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Mobile Melt-Dilute Treatment for Russian Spent Nuclear Fuel

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MOBILE MELT-DILUTE TREATMENT FOR RUSSIAN SPENT NUCLEAR FUEL

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ABSTRACT

Treatment of spent Russian fuel using a Melt-Dilute (MD) process is proposed to consolidate fuel assemblies into a form that is proliferation resistant and provides criticality safety under storage and disposal configurations. Russian fuel elements contain a variety of fuel meat and cladding materials. The Melt-Dilute treatment process was initially developed for aluminum-based fuels so additional development is needed for several cladding and fuel meat combinations in the Russian fuel inventory (e.g. zirconium-clad, uranium-zirconium alloy fuel).

A Mobile Melt-Dilute facility (MMD) is being proposed for treatment of spent fuels at reactor site storage locations in Russia; thereby, avoiding the costs of building separate treatment facilities at each site and avoiding shipment of enriched fuel assemblies over the road. The MMD facility concept is based on laboratory tests conducted at the Savannah River Technology Center (SRTC), and modular pilot-scale facilities constructed at the Savannah River Site for treatment of U.S. spent fuel. SRTC laboratory tests have shown the feasibility of operating a Melt-Dilute treatment process with either a closed system or a filtered off-gas system.

INTRODUCTION

The U.S. Department of Energy is collaborating with Russia to reduce proliferation challenges posed by weapons-usable nuclear material. Activities between the two countries reflect their concern over the risk of theft and diversion of these materials. Joint research and development efforts between the countries are directed at enhancing proliferation resistance by focusing on the development of disposal options that maximize proliferation barriers.

Melt-Dilute technology for treatment of aluminum spent nuclear fuel has been developed by the Westinghouse Savannah River Company, Savannah River Technology Center. A pilot-scale facility has been constructed and start-up tests completed [1]. The basic process simply melts the fuel assembly, adds depleted uranium to decrease the isotopic content and, if needed, adds aluminum to adjust the melt composition to the uranium-aluminum eutectic.

A mobile, closed system approach is being proposed for treatment of Russian spent fuel assemblies using the Melt-Dilute concept. The closed system approach to melting fuel assemblies eliminates the need for the offgas system and simplifies the design. The mobile process will require approximately two trailers that can be easily moved over the road to various locations to treat the spent fuel at the site.

The proposed MMD process is presented in this paper.

MELT-DILUTE PROCESS

The MD treatment process is a batch process that involves melting several spent fuel assemblies and adding depleted uranium to dilute the uranium isotopic content to less than 20% U235, the proliferation limit. Furthermore, because the isotopic content of diluted fuel is low, criticality concerns are reduced for storage or geologic disposal. For aluminum-based fuels, aluminum is added, as necessary, to keep the melt composition near 13.8 wt% uranium in aluminum, the eutectic composition. This is done to minimize the process temperature because the eutectic composition provides the lowest liquidus temperature in the uranium-aluminum alloy system. Low operating temperatures reduce fission product volatility as well as enhance furnace and crucible life. Once solidified, the ingot becomes a wasteform that can be put into a canister for dry storage or for ultimate disposal in a geologic repository.

The general process flowsheet for the Melt-Dilute treatment technology developed at SRTC is shown in Figure 1. The treatment steps depict the flow of spent nuclear fuels through a full-scale production facility. A sub-set of these treatment steps—namely, the Melt-Dilute Treatment and Post-Treatment Characterization steps could also be performed using a modular, transportable melt-dilute system with an offgas capability design to allow full consolidation of the ingots into a canister or without an offgas system to melt within a canister. Additional volume to contain the pressure from the volatile species is required in the closed system.

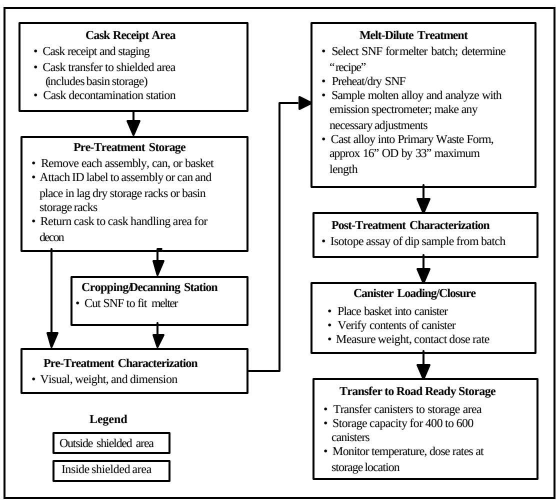


Figure 1. Process Steps for Melt-Dilute Treatment using either a Fixed or Mobile, Modular facility

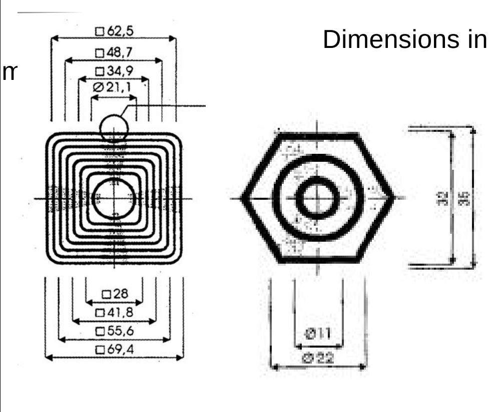
RUSSIAN SPENT FUEL INVENTORY

Russia's research and tests reactor spent nuclear fuel inventory contains mostly aluminum clad fuel assemblies mixed with enriched uranium fuel forms. The vast majority of fuel element meats contain uranium-aluminum alloy and UO_2-aluminum dispersions. There are some UO_2 mixed with magnesium as well as small quantities of U_3O_8-aluminum, uranium metal and uranium-chromium-nickel alloy. The uranium-chrominum-nickel alloy rods are clad with stainless steel. There are also some uranium-zirconium fuels clad with zirconium. The Russian fuel elements were fabricated using 10, 36, or 80-90% enriched uranium. The average burnup was about 30-50%.

There are about 15,000 to 20,000 research assemblies identified that contain approximately 1000 metric tons of enriched uranium.

There are many fuel element types but the IRT and WWR are typical Russian reactor fuel assemblies.[2] The IRT assembly is similar in size to the Material Test Reactor (MTR) fuel assembly developed in the U.S. but the IRT has a square geometrical cross section, as shown in Figure 2. The WWR elements resemble Triga fuel rods with a hexagonal cross section, also shown in Figure 2. The fuel meat sections are each about 600 mm long. Typical Russian assembly cross sections are shown in Figure 2.

Dimensions in mm



IRT WWR

Figure 2. Typical Russian Fuel Assemblies.

MOBILE MELT-DILUTE CONCEPT

A Mobile Melt-Dilute facility (MMD) using a closed system approach is proposed for treatment of spent fuel at storage locations in Russia. A mobile system concept avoids the costs of building separate treatment facilities at each site and avoids shipment of enriched fuel assemblies over the road. The MMD facility concept is based on SRTC tests, and modular pilot-scale facilities designed and constructed at SRS for treatment of U.S. spent fuel. Laboratory tests at SRTC have shown the feasibility of operating both a closed and a filtered off-gas system. The closed system approach encapsulates the fuel assemblies in a container, melts the fuel inside the container in a furnace and finally stores the container at the treatment site or a central storage location site.

SRTC LABORATORY TEST OF CLOSED SYSTEM

Laboratory tests for a closed system approach to melting spent fuel were performed at SRTC in 1997. The test apparatus, shown in Figure 3, consisted of the 8 inch long stainless steel tube with a bolted top containing cooling fins.

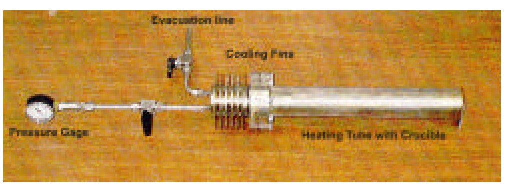


Figure 3. Closed System Test Apparatus

The assembled unit was loaded with simulated fuel and sealed after evacuation to about 10^{-3} torr. Air was removed to eliminate its contribution to any increase in pressure during heating. The pressure gage was used to measure the increase in pressure due to volatile elements while heating. Cesium carbonate as well as other fission product compounds was added to the simulated fuel using powder metallurgy procedures.

Cesium is the most volatile fission product in irradiated fuel. Vapor pressure data up to 686 ºC, the boiling point of Cesium., is expressed by equation. (1)

$$\text{Log } p = -2.9708 - 3.63\text{x}10^{3}/t + 4.06\text{Log } t - 3.66\text{x}10^{-3}t + 7.96\text{x}10^{-7}t^{2} \qquad (1)$$

In the equation, p is the vapor pressure in atmospheres, t is the temperature in K and all logarithms are to the base 10 [3]. At the boiling point, the vapor pressure is calculated to be several atmospheres indicating practically all of the cesium evaporates. However, tests have shown that less than 20% cesium evaporates with the remainder trapped in the melt and oxide skull [4].

The stainless steel tube containing a crucible with simulated fuel was heated in a resistance furnace. After 1 hour at 850 ºC, the test chamber was removed from the furnace, cooled and opened. A white powder was observed near the top surface of the chamber where cesium and other simulated volatile fission products had condensed. The white powder, most likely cesium metal, oxidized upon exposure to air [5]. If this approach is used for spent fuel storage, the container would not be opened, so the ingot along with all volatile fission products would remain inside, thus eliminating the need for the filtered off-gas system. Upon cooling the gas pressure inside returned to approximately its original level.

MOBILE MELT-DILUTE FURNACE

It is feasible to build a furnace system that would utilize the closed system approach. The melting container made from carbon steel would have to be large enough to accommodate the as-received spent fuel assembly. After melting, the ingot would occupy about 30% of the spent fuel assembly volume so a drawback is that an amount of space inside the storage or disposal container would not be full of the ingot.

A schematic showing a possible method for melting using the closed system method is shown in Figure 4. Induction heating is selected because with this technique both melting and stirring the melt for ready homogenization. On the other hand, the induction coils may require water cooling, so for simplicity and safety, resistance heating may be considered using convection stirring.

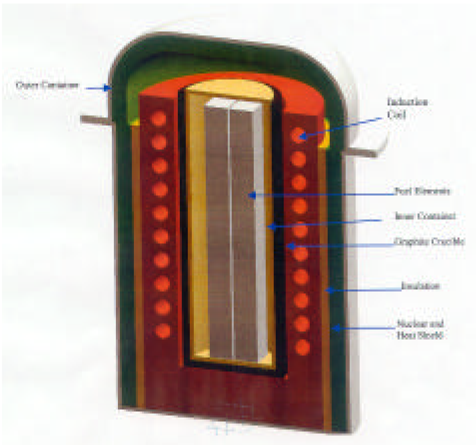


Figure 4. Proposed Furnace Design for Closed System Melting of Spent Reactor Fuel Assemblies.

The furnace will be enclosed with an outer container or dome, similar to a reactor dome, to contain any volatile gases in the unlikely event the closed melting container leaks during melting. The dome may be designed to provide sufficient shielding so additional shielding may not be needed around the furnace or area.

Ideally, only one element would be melted at a time, but the system could be designed to melt 4-6 elements per batch. With one element the recipe for dilution and alloy composition control as well as uranium accountability might be easier.

Loading and unloading of the furnace with spent fuel would be done remotely. Once the fuel assembly is brought to the MMD facility in a cask, it would be unloaded using a forklift or crane and placed onto a remote system to move it to the furnace. It is expected that the cask would provide radiological shielding while furnace loading, unloading, and transporting the spent fuel.

The furnace and control system would by installed in separate transportable modules. The modules would be easily loaded onto trailers for transportation to various sites and assembled quickly at the site.

The concept for transportation is shown in Figure 5.

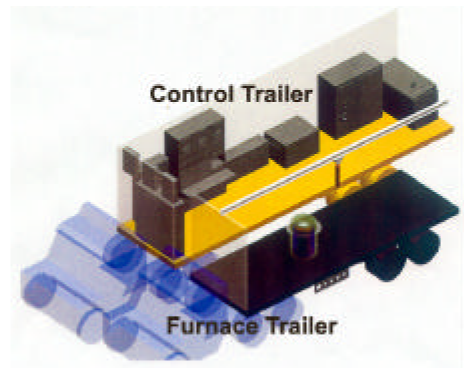


Figure 5. Trailers containing Control and Furnace Modules.

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