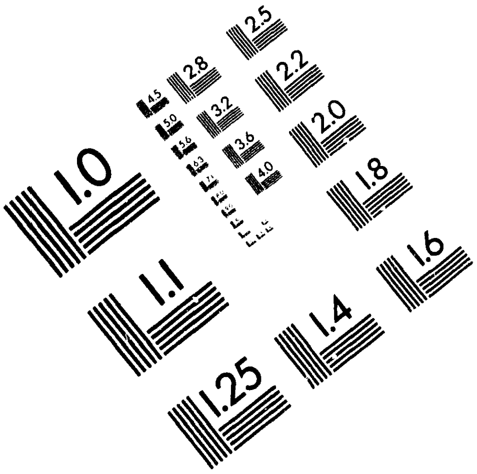

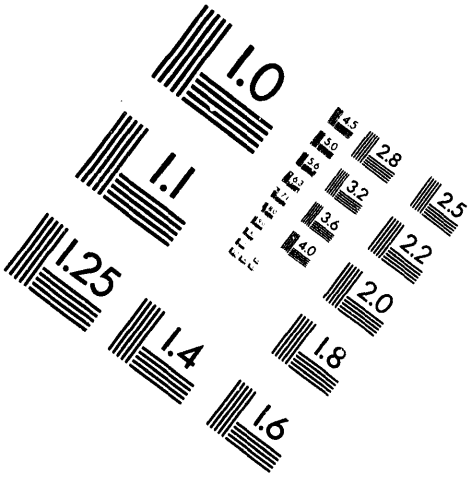

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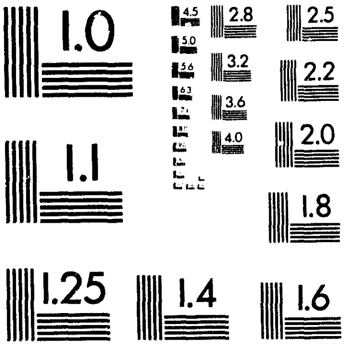

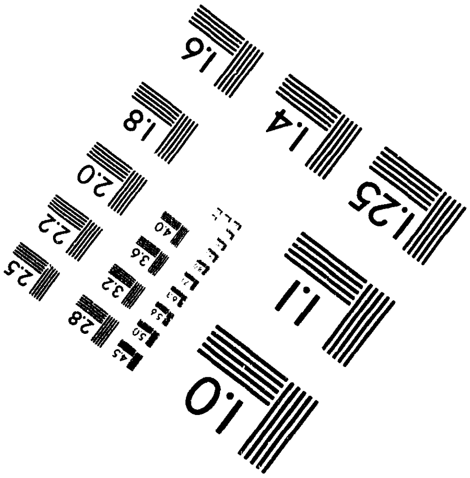

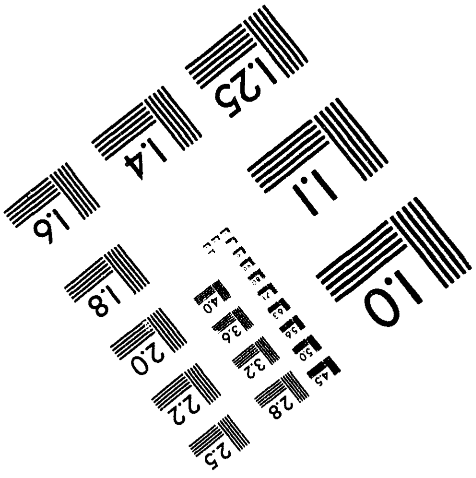

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SAFEGUARDS OPERATIONS IN THE INTEGRAL FAST REACTOR FUEL CYCLE

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ABSTRACT

Argonne National Laboratory* is currently demonstrating the fuel cycle for the Integral Fast Reactor (IFR), an advanced reactor concept that takes advantage of the properties of metallic fuel and liquid metal cooling to offer significant improvements in reactor safety, operation, fuel-cycle economics, environmental protection, and safeguards.[1] The IFR fuel cycle employs a pyrometallurgical process using molten salts and liquid metals to recover actinides from spent fuel. The safeguards aspects of the fuel cycle demonstration must be approved by the United States Department of Energy, but a further goal of the program is to develop a safeguards system that could gain acceptance from the Nuclear Regulatory Commission and International Atomic Energy Agency. This fuel cycle is described with emphasis on aspects that differ from aqueous reprocessing and on its improved safeguardability due to decreased attractiveness and diversion potential of all process streams, including the fuel product.

INTRODUCTION

The IFR concept makes use of a metallic uranium-plutonium-zirconium fuel and a recycling process where uranium, plutonium, and the minor actinides (neptunium, americium, curium, etc.) from spent fuel will be recovered and used to make new fuel. In this system all the actinides will be burned completely in the reactor. Many reactor-specific aspects of this concept have been demonstrated using EBR-II at Argonne-West. As part of the IFR fuel cycle demonstration, the spent fuel from EBR-II will be processed in the Fuel Cycle Facility (FCF), which is a hot-cell complex adjacent to the reactor.

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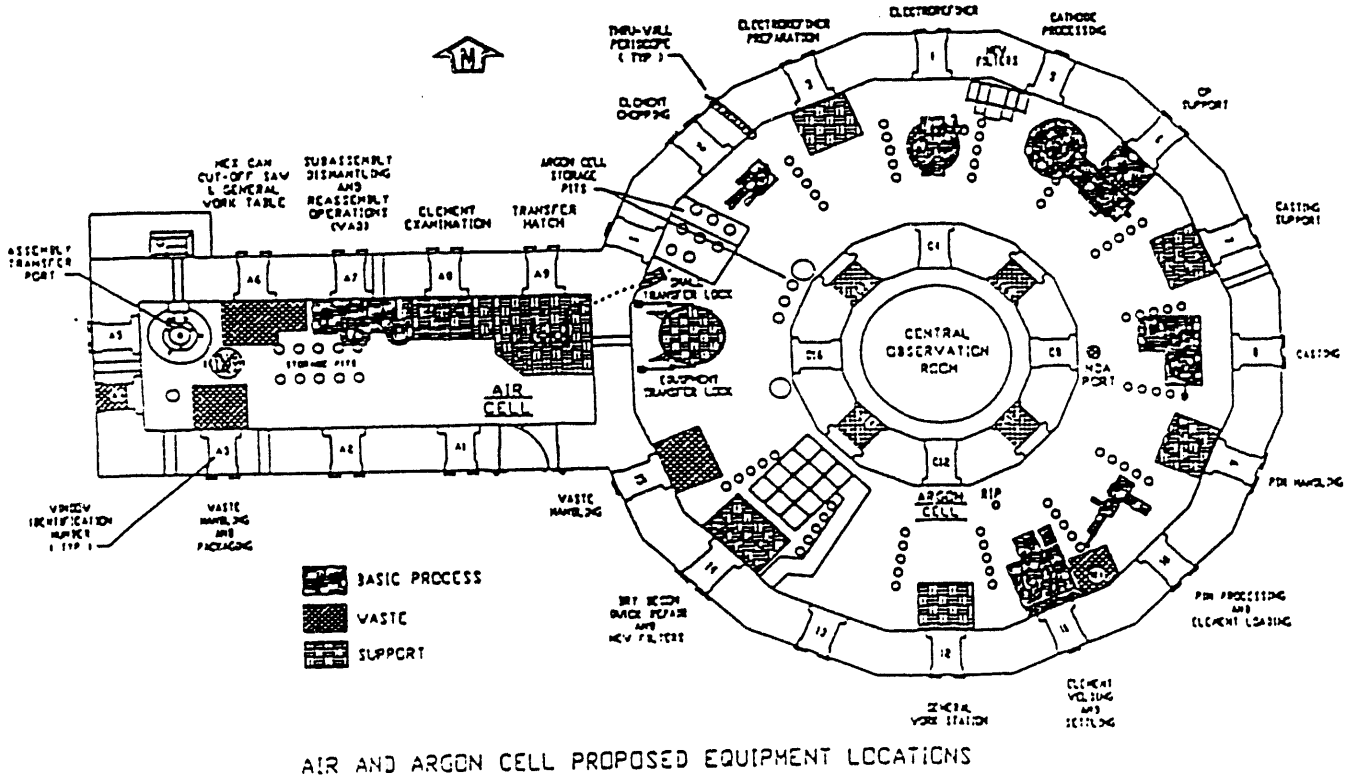

Figure 1. Schematic of the Hot Cells in the Fuel Cycle Facility (FCF)

This fuel cycle is based on a pyrochemical process employing molten salts and liquid metals in an electrorefining operation. The molten salt medium in the electrorefiner is a mixture of LiCl-KCl eutectic and actinide chlorides. Below the salt phase is a pool of molten cadmium which can serve as an anode, cathode, or just a collector for nonreactive metals. The electrorefiner in FCF has a diameter of 101 cm (40 inches). During refining operations, it will have approximately a 31-cm (14 inches) salt depth and a 10-cm (4 inches) cadmium depth.

With this system, uranium and the TRU elements can be electrochemically separated from the fission products. Uranium that is free of TRU elements can be collected on steel mandrel cathodes (solid cathodes). In a commercial IFR system, this uranium will be depleted. In EBR-II, enriched uranium is used, and in the fuel cycle it will be safeguarded accordingly.

Cathodes that consist of a ceramic crucible filled with approximately 30 kg of liquid cadmium (liquid cathodes) can be used to collect uranium and the TRU elements simultaneously. A portion of the lanthanide fission products will also be collected in the liquid cathodes. The quantity collected will not be enough to cause fuel performance problems, but it will be enough to make the material unattractive for diversion.

At Argonne-West, the spent fuel from EBR-II will be brought into FCF and washed of adhering sodium coolant. FCF has two hot cells, a rectangular-shaped air-filled cell and an annular-shaped argon-filled cell. Figure 1 is a schematic of the FCF hot cells. The cleaned subassemblies will first be brought into the air cell where they will be dismantled into individual elements. The elements will then be transferred into the connecting argon cell.

In the argon cell the elements will be chopped into quarter inch segments and loaded into the electrorefiner in steel baskets (anode baskets). The spent fuel can be electrotransported out of the anode baskets and an equivalent amount of material deposited either in the cadmium pool (anodic dissolution) or directly to a solid or liquid cathode (direct transport). Material deposited in the cadmium pool can later be electrotransported to a solid or liquid cathode.

These electrorefining operations have been demonstrated on the laboratory and engineering scales in the Chemical Technology Division at Argonne in Illinois.[2] Initial demonstrations did not include fission products or large-scale plutonium operations.

Cathode products from the electrorefining operations will be processed to distill any adhering salt or cadmium and consolidate the remaining actinides. These operations are performed in a separate piece of equipment, the cathode processor. The recovered ingots will be used to produce new fuel for EBR-II.

The fuel elements will be fabricated in the argon cell. They will be assembled into subassemblies in the air cell and will be transferred in a shielded cask back to the reactor. Figure 2 depicts the flowsheet of the fuel cycle for the FCF demonstration.

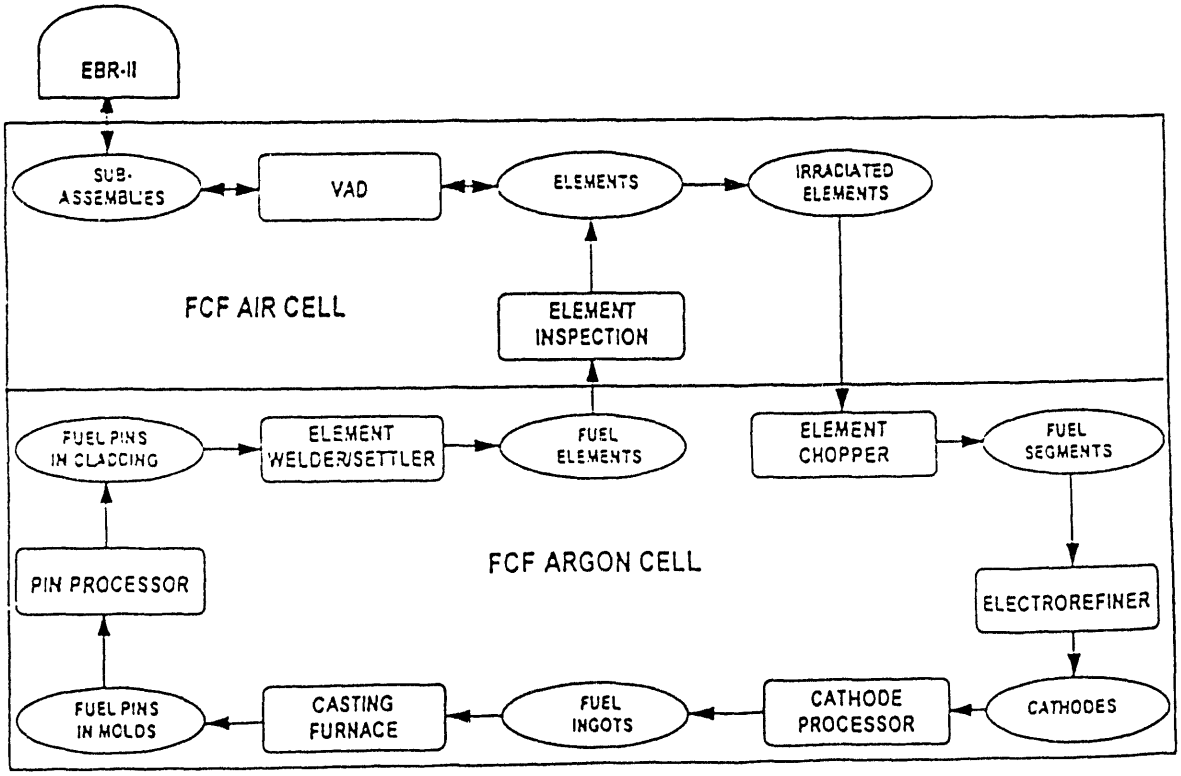

Figure 2. Flowsheet of the Fuel Cycle Operations in FCF

SAMPLING

The safeguards aspects of the fuel cycle demonstration must be approved by the United States Department of Energy. As part of this approval process, the FCF Measurement and Control Plan was prepared to describe the specific controls placed on the measurements that provide mass values of nuclear materials used for material control and accountability (MCA) purposes in FCF.

The accountability of nuclear materials in the FCF includes a variety of measurements. Near real-time control and acceptability is accomplished by a combination of neutronics calculations, process models, physical measurements, and a computer-based mass tracking (MTG) system. The MTG system tracks the location and masses, by element and isotope, of nuclear material-containing items in near real time. Items may be in storage containers, processing equipment, fuel elements, and fuel subassemblies. The masses are determined using in-cell balances, and isotopics and elemental compositions are determined by neutronics calculations, by previous measurements, or by computations based on process models. The values determined by process models are also verified by measurement.

As part of FCF operations, there will be two types of nuclear material input, irradiated fuel subassemblies and unirradiated feedstock. The determination for accountability of the irradiated fuel will be by neutronics calculations based on the initial masses charged to the reactor and in-reactor radiation history. A series of measurements has already been performed to validate the burnup calculation method.[3] Still, samples will be taken from the subassemblies at the element chopper to further validate the code. For the burnup analysis, isotope dilution mass spectrometry (IDMS) will be used to determine the following: total uranium in solution, uranium isotope ratio, total plutonium in solution, plutonium isotope ratio, lanthanum-139 in solution, and neodymium-148 in solution. The isotopes of lanthanum and neodymium are used as burnup indicators. IDMS will also be used to characterize the feedstock materials with respect to their uranium and plutonium contents.

For operations in the electrorefiner, a computer code, PYRO, has been developed based on chemical thermodynamics to model the transport of material through the system.[4] Initial validation of the model has been performed.[5] The data will be further validated by taking salt and cadmium samples after each run, as well as samples from the output materials, which will include the cladding hulls and the recovered cathode products.

Samples from the recovered cathode products will be taken after the actinide products are consolidated in the cathode processor. These samples will be analyzed by IDMS. The cladding hulls from the electrorefiner will initially be characterized by taking a random sample of hulls from the dissolution baskets. These hulls will be analyzed by IDMS. Additionally, a nondestructive assay (NDA) method based on neutron activation and delayed neutron detection is being developed to characterize this stream.

The consolidated ingots from the cathode processor will be used for the production of fuel pins in the casting furnace. At least one pin per batch of cast fuel will be sacrificed for IDMS chemical analysis.

DIVERSION RESISTANCE

This fuel cycle has a number of innate properties that make it very diversion resistant. The first involves the attractiveness of the material for diversion. Pure plutonium metal is never produced as a part of this fuel cycle.

When plutonium is recovered in the liquid cathodes, it is always in the presence of the other transuranics, uranium, and the lanthanide fission products. A Department of Energy report has concluded that this material cannot be used for weapons production without further significant processing.[6]

Because of the presence of the lanthanide fission products and the transuranics, this material is always extremely radioactive. All of the materials in the cells produce radiation fields that well exceed the self-protecting limit of 100 rem/hr of gamma at one meter. The estimated dose associated with the uranium-plutonium mixtures in the standard liquid cathode is 450 rem/hr at one meter for a 6 kg heavy metal product assuming 120-day cooled lanthanide fission products. After adhering salt and cadmium is distilled, the dose is still approximately 225 rem/hr. This estimate was prepared using MicroShield 4.10.

Additionally, because of the high radiation field associated with all the fuel cycle materials, everything is remotely handled. Materials are always either in the hot cells or within large shielded casks. Access to special nuclear material is easily controlled.

CONCLUSIONS

The IFR fuel cycle is unique with respect to standard reprocessing methods. Its uniqueness requires the development of new sampling means for materials control and accountability, but the inherit properties of this fuel cycle, which produces unattractive material for weapons production and includes high radiation fields, make it an extremely diversion resistant system.

ACKNOWLEDGMENT

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