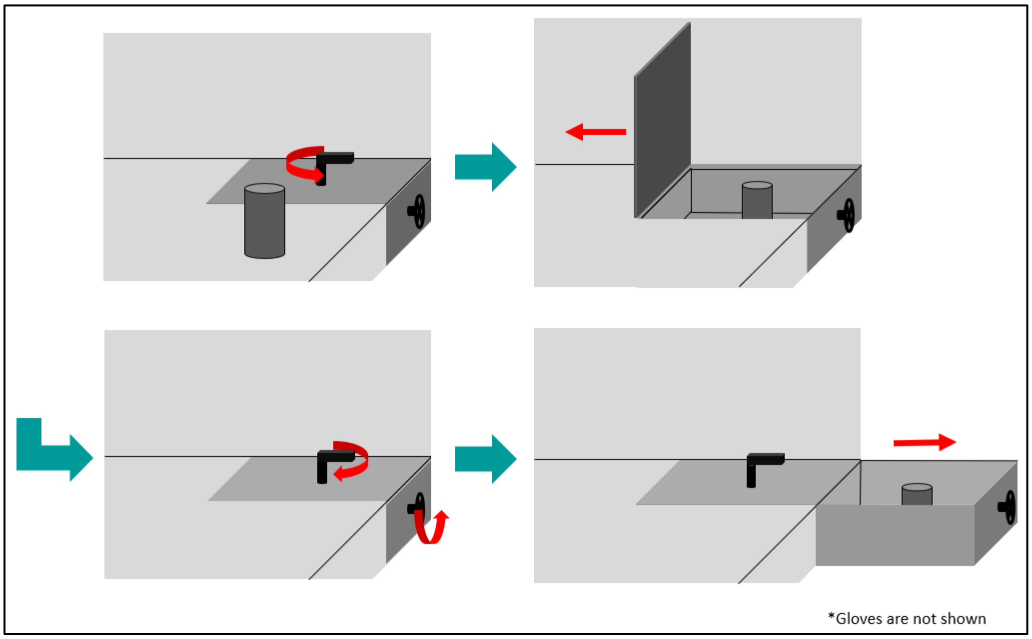

FIGURE 4. Slide-out drawer access system

Antechamber Double Door Access System

After further considerations, SRNL recommended moving away from the drawer-style design. The new design takes a more traditional approach similar to a "transfer tunnel" and removes dropping and spill hazards. The new design will also require significantly less research and development, can be easily modified, and offer additional storage on top of the chamber. The first iteration uses two doors at ninety degrees and features a spill resistant lip and slide out tray. However, a second iteration was developed based on feedback from the AMIP to add further shielding between the operator and processing hot cell.

The antechamber double door solution is an extension of the hot-cell and is shown in Fig 5. The door inside the hot cell will swing into the cell and away from the operator. A tray mounted on a fixed track inside the airlock will slide out into the hot cell area. The irradiated material will be loaded onto the tray and placed inside the antechamber. The interior door will close to maintain the confinement boundary and the access door will open so the irradiated material can be removed. While this solution is promising, a lift may be required to move the material over the protective spill lip and onto the tray due to the weight of the material being transferred. Also, the doors will use rubber gaskets to ensure the contamination boundary is maintained, but SRNL has advised that dust and other debris could build under the gaskets leading to a possible leakage point.

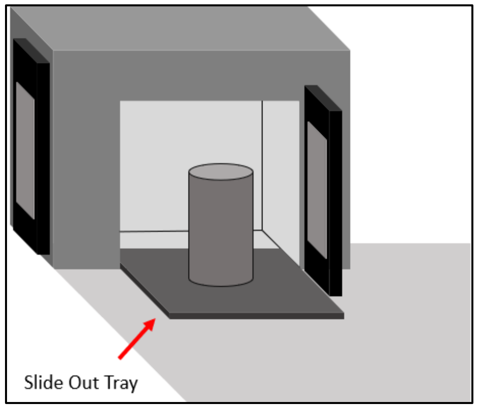

FIGURE 5. Antechamber double door access system

The second iteration of the double-door design includes a carousel made of lead to add shielding protection as shown in Fig 6. The carousel will be mounted from the top to a steel support structure as the carousel will weigh approximately 1300 lbs when designed to specifications provided by the AMIP. Gears will be mounted above the carousel and be operated by a pneumatic motor. The carousel will rotate ninety-degrees to allow easy access to the operator.

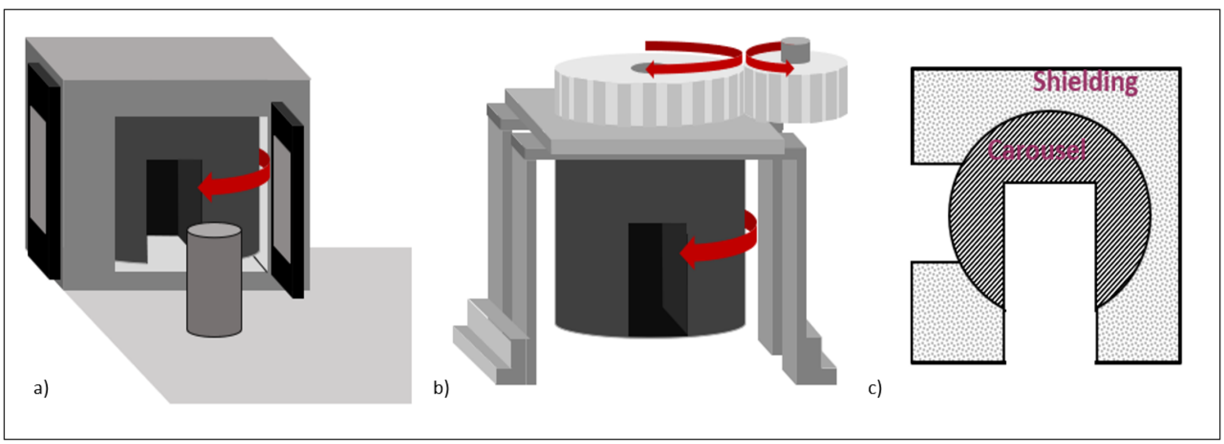

FIGURE 6. a) Antechamber double door with a lead carousel for additional shielding. b) A mounting system to support the carousel and provide additional movement. c) Internal schematics of the antechamber to show total shielding.

CONCLUSION

In support of the United States American Medical Isotope Production ACT, SRNL has evaluated and designed three individual systems for containment, handling, and transport of irradiated materials. At the AMIP's request, SRNL developed a horizontal target transport system composed of a cart guided by linear rail guides, driven by a lead screw, and powered using a pneumatic motor. This design mitigates fire hazards, points of failure, and eventual maintenance. A vertical target transport system was designed with two metal forks that will slot into the target transport carrier. The forklift is driven with two lead screws to maintain simplicity and further reduce eventual maintenance. Once the Mo-99 has been through decontamination, it must be removed from the processing hot cell. To solve this, SRNL designed an antechamber double door access system with options for additional shielding. This additional shielding turns on a carousel, is supported by a steel structure, and driven by a pneumatic motor. Each system has been carefully evaluated with a focus on simplicity as this is ideal for nuclear facilities. SRNL's objective for each design was also to reduce eventual maintenance which will reduce facility downtime and increase revenue for the AMIP. The AMIP has given extremely positive feedback on all three designs and plans to implement each into the new facility.

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