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PLUTONIUM IMMOBILIZATION

CAN-IN-CANISTER HARDWARE DEVELOPMENT/SELECTION (U)

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ABSTRACT

The Plutonium Immobilization Project (PIP) is a program funded by the U.S. Department of Energy to develop technology to disposition excess weapons grade plutonium. This program introduces the "Can-in-Canister" (CIC) technology that immobilizes the plutonium by encapsulating it in ceramic forms (or pucks) and ultimately surrounding it with high-level waste glass to provide a deterrent to recovery. Since there are significant radiation, contamination and security concerns, the project team is developing unique technologies to remotely perform plutonium immobilization tasks. This paper covers the design, development and testing of the magazines (cylinders containing cans of ceramic pucks) and the rack that holds them in place inside the waste glass canister. Several magazine and rack concepts were evaluated to produce a design that gives the optimal balance between resistance to thermal degradation and facilitation of remote handling. This paper also reviews the effort to develop a jointed arm robot that can remotely load seven magazines into defined locations inside a stationary canister working only through the 4" (102mm) diameter canister throat.

1. INTRODUCTION

The Plutonium Immobilization Project (PIP) is a program funded by the U.S. Department of Energy to develop technology to disposition excess weapons grade plutonium. Lawrence Livermore National Laboratory (LLNL) is the lead laboratory for the program with the Savannah River Site (SRS) partnering on key technical and engineering aspects of the program. When operational, the PIP will fulfill the nation's nonproliferation commitment by combining 9.5-weight percent weapons-grade plutonium with ceramic and uranium materials to produce ceramic forms (pucks), which will subsequently be immobilized in high-level waste glass.

2. PROCESS DESCRIPTION

"Can-in-Canister" (CIC) refers to the system for immobilizing and handling excess plutonium in the PIP. Five components work together to form the system – the puck, puck can, magazine, rack and DWPF canister. The 2 5/8" (67mm) diameter, 1" (25mm) thick plutonium oxide-ceramic puck is the basic component of the CIC. Twenty pucks are placed in each 20" (0.5 m) long puck can and sealed by a remote welding process. Automated equipment then inserts four sealed puck cans into each magazine (Figure 1) and closes the magazine with a mechanical, snap-type permanent closure. Other automated equipment then takes magazines to a staging area for canister loading. In the staging area, a DWPF canister with pre-installed rack is brought into the facility on an automated cart. A three degree-of-freedom telescoping bridge robot with a three degree-of-freedom manipulator obtains a loaded magazine from the staging area and carries the magazine to the canister. The robot then lowers the magazine through the canister throat until it is entirely inside the canister. At this point, the operator uses remote viewing and manual control to align the magazine radially with a socket and place the magazine into a storage position on the rack. The robot then indexes from the first magazine and repeats the process with six additional magazines until all seven rack positions are occupied. Loaded canisters are then taken to the DWPF, where they are filled with a molten mixture of high level radioactive waste glass and welded closed. After cooling, the canisters are inspected and sent to an interim storage facility where they will stay until a federal repository is available.

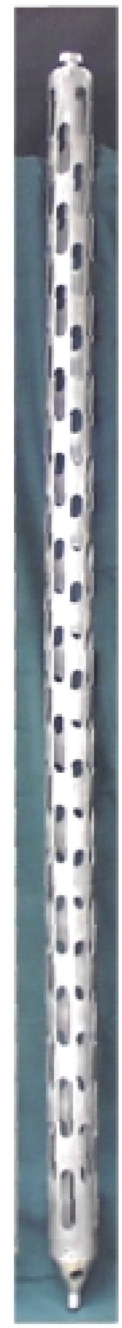


Figure 1: Magazine

3. DEVELOPMENT PROGRAM (TEST PLAN)

The DWPF has been pouring glass into empty canisters since it opened in 1996, and the behavior of the glass in an empty canister is well understood. However, the addition of a stainless steel rack, magazines, cans, and ceramic pucks to the canisters introduces a new set of design and operational challenges. The CIC had to be robust enough for remote handling and to remain dimensionally stable when heated to about 1000C, yet open enough to allow molten glass to flow around the assembly. During the early stages of component design, remote loading tests were conducted to develop the magazine and rack features. Thermal behavior and the effect of the CIC on the glass fill were next evaluated through modeling and two cold (non-radioactive) pour tests. Phase 1, conducted in 1999, was a scoping test that evaluated the thermal behavior of several hardware concepts to select the baseline design. Phase 2 cold pour tests conducted in 2000 verified the adequacy of the baseline design for the start of Title 1 plant design. Phase 2 was also used to demonstrate compliance with the Plutonium Immobilization Product Specifications (PIPS) and hence was performed in accordance with repository quality assurance requirements (i.e. DOE-RW-0333P).

4. EQUIPMENT DESCRIPTION

A. Magazine

Early in the CIC development, the team evaluated several concepts for getting puck cans into the canister. The two alternatives were the “ship in a bottle” approach of loading puck cans through the canister throat, and the “open top” method of loading the puck cans and rack as a unit into an open canister, then remotely attaching the top. Since the canister design could not be changed, the remote weld was deemed too difficult and the “open top” method was dropped. Several imaginative “ship in a bottle” concepts were then considered before settling on the magazine and rack design.

Magazines group the puck cans for remote operations and later hold them out of the pour stream when the high level waste glass is poured into the canister. Magazines, so called because of their resemblance to rifle magazines, are made of 3” Schedule-10 304L stainless steel pipe. They are 87” (2.2 m) long, have a 3.5-inch (89 mm) outside diameter and weigh 135 pounds (61 kg) [loaded]. At the top of the magazine is a gripper knob and at the bottom is a cone to assist in guiding the magazine into the magazine rack. The most noticeable feature of the magazines is the laser-cut slots. During pouring, glass flows through the slots and contacts the puck cans, forming a void-free glass-metal matrix surrounding the puck cans.

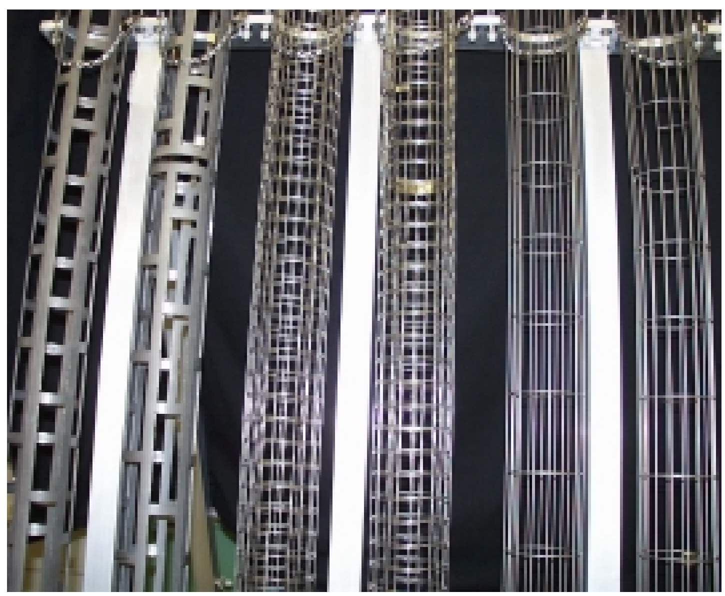


Figure 2 Six early magazine concepts

The current slotted pipe magazine is the result of an intense search for the optimum combination of handling and glass-flow characteristics. Remoteability concerns favor a dimensionally consistent, structurally robust magazine that deflects minimally during loading operations, i.e. fabricated from pipe. However, glass flow is optimized with a magazine that offers minimal obstruction to molten glass so that glass completely surrounds the puck cans. The ideal magazine for glass flow is one that maximizes open area, such as a welded wire or wire mesh design. Finite Element Analysis verified by actual remote handling tests on six different wire magazines revealed that they were too fragile, too costly or too dimensionally inconsistent to meet design requirements. Pipe magazines with different wall thicknesses and perforation configurations were evaluated in the cold pour tests, along with welded wire and wire mesh magazines.(Figure 2). In all cases, glass completely filled magazine crevices, and wire magazines showed no advantage over pipe designs. Subsequently, the team chose a magazine design produced from common 3” schedule 10 (89 mm OD) stainless pipe with laser-cut slots that offers ideal remoteability characteristics (light weight and stiffness).

B. Rack

The rack is the framework inside the DWPF canister that receives the loaded magazines. The rack holds the magazines in a predetermined, symmetric orientation inside the canister and allows glass to flow around puck cans to encapsulate them. It also provides both lateral and vertical latching to reduce the possibility of magazines leaving their positions during transport to DWPF and glass pouring. The rack must be robust enough to give structural support at elevated temperatures while minimizing both mass and resistance to glass flow. It is constructed entirely of stainless steel and consists of four scalloped plates and one bottom plate joined by seven round bars. Racks are free-standing inside the DWPF canister and are not welded in place, since canister modification is not permitted (Figure 3). Like the magazines, the rack has large openings to permit unobstructed glass flow. Seven "sockets" in the bottom plate provide the resting surface for magazines. The sockets accept the cones at the bottom of each magazine. Snap rings at the cone/socket interface constrain the magazine vertically, while unique butterfly latches on the scalloped plates constrain lateral movement. (The operation of the lateral latches is described below in the frames of Figure 4.) Canisters will be delivered to the PIP facility with racks pre-installed.

Figure 3 - Canister inside view showing rack, cans and magazines before pouring glass

Seven racks were fabricated and tested with non-radioactive glass during the cold pours. Three different designs were tested. All racks performed well and did not deform or impede glass flow around the puck cans.

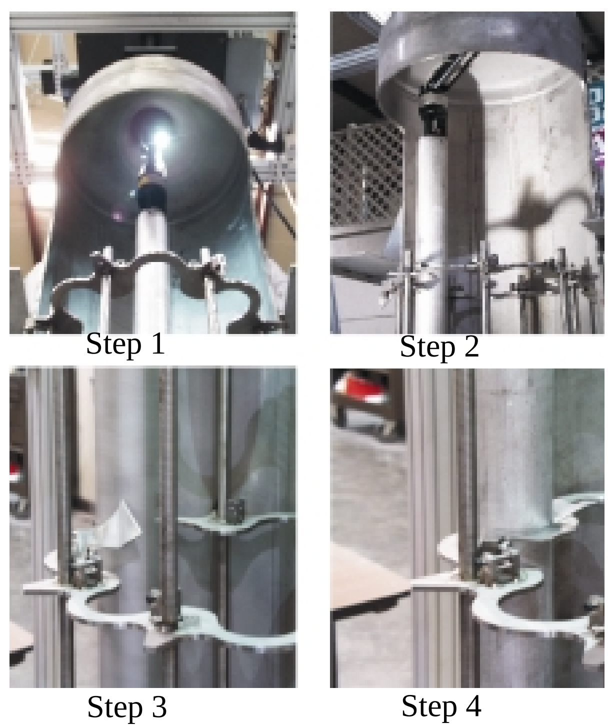
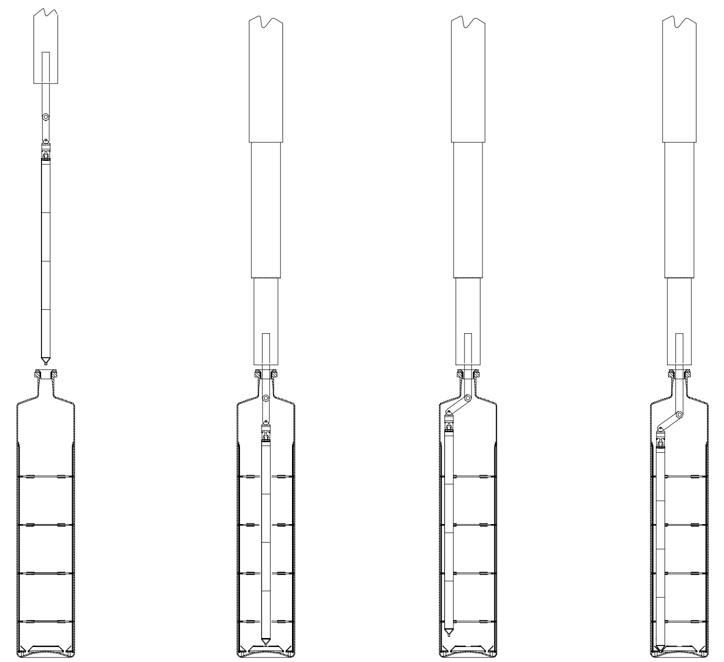


Figure 4: Step 1 shows the magazine lowered into the canister. [The white spot is the light source.] In Step 2, the operator rotates the arm to align the magazine with the latches mounted in the storage rack using miniature cameras mounted on the arm. In Step 3, the manipulator arm pivots to engage the magazine into the lateral latches. Step 4 shows the latch engaged with the magazine seated in the socket.

C. Canister Loading Robot

The Canister Loading Robot is uniquely designed for the canister loading process. It is a three degree-of-freedom telescoping bridge robot with a three-degree-of-freedom manipulator. While in the loading position, canisters are stationary, in a vertical orientation, and do not rotate. Therefore the Canister Loading Robot must provide all movement necessary to load magazines into a canister and lock the magazines to the rack (Figure 5). Loading begins when the robot lowers the loaded magazine through the canister throat (Step 1). The robot is capable of three motions once inside the canister: tilt, rotation and vertical translation. Rotation is used to align the magazine radially with a socket (Step 2). Then tilt is used to rotate the magazine through the rack's butterfly latches (Step 3), and finally vertical translation is used to lower the magazine to its stored position (Step 4). The wrist holding the gripper is constrained to ensure the magazine remains vertical at all times. It does this through a 4-bar link to the robot mast.



Step 1 Step 2 Step 3 Step 4

Figure 5 - Canister Loading Process

The canister loading robot has not yet been built, however three mockups were constructed and operated to demonstrate feasibility. The first mockup was a stationary test stand that contained a magazine and a single socket. It had an articulated arm that was only capable of tilt and vertical translation. It was used to develop the butterfly latches and magazine/socket interface. The second mockup used a gripper attached to an existing bridge robot. It was used to evaluate magazine designs and to prove that a magazine could be moved the length of a building without operator intervention and then precisely lowered through a canister throat without touching the throat sides. The final mockup (Figure 6) was a freestanding robot that includes both rotations and the translation to seat a magazine in the socket. This demonstrated that the magazine can be locked into place inside a prototypical rack, and that the robot can load all seven rack positions without rotating the canister.

The final mockup was also used to develop the user interface and control system for the three-degree-of-freedom manipulator attached to the bridge robot. It is currently envisioned that the robot will obtain a loaded magazine from the staging area and lower it down into the canister under fully automatic control. Next, the operator will place the robot in a teleoperated mode and drive the magazine into a rack socket. Indexing from the first loaded magazine, the robot will then load the six remaining magazines without operator intervention. To enable this concept to be tested, the mockup had to be constructed to enable both automatic and teleoperation.

In either the teleoperated or semi-automatic mode, the operator can choose between tactile (joystick) and numeric (touchpad) controls. To enable teleoperation, the robot is equipped with cameras and a light source, which can be seen in Figure 4. (During testing a drape is placed over the opening in the canister mockup to force the operator to rely on the cameras.) In automatic mode, an Allen Bradley 504 series PLC controls all three axes of movement (vertical movement, arm rotation, and tilt.) Each servomotor has incremental encoder feedback so the system controls acceleration, position, and velocity for each motion. To avoid having to return to a "home" position following restarts, absolute encoders are also provided for each motor.

Figure 6 - Canister Loading Robot Mockup

5. PLANNED ACTIVITIES

Though the cold pour tests are finished, several development tasks remain. Among these, automated magazine loading and magazine closure will take the most effort. Additional testing is also planned for the Canister Loading Robot in FY2001. After equipment development is complete, then the team will complete a System Design Description. This document will be the design basis for the Engineering Firm chosen to build the PIP facility.

ACKNOWLEDGEMENTS

Lee Hamilton is a Senior Mechanical Engineer in the Engineered Equipment and Systems Department in the Savannah River Technology Center (SRTC). [SRTC is the applied research and development laboratory at the SRS.] Dr. Gregory L. Hovis was formerly a Principal Engineer in the SRTC Engineered Equipment and Systems Department, and Mitchell W. Stokes is a Fellow Engineer in the SRTC Engineered Equipment and Systems Department.

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