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DEVELOPMENT OF MELT DILUTE TECHNOLOGY FOR DISPOSITION OF ALUMINUM BASED SPENT NUCLEAR FUEL

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ABSTRACT

The US Department of Energy (DOE) has for many years had a program for receipt and disposition of spent nuclear fuels of US origin from research reactors around the world. The research reactor spent nuclear fuel that consists of aluminum alloy composition has historically been returned to the Savannah River Site (SRS) and dispositioned via chemical reprocessing. In 1995, the DOE evaluated a number of alternatives to chemical reprocessing. In 2000, the DOE selected the melt-dilute alternative as the primary disposition path and direct disposal as the backup path. The melt-dilute technology has been developed from lab-scale demonstration up through the construction of a pilot-scale facility. The pilot-scale L-Area Experimental Facility (LEF) has been constructed and is ready for operation. The LEF will be used primarily, to confirm laboratory research on zeolite media for off-gas trapping and remote operability. Favorable results from the LEF are expected to lead to final design of the production melt-dilute facility identified as the Treatment and Storage Facility (TSF). This paper will describe the melt-dilute process and provide a status of the program development.

INTRODUCTION

Since the early 1960's the United States Department of Energy (DOE) has received spent nuclear fuel for disposition by processing at the Savannah River Site (SRS). The program stopped in the late 1980's. When it was restarted in 1996, the DOE also decided to pursue alternatives to processing the fuel. Research and development was begun to develop technology for two strong alternatives. One alternative was direct disposal of the fuel in an underground repository. The other involved a melt treatment for volume reduction and U235 dilution followed by disposal in an underground repository. By 2000, the DOE decided to pursue the melt and dilute technology as a primary disposition path and direct disposal as a backup. This paper will describe the melt dilute process as it has been developed at the pilot scale. This paper will also discuss some of the challenges remaining.

BACKGROUND

Historically aluminum based spent nuclear fuel has been chemically reprocessed at the SRS to separate fissile species. This process results in generation of aqueous waste streams. In the mid-1990's the DOE decided to pursue an alternative to chemical reprocessing. Today, only fuels designated as 'at risk' are being reprocessed at SRS. All other aluminum based fuel such as the research reactor spent nuclear fuel are being stored in a pool until a final disposition path is implemented.

Direct disposal of the SNF was developed as a primary path for several years before being declared the backup path. Direct disposal entails placing the SNF in a canister, drying the canister, sealing it and ultimately transporting it the underground repository. Major issues include how dry the fuel needs to be before storage, characterization of the fuel, addition of any neutron poisons required for repository disposal and degradation considering reconfiguration processes.

The melt dilute technology has also been developed. It was initially developed as an alternative to direct disposal. Many questions were resolved during the early development, and by 2000 the technology was sufficiently developed to declare this the primary disposition technology for aluminum based fuels.

MELT-DILUTE PROCESS

The melt-dilute process is conceptually simple, and flexible in the treatment process to produce a desired waste form for disposal. An intact fuel element is placed in a furnace and melted. Depleted uranium is added to dilute the uranium-235 enrichment to a desired level. In the process being developed at SRS, the enrichment is being targeted to below 20% to eliminate proliferation concerns during the storage and transportation of the waste forms prior to ultimate disposal. Aluminum is also added to the melt in order to keep the mixture near the eutectic (13.8 wt% uranium – aluminum) for the uranium/aluminum alloy and consequently near it's lowest melting point (646C). This minimizes release of volatile radionuclides from the spent fuel.

The melting and casting processes for production of aluminum fuel materials are well established at the site. The melt-dilute process for spent fuel necessitates contamination control and the need to work remotely. The L-Area Experimental Facility (LEF) furnace is an induction furnace that eliminates the need to have a mechanical stirrer in the operation. All stirring is accomplished inductively.

All fuel movements are done remotely or with the fuel in a shielded container such as a cask. For the demonstration facility, an existing crane is used to move the fuel. The fuel is picked up from a cask using a specially designed fuel handling tool. The tool is designed to operate when it is placed on a special power port. The power port provides electricity and/or air to operate the tool. As a safety feature, when the tool is not on a power port, none of its functions will operate. Power ports are provided on tool stands and on a datum plate above the furnace. The cask with fuel to be melted is placed under a tool stand. The tool is placed on the stand and used to pick up the fuel. The tool is a rectangular shaped box with an opening in one end. A gripper that travels the length of the box is used to draw the fuel up into the box through the opening. When the tool is removed from the tool stand a cover plate will swing under the opening. The box and cover plate are designed to contain any loose contamination on the fuel. The cover plate is also capable of holding the fuel if it is dropped. The tool has a camera inside that can be used to monitor the fuel.

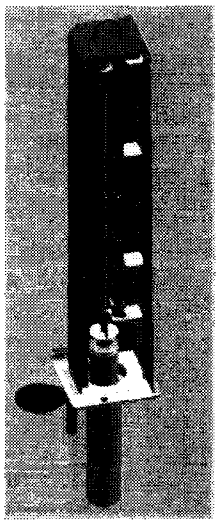

Fig. 1 Fuel Handling Tool

The fuel handling tool is moved from the tool stand to the induction furnace. A similar power port is present over the furnace, which allows the tool to be operated to lower the fuel into the furnace. The furnace contains a graphite crucible, a carbon steel crucible liner, and a quartz liner outside of the crucible. After fuel loading, an equipment plate is loaded on top of the crucible. The equipment plate contains the primary zeolite absorber bed, a camera, and two samplers. The samplers allow samples of the molten metal to be obtained. After the system is closed and ventilation initiated, power is applied to the furnace to heat the fuel. For the demonstration facility the temperature of the fuel will be held at about 350C for one hour to drive off all residual free water. For the production scale facility the fuel will be dried before being charged to the furnace. The temperature will be increased to 850C after the one hour hold-point to ensure that the alloy melt is fully liquid. The melt will be inductively stirred, two samples retrieved, and the furnace shutdown. The molten metal will be allowed to cool in the crucible. Once cooled, the system can be opened remotely, the metal ingot removed and stored in a shielded cask and the system prepared for another melt.

The metal ingot is removed with the carbon steel crucible liner. A separate tool similar to the fuel handling tool but with a gripper designed to pick up the crucible liner is used to move the ingot to the cask. This tool is also equipped with a camera and bottom cover plate capable of holding a dropped ingot.

A third, similar tool is used to move a crucible if that becomes necessary. Because of the crucible liner, the crucible is designed to be used for all the demonstration facility melts.

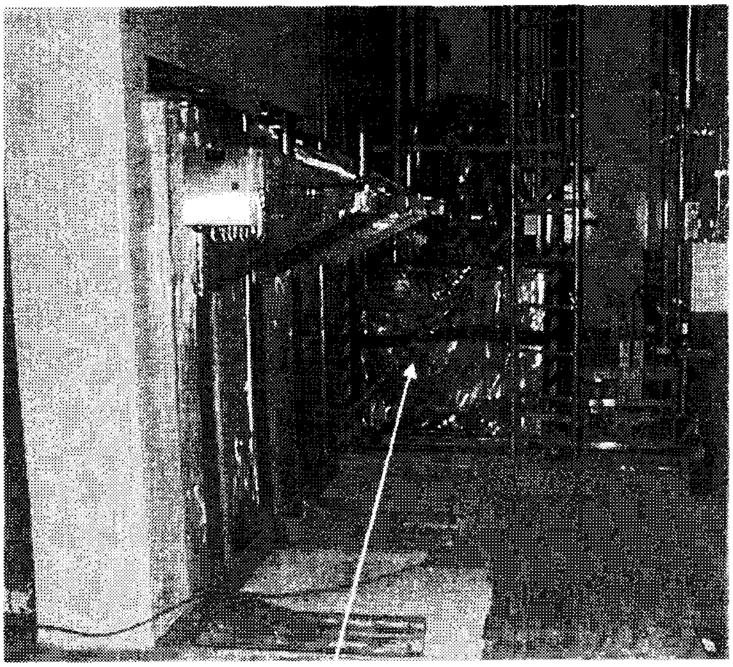

Fig. 2. Furnace in trailer space

Fig. 3. Furnace control

The last major component of the melt and dilute demonstration facility is the control building. The control building is a fifteen by twenty-foot prefabricated building that houses the furnace controls, alarm panel and data acquisition system. The furnace controls are standard induction furnace controls with the addition of two interlocks to shutdown the furnace on high furnace temperature and on the presence of moisture in the furnace refractory material surrounding the crucible. The alarm panel is also a standard alarm panel design that indicates which sensor is in alarm condition. The data acquisition system is uniquely designed for this system. The data acquisition system records all process system measurements for the duration of the melt. Any of the twelve cameras used in the process can be monitored and recorded at the data acquisition station. Finally, control of the fuel handling tool, ingot handling tool, and crucible handling tool functions is at the data acquisition system.

Appropriate administrative and engineering controls have been included in the L-Area Experimental Facility (LEF) design to protect against postulated adverse events. Engineered controls include multiple barriers between water and molten metal, redundant zeolite absorber beds and several interlocks to shutdown the furnace upon loss of ventilation control, high temperature, and loss of cooling water. Administrative controls include controlled access, limit on number of fuel elements allowed in furnace area, limit on total number of melts allowed and limits on amount of combustible material allowed near the furnace.

Concurrent with developing a process for disposition of research reactor spent nuclear fuel, the waste form must be shown to be able to meet disposal system requirements or "qualified" for disposal in the repository. Qualification of the waste form is accomplished by evaluating the waste form on repository performance during its disposal lifetime. Studies have been in progress to determine the waste form thermal loads and degradation modes and rates. The waste form has also been evaluated for criticality potential under various degradation configurations. The results show that either gadolinium or hafnium up to 3 wt% will be included in the melt to ensure that the melt-dilute product remains subcritical under all postulated conditions. It has also been shown that the gadolinium and hafnium will remain with the uranium during decomposition and will not be preferentially separated.

TECHNOLOGY DEVELOPMENT

The construction and installation of the LEF for demonstrating the melt-dilute treatment on a single spent nuclear fuel assembly scale is complete. Startup checks have been completed including integrated system tests using aluminum mock fuel. The overall system and operating procedures have been reviewed for readiness. The completion of an operational readiness review will allow operations with spent fuel to begin. The program has been placed on hold awaiting additional funding.

The major issue for the melt-dilute treatment technology development is the ability to continue funding the development. While the disposition path appears favorable, it requires a significant up-front expenditure to construct the TSF. Today's funding climate does not support this expenditure. The LEF demonstration has been suspended to make funds available for other DOE priorities. It is now likely that a disposition alternative with a more level funding profile will be executed.

The objectives of the pilot-scale experiments remain to be achieved. It should be shown on this scale that contamination can be controlled and that volatile radionuclides can be captured. Bench scale work to date continues to prove that the technology is viable. The melt-dilute treatment process will be demonstrated at a scaled up level before construction of a production scale facility to reduce the risks.

CONCLUSIONS

The melt-dilute technology is a viable technology to treat highly-enriched spent nuclear fuels for ultimate disposition. It provides for spent SNF to be consolidated with flexibility and control of the composition of the waste form. In contrast, direct disposal of the fuel requires that analysis consider many types of fuel. Converting the fuel to a melt dilute waste form allows the enrichment and uranium composition to be adjusted to a specified level. Use of a melt dilute waste form also allows easier recovery of samples for confirmation of composition.