This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U.S. Department of Energy.

DISCLAIMER

PLUTONIUM IMMOBILIZATION PROJECT

COLD POUR PHASE 2 TEST RESULTS (U)

Lee Hamilton, Michael E. Smith, Gregg Hovis

Westinghouse Savannah River Company, LLC

Building 773-A

Aiken, SC 29808

Lee.hamilton@srs.gov

(803) 725-3472

ABSTRACT

The Plutonium Immobilization Project (PIP) is funded by the U.S. Department of Energy to develop technology for dispositioning excess weapons usable plutonium. This program is developing the "Can-in-Canister" (CIC) technology that immobilizes the plutonium by encapsulating it in ceramic forms (or pucks) and ultimately surrounding canned forms with high-level waste glass to provide a deterrent to recovery. A cold (non-radioactive) test program was conducted to develop and verify the baseline design for the canister and internal hardware. Tests were conducted in two phases. Phase 1 Cold Pour Tests, conducted in 1999, were scoping tests. This paper describes the Phase 2 tests conducted in 2000 that verified the adequacy of the baseline CIC design and assured that the system would meet repository quality assurance requirements.

1. INTRODUCTION

The Plutonium Immobilization Project (PIP) is funded by the U.S. Department of Energy to develop technology for dispositioning excess weapons usable plutonium. Lawrence Livermore National Laboratory (LLNL) is the lead laboratory 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-usable plutonium with ceramic and uranium materials to produce ceramic forms (pucks). The 2 5/8" (67mm) diameter, 1" (25mm) thick puck is the basic component of the "Can-in-Canister" (CIC) system. Five components work together to form the CIC – the puck, puck can, magazine, rack and DWPF canister. Approximately twenty pucks are placed in each 20" (0.5 m) long puck can and sealed by a SRS-developed remote welding process known as Bagless Transfer. Four puck cans are then loaded into each magazine. (Magazines (Figure 1) are 87" (2.2m) long perforated cylinders that 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.) Seven magazines are then loaded one at a time into a specially prepared DWPF canister with a rack preinstalled by the canister

manufacturer (Figure 2). The rack holds the magazines in place during transport to the Defense Waste Processing Facility (DWPF) and glass pouring. At the DWPF, the canisters are filled with a molten mixture of high level waste and glass. The glass flows through the magazines and surrounds the puck cans, immobilizing them and providing a radioactive deterrent to recovering the plutonium. After cooling, the canisters are inspected and sent to an interim storage facility where they will stay until a federal repository is available.

2. BACKGROUND

The DWPF has filled hundreds of 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 rack, magazines, cans, and ceramic pucks to the canisters introduces a new set of design and operational challenges. Among these, glass voiding and CIC hardware structural integrity are issues that require additional study. The CIC must be robust enough for remote handling and to remain dimensionally stable when heated to about 1000C. Conversely, the CIC must be 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. After establishing a baseline with acceptable remote handling characteristics, the thermal behavior and the effect of the CIC on the glass fill were evaluated through modeling and two cold (non-radioactive) pour tests. The Phase 1 Cold Pour Test, conducted in 1999, was a scoping test that evaluated the thermal behavior of several hardware concepts. The results of this successful test were used to select the baseline design. The Phase 2 cold pour test, 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).
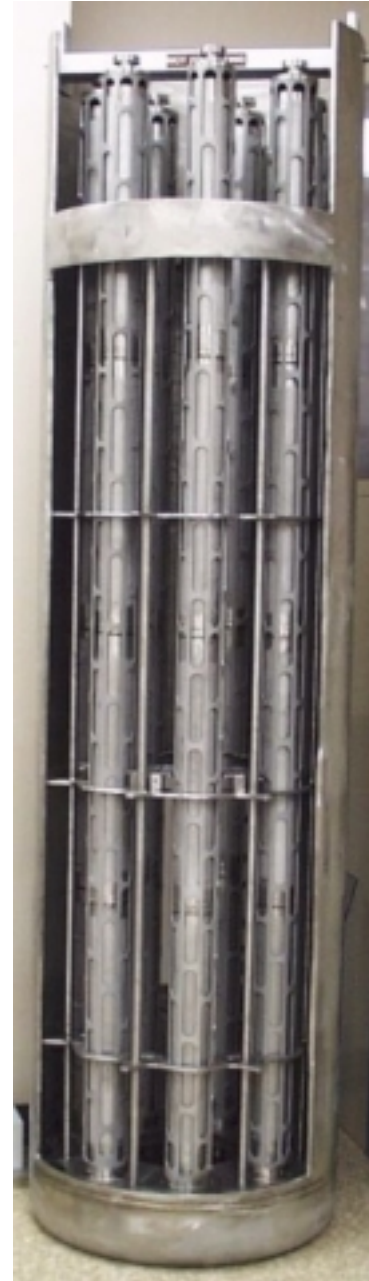

Figure 1: Magazine

Figure 2 - CIC assembly showing canister, rack magazines, and cans in their final positions.

3. PHASE 2 TEST DETAILS

Phase 1 Testing demonstrated that the CIC hardware had little effect on the pouring process. There was little change in monitored characteristics including temperatures and glass flow patterns inside the canister, heat up rate, and cooling rate. The post-test analysis showed that voids were unlikely and hardware deformation was negligible.

Three rack designs, eight magazine designs, and two lateral latching configurations were tested in Phase 1. Since all worked equally well with respect to the monitored parameters, the Phase 2 baseline design was chosen that gave the best combination of remote handling characteristics, proliferation resistance and lifetime cost. (If the hardware is unnecessarily bulky, then in addition to greater initial cost per unit, less glass can be poured into each canister and more canisters will be needed to complete the campaign.) 304L SS was used exclusively in the construction of the CIC, with the exception of some stainless fasteners. The Phase 2 rack configuration was constructed of 1/4" (6mm) plate and 3/4" (19mm) rod. For vertical latching, a snap ring was used to lock the magazine cone into the socket on the bottom plate of the rack. Lateral magazine latching was achieved using the 'butterfly' latch design tested in Phase 1. Test magazines were 3" schedule-10 pipe (90mm OD) with laser cut slots. They were equipped with remote handling features, even though they were loaded and installed by hand, so the test results would be typical of actual magazines. Puck cans were simulated using 3" (76mm) tubing with 0.065" (1.5mm) wall and a 1/4" (6mm) welded bottom. After pucks were installed by hand, plugs made to resemble actual bagless transfer can tops were welded to the puck cans. Actual radioactive materials were not used in any of the tests. The cans were loaded with either non-radioactive titanate-based ceramic pucks (fabricated by LLNL), ceramic surrogate logs, or ceramic surrogate pucks. The LLNL pucks were not used exclusively because there were not enough of them available in time for the test. Therefore, ceramic surrogates (Harbison-Walker Aurex 95 chrome-alumina brick) were used that had thermal properties similar to the actual pucks. Table 1 shows the configurations tested.

Canister	Purpose	Targeted Pour Rate	Can Contents	Instrumented (Yes/No)
Low Pour Rate	Destructive analysis	Low (45 kg/hr)	LLNL pucks and Aurex 95 logs	No
Nominal Instrumented	Destructive analysis and thermal information	Nominal (82 to 109 kg/hr)	LLNL pucks and Aurex 95 logs	Yes
Proliferation (PR1 and PR2)	Proliferation tests	Nominal (82 to 109 kg/hr)	LLNL pucks and Aurex 95 pucks	No

Table 1 – Phase 2 Cold Pour Test canister configurations

As in Phase 1, the two main phenomena investigated in the Phase 2 tests were the degree of hardware structural deformation and the extent of glass void formation in the canisters. The controlled test parameters were the pour rate, glass composition, glass stream temperature, glass stream fall height, hardware configuration and glass fill height. Two

canisters were required to adequately determine whether or not the system would work in DWPF. One of the canisters was a "worst case" which was filled at an extremely low pour rate of 45kg/hr. The second test canister was filled at 73 kg/hr, the maximum pour rate for the test melter using this glass composition. This is slightly below the nominal DWPF pour rate of 82-109 kg/hr, however it is above the minimum value specified in the test plan. Two other canisters were filled at a rate near 70 kg/hr and stored for future non-proliferation tests. A high viscosity glass (about 90 poise at 1150 °C) was used in all four canisters. This viscosity was determined to be the highest possible viscosity glass that would be fed to the DWPF Melter during the PIP campaign.
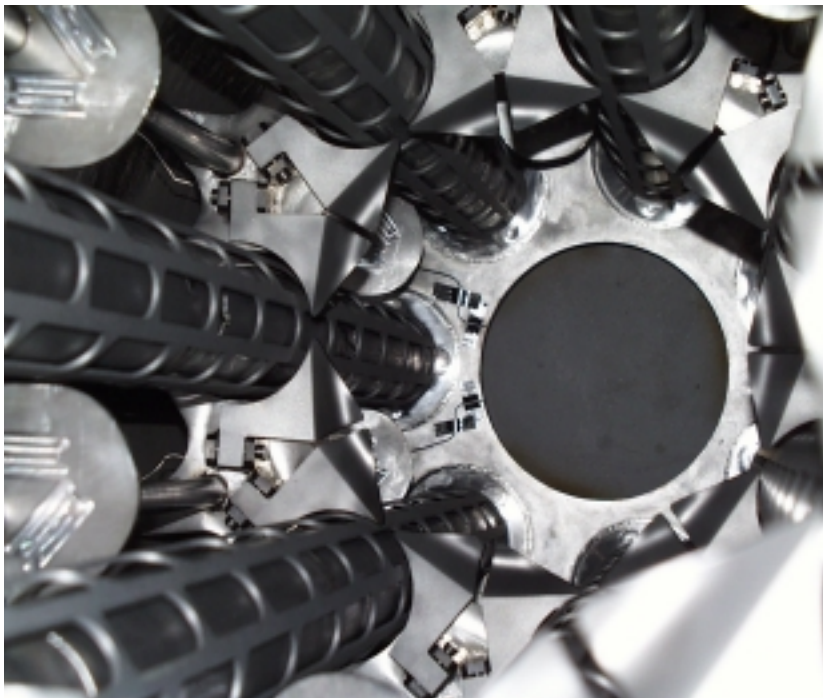

Figure 3 – Inside of instrumented canister as seen from installed camera before pouring glass.

Filled first were the two proliferation test canisters (PR1 and PR2). These canisters had 4 magazines (16 cans) of Harbison-Walker Aurex 95 ceramic pucks (about 20 per can) and 3 magazines (12 cans) of surrogate plutonium ceramic pucks (about 20 per can) supplied by LLNL. The low pour rate and instrumented canisters were both filled with six magazines (24 cans) of Aurex 95 ceramic logs (4 per can) and one magazine (4 cans) of surrogate plutonium ceramic pucks (about 20 per can). The instrumented canister had thermocouples installed on the surface of the canister, the surface of cans, on the base plate, and inside the canister at various heights. It also had a camera installed on the top of the canister so that the inside of the canister could be viewed during glass pouring (Figure 3).

4. TEST RESULTS

    Proliferation Canisters (PR1 and PR2) were the first canisters poured in the Phase 2 tests. The overall calculated pour rate was about 69 kg/hr, which is lower than the target rate of 82 – 109 kg/hr. The decreased pour rate is attributed to the inability of the melter to compensate for the high viscosity glass. When the pour finished, 1456 kg of glass had been poured into the canister and the glass height was 246 cm. If there were no voids in the glass, the glass weight would have been 1518 kg (assuming 6.17 kilograms of glass per one centimeter of glass in the canister). The closeness of the calculated weight (1518 kg) to the actual weight

(1456 kg) indicated that significant voids were unlikely. The measured temperature of the glass just before the melter pour valve ranged from 1084 to 1109°C during the filling of this canister. In addition, the pour stream temperatures as measured by an optical pyrometer during the pour was 1070°C. The expected DWPF glass stream temperature at a pour rate of 68 kg/hr is about 1040°C. Therefore this pour stream appears to have been thermally similar to a DWPF pour at this fill rate. PR2 data were similar with no indications of voiding or other problems.

The calculated pour rate for the low pour rate (worst case) canister was only 48 kg/hr, based on a final glass height of 244 cm. The calculated weight (1503 kg) was near the actual weight (1453 kg), again indicating that no significant voiding occurred. However, about half way into the pour there was an indication of a cone (stalagmite) forming on the glass pool surface. During a pour, the canister exterior oxidizes as the hot glass reaches the corresponding point on the canister interior. The oxide layer indicates the glass level inside the canister. About twelve hours into the pour the canister weight was 567 kg. However, the oxide layer on the canister exterior was only 66 cm high. This glass height implied that only 407 kg of glass had been poured. Additionally, the outline of a cone became apparent in the oxide layer on the canister exterior (Figure 4). The cone grew until its top was about 1m above the glass pool, then the glass began to spill over the cone and fill in the surrounding empty space. This is an ideal condition for the formation of voids, but the final weight versus glass height data showed that significant voiding did not occur.

Figure 4 –Oxide on low pour rate canister

The instrumented canister differed from the other canisters only in having instruments installed, therefore results were very similar to PR1 and PR2. The overall calculated weight was 1456 kg and the pour rate was 72 kg/hr. Comparison with the measured glass weight of 1446 kg shows that this canister was unlikely to have significant voids. The instrumented canister had 30 Type K thermocouples sheathed in closed-end 304L SS tubes and a camera that viewed the inside of the canister during glass pouring. The thermocouples were configured to provide a thermal profile of the pour, and measured the glass temperature at different heights along the canister centerline, 3" (76mm) from the canister centerline, and 10" (26 cm) from the canister centerline. Thermocouples were also welded to the puck cans, base plate, canister exterior and throat. The maximum observed can temperatures (900 °C) were well below that in which the stainless steel would be expected to fail, and glass cool down rates were similar to rates for canisters without CIC hardware. This is important because devitrification (crystallization) can occur if the glass cooling rate is too slow. The camera showed that the glass flowed from the centerline of the canister to the outside of the magazines. Sometimes the glass would flow around one magazine and then around the outside of adjacent magazines before returning back to the centerline of the canister at a different location. This observation indicated that glass voiding was not occurring in this canister, a fact backed up by the closeness of the measured and calculated glass weights. In summary, all data from the instrumented canister indicated that the Phase 2 test was thermally similar to a typical DWPF pour.

5. POST TEST ANALYSIS

Figure 5 – Bluegrass Bit, Inc. diamond wire saw cutting a canister

After the low pour rate and instrumented canisters cooled, Bluegrass Bit, Inc. used a diamond wire saw to section them at four heights (Figure 5). The sections were then studied for evidence of hardware deformation and glass voids. Following are some observations:

• There was good glass flow into the region between the cans and the magazines (Figure 6).

• Cans were tightly locked in place and could not be moved by hand

• There was no measurable plastic deformation of the CIC hardware.

• There was one small void (Figure 7) in the low pour rate canister at a height of 23" (58 cm). No other voids were observed.

Small voids like the one in the 23" section have been observed in DWPF canisters that did not contain CIC hardware. Therefore, this void is considered insignificant. The fact that only one small void was found in a worst case test with a low pour rate and high viscosity glass means that the CIC hardware has a negligible effect on the DWPF pouring process.

Figure 6 - Section of Low Pour Rate Canister at 5.75" (15cm) height shows glass completely surrounding the puck can and no voids.
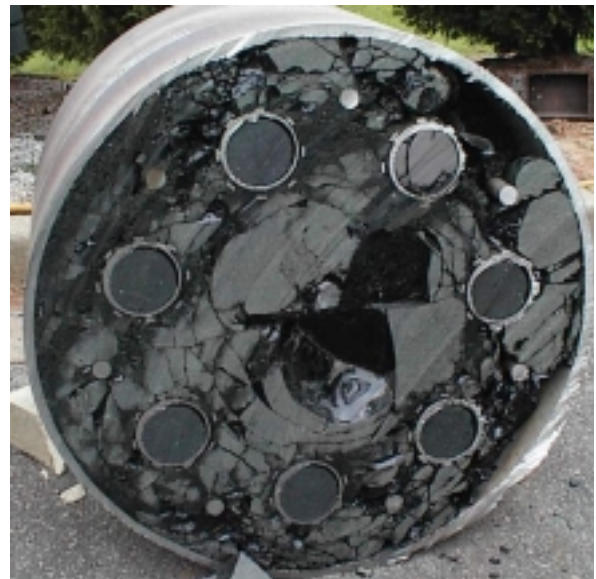

Figure 7 - Section of Low Pour Rate Canister at 23" (58 cm) height with small glass void

6. OPEN ITEMS

The hardware tested in Phase 2 is representative of a final design, yet a couple of open items remain that may require additional development, testing, and/or modeling, as discussed below.

Puck cans used in PIP facility operations will differ from cans tested in Phase 1 and 2. The PIP facility will use cold-worked stainless steel cans that are flowformed from a single piece of metal. After loading, the tops are TIG welded to the cans in an automated bagless transfer process. The cans used in Phase 1 and 2 are made from standard 300 series stainless steel pipe with a hand-welded top and bottom. While these differences are not expected to significantly impact the baseline hardware design, the performance of actual bagless transfer cans at glass temperature has not been tested. This type of testing is not possible until a prototype bagless transfer unit is developed for PIP.

The lateral latches used in the cold pour tests were dimensionally similar to actual latches, but they are not adequate for remote operation. Remote operation tests were conducted with hand-formed latches. A canister loading arm was designed and fabricated to work with an existing robot, but the robot was dismantled before testing finished. Additional development may change the lateral and vertical latching designs, though changes in the latch mechanism would most likely have no effect on pour dynamics.

7. CONCLUSION

The CIC can be expected to perform as required to fulfil the PIP mission. Additionally, the performance characteristics of the CIC system are similar to a normal (without CIC hardware) DWPF canister, so test results and conclusions valid for current DWPF canisters are reasonably valid for CIC equipped canisters. Predicted glass weights compare favorably with measured glass weights, indicating that voids are not a problem. This is reinforced by the pour video, which shows glass completely surrounding the puck cans. Post-test measurements of the hardware also suggest that the hardware will not experience measurable plastic deformation during pouring. In addition, temperature data from the instrumented canister indicate that the puck cans will not reach temperatures that could cause their rupture. Therefore, the CIC System was proven to be a viable option for the disposition of excess weapons usable plutonium that will not negatively effect glass quality.

REFERENCES

M. W. Stokes, G. L. Hovis, E. L. Hamilton, J. B. Fiscus and R. H. Jones, "Magazine, Rack and Canister: Designing the Plutonium Immobilization Program System," *Radwaste Magazine*, Vol. 6, No. 4, pp. 49-54, pub. American Nuclear Society, LaGrange Park, IL., 1999.

E. L. Hamilton, G. L. Hovis, M. W. Stokes, "Plutonium Immobilization Project – Cold Pour Phase 1 Test Results," *Proceedings of the Embedded Topical Meeting on DOE Spent Nuclear Fuel and Fissile Material Management*, pp. 35-38, ANS, LaGrange Park, IL., 2000.