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Development of a Pilot-Scale Facility for Melt-Dilute Treatment of Spent Nuclear Fuel

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DEVELOPMENT OF A PILOT-SCALE FACILITY FOR MELT-DILUTE TREATMENT OF SPENT NUCLEAR FUEL

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INTRODUCTION

The United States Department of Energy (DOE) has selected the Savannah River Site (SRS) as the location to consolidate and store Al-SNF, originating in the United States, from foreign research reactors (FRR) and from domestic research reactors (DRR) through the Environmental Impact Statement (EIS) process. These spent nuclear fuel (SNF) assemblies are either in service, stored at various reactor sites in water basins or in dry storage casks, or have been transferred to SRS and stored in water basins on site. A portion of this inventory contains highly enriched uranium (HEU).

The DOE through the SRS completed an evaluation and identified Melt-Dilute Treatment Technology (MD) as the preferred alternative in the Final Environmental Impact Statement for ultimate disposal of Al-SNF in the Monitored Geologic Repository.[1] The final EIS was issued in FY 2000. The melt-dilute process simply melts spent nuclear fuel assemblies to produce ingots that reduce criticality and proliferation issues as well as reduce the waste volume by up to 70%.

Based on these decisions, Savannah River Technology Center (SRTC) developed the melt-dilute process for treating spent fuel. Using laboratory concepts, SRTC designed and constructed a pilot-scale facility for processing radioactive fuel. Start-up testing of the facility confirmed cell operations and remote handling of fuel assemblies. In early 2002, the DOE decided to shut down the L-Area facility at SRS prior to melting any irradiated fuel. The modular facility is now in cold stand-by.

This paper discusses the design and testing of the pilot-scale facility.

DISCUSSION

Treatment of aluminum-base spent nuclear fuel by melting the assembly and diluting the alloy has been fully developed at the Savannah River Technology Center (SRTC).[2,3] The basic melt-dilute process involves melting the SNF in an induction furnace, diluting the enriched uranium alloy with depleted uranium to reduce the isotopic content to less than 20% and then mixing the alloy uniformly. Figure 1 shows the basic flow chart for the melt-dilute process.

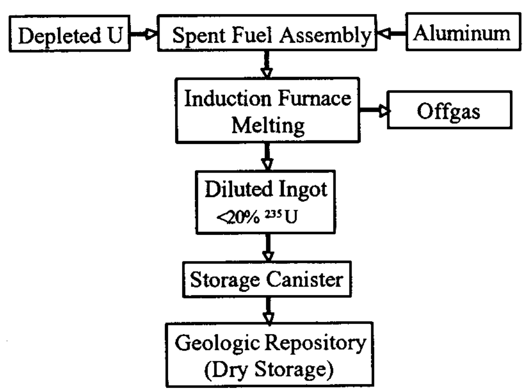

Figure 1. Process flow schematic for Melt-Dilute Process.

Dilution of the SNF alloy to reduce the ^{235}U content of HEU to low enriched uranium (LEU) levels offers the benefit of reducing criticality during storage and increasing proliferation resistance. The final product is an isotopically diluted SNF form that can be tailored to optimize the alloy composition by adding aluminum to the melt or even other alloying elements, i.e., gadolinium or hafnium as neutron absorbers to reduce criticality. The treated alloy is less attractive for reprocessing, which enhances its proliferation resistance.

Advantages of diluting the uranium content to below 20% ^{235}U and the alloy composition to the eutectic include: (1) lower process operating temperatures, (2) minimum gravity segregation in the casting, (3) less volatile offgas products and (4) lower associated costs. With the MD process, waste volume can be significantly reduced. The melt-dilute treatment process produces a waste form that could be processed, but with greater difficulty, later to reclaim the enriched uranium.

MELT-DILUTE PROCESS

The basic melt-dilute process is simple and versatile. Radioactive fuel assemblies are remotely loaded into an induction furnace and melted in air at about 850 ºC, which is approximately 200 ºC above the uranium-aluminum eutectic temperature or the aluminum melting point.

The SNF assemblies for MD treatment, the depleted uranium metal for isotopic dilution, and the aluminum for compositional control are all put into an aluminum basket when the fuel assembly is loaded. The basket is moved from the wet storage basin to the facility using an 8-ton cask. The basket is later remotely inserted into the furnace. Induction melting takes place in a graphite crucible containing a carbon steel liner that is used to melt the fuel and contain the solidified ingot. Induction stirring is also done to achieve homogeneity. All operations involving fuel assemblies, processed ingots or contamination products are controlled remotely by personnel outside of the heavily shielded processing cell.

Not all SNF will require dilution or aluminum additions because the final isotopic content is less than the proliferation limit and the melt composition is less than the eutectic composition. The process operating temperature is kept as low as possible because of the high vapor pressure and volatility of some radionuclide species, such as cesium and inert gases, in the SNF assemblies. [4]

To trap volatile radioactive gases an offgas system was installed. Studies have shown zeolite to be an effective getter for cesium.[5] Zeolite absorber beds and HEPA filters are installed as an integral part of the melt-dilute process. Up to about 70% waste reduction can be achieved for Material Test Reactor (MTR) type assemblies using zeolite adsorption beds.

MD FACILITY IN L-AREA AT SRS

Physical Layout

The pilot scale facility is located in L-Area at SRS in a DOE Hazard Category 2 structure for handling and processing radioactive materials, shown in Figure 2. Outside the facility is the control room where operators run and observed process operations while the furnace and associated equipment are located inside the hardened structure. The furnace is located inside a stainless steel box, which acts as secondary containment for radioactive releases to the room.

Figure 2. L-Area Pilot-Scale Melt-Dilute Facility

The floor plan for the facility is shown in Figure 3. Shown on the figure are the uninterruptable power supply, the crane aisle access corridor, the trailer well, furnace and associated equipment and the control room. The induction furnace is located behind a shield wall to protect operators from radiation during entry into the trailer well to unload casks.

Process Room

The SNF is brought to the facility in an 8-ton cask on a flatbed trailer. The roll-up door is opened and the trailer is backed into the trailer well where the cask is removed. After removing the cask lid bolts, the trailer is removed and the door closed and locked. Further operations are done remotely by operators using the crane, specialized tooling and computer controls. The cask is moved to the unloading station inside the cell, the lid is removed and the fuel basket containing the spent fuel assembly is removed. The fuel basket remote handling tool

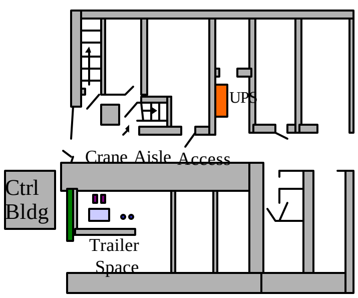

Figure 3. Layout of L-Area Pilot-Scale Melt-Dilute Facility.

is placed on guide pins located on top of a datum plate that is attached to the furnace. The fuel basket is lowered into the graphite crucible containing the carbon steel liner. The unloading tool is then returned to the tool stand (Figure 4).

Figure 4. Remote Handling Tool is returned to the Tool Stand.

Next the equipment plate containing two melt samplers, the primary zeolite bed and the crucible camera is lowered onto the top of the furnace crucible (Figure 5). The guide pins on the datum plate help guide the equipment plate to align the zeolite bed and crucible. The equipment plate engages a robot end-of-arm tool changer on the datum plate to connect pneumatic and electrical lines for operation of equipment on the equipment plate.

Figure 5. Lowering the Equipment Plate onto the Furnace using the Overhead Crane.

The stainless steel containment box lid is put onto the enclosure base and clamped in place using pneumatic clamps.

Control Room

The melt-dilute facility is operated from the control room. All operations are observed on video screens located on the console. A custom computer application reads and graphically displays system status and parameters on the computer monitor located in the center of the control console. All parameters are logged for future analysis. The computer application also provides graphical controls and computer guided sequences for the remote loading and unloading operations. A photograph of the operating console is shown in Figure 6.

The operator manually controls the induction furnace start-up and power levels, the airflow into the furnace containment box and the flow through the zeolite bed using hand operated remote controls. The pressure drop across the containment boundary is monitored to maintain a negative pressure so all airflow is from the room into the containment box. Dilution air from inside the box is used to cool hot offgas so the exit gas temperature is less than 50 ºC at the HEPA filters.

The ingot remote-handling tool is similar to the fuel-handling tool and is used to remove the solidified ingot and place it into a cask after the completion of the MD cycle. The crucible remote-handling tool is used to remove and replace the crucible as needed for maintenance.

All routine furnace operations are done remotely to protect personnel from contamination and radiation. A secondary shield wall shown next to the furnace in Figure 3 provides protection to personnel entering the truck well. All radiological sources (i.e. fuel, ingots or melt samples) and all contamination control objects (i.e. crucibles) can be remotely removed and placed in casks for system maintenance.

Figure 6. Control Room for Melt-Dilute Pilot-Scale Process in L-Area.

Two samples from the molten alloy are taken remotely during the melting operation to confirm the alloy composition. The samples are transferred to small-sample shipping casks for instrumental analysis at the analytical laboratory. Results are used to address material accountability issues and dilution requirements. Ingots can be remelted if found to be outside alloy specifications.

START-UP TESTING

The facility was operational in September 2001 and start-up testing began using aluminum assemblies. Several successful tests were made where data on furnace operations, the ventilation system, the cooling water system, and the uninterruptible power system (UPS) was obtained. Furnace operations and all remote tooling functioned per design.

The 125 KW induction power supply was more than ample for melting the assembly and heating the melt to 850 ºC. Operating parameters used in start-up testing are shown in Table 1.

Table 1
Start-up test Operating Parameters

Furnace Power, kw	Temperature, C Crucible	HEPA	Pressure Differential, in H2O HEPA	Box/TS*	Air Flow, cfm Crucible	Dilution
5	360	19	-2,8	-8.7	0.23	7.8
10	850	24	-2.5	-9.6	0.21	8.6

* Pressure differential between MD room and containment box.

At only 10 KW the molten alloy was heated to 850 ºC. Air was continually drawn through the crucible at a rate of about 0.2 cfm while dilution air from the box was approximately 8 cfm. The cooler dilution air lowered the offgas temperature at the HEPA inlet to less than the 50 ºC requirement. The pressure differential across the HEPA was monitored to ascertain flow through the filter, and a negative pressure differential of about 9 inches of water was maintained on the MD box to ensure airflow into the primary containment and through the offgas train.

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