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THE EBR-II SPENT FUEL TREATMENT PROGRAM

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ABSTRACT

Argonne National Laboratory has refurbished and equipped an existing hot cell facility for demonstrating a high-temperature electrometallurgical process for treating spent nuclear fuel from the Experimental Breeder Reactor-II. Two waste forms will be produced and qualified for geologic disposal of the fission and activation products. Relatively pure uranium will be separated for storage. Following additional development, transuranium elements will be blended into one of the high-level waste streams. The spent fuel treatment program will help assess the viability of electrometallurgical technology as a spent fuel management option.

INTRODUCTION

Cancellation of the Integral Fast Reactor (IFR) program *(1)* by the U. S. Department of Energy (DOE) resulted in shutdown of the Experimental Breeder Reactor-II (EBR-II) power plant in late September 1994. Had the IFR program continued, the metallic EBR-II fuel was to be recycled in a demonstration of metal fuel cycle technology based on electrometallurgical techniques. The roots of this technology lie in an incomplete melt-refining metal fuel cycle demonstrated from 1965 to 1969 as part of initial plant operation. *(2)* Although the modern electrometallurgical process is more complete, any recovered plutonium would still be highly diluted with uranium, minor actinides, and lanthanide fission products. This characteristic renders the plutonium essentially useless for military or light water reactor (LWR) applications, but makes a perfectly acceptable ingredient for fast reactor fuel. While the process produces a contaminated fuel product, it also produces minimal waste streams, clean in the sense that they can be made essentially free of actinides. Appropriate elements of the IFR fuel cycle technology are being used to treat the accumulated spent EBR-II fuel to meet environmental regulations and to process the waste residue into forms suitable for permanent geologic disposal.

The Fuel Conditioning Facility (FCF — the name replaces the earlier 'Fuel Cycle Facility'), which was used for the original melt-refining demonstration, was refurbished for the IFR fuel cycle demonstration. *(3)* To meet modern safety standards for plutonium handling facilities, many improvements were mandated by the current generation of DOE orders. These modifications principally improve confinement of radioactive particles, particularly any plutonium aerosols that could be generated during a severe accident. The modifications included installation of a safety-class exhaust system and a 360 kW emergency diesel system in a new interconnected building. DOE review and approval of the safety documentation, including the Final Safety Analysis Report, the Technical Safety Requirements, and the Criticality Safety Hazards Report were obtained during 1993. All necessary construction was completed in 1994. Full operation will commence in June of 1995.

Operation of FCF is dependent upon chemical analyses of the incoming fuel, the electrorefiner salts, the cathode products, and the waste materials. Six hot cells in the Analytical Chemistry Laboratory were restored to accommodate the equipment to be used for analytical support of FCF. The cells were decontaminated, the hot cell windows were restored to their original condition, an improved ventilation system was installed, all penetrations were sealed, advanced remote manipulators were installed, and an efficient cell-to-cell transfer system was designed and installed.

The EBR-II fuel inventory to be treated consists of approximately one tonne of highly enriched

experimental driver assemblies and 14 tonnes of depleted uranium blanket assemblies. Both categories of fuel contain elemental sodium which acts as a thermal bond between the fuel pin and the cladding. During irradiation, liquid sodium fills fission gas pores created within the fuel. Sodium is a reactive metal that by U. S. law cannot be disposed by burial. End-of-life enrichments for the driver fuel range from 53 to 75 weight percent ^{235}U. The blanket assemblies contain a nominal one weight percent plutonium at discharge. Typical burnups at discharge are 7-9 atom percent for the driver assemblies and 0.4 atom percent for the blanket assemblies.

Spent fuel assemblies are washed to remove external sodium, but trace quantities of sodium reaction products (sodium hydroxide or carbonates) remain. The washed fuel is susceptible to a mechanism of degradation that begins immediately upon washing. Given sufficient conditions of stress, temperature, and available oxygen, a reaction of the sodium reaction products with the austenitic stainless steel cladding of both fuel and blanket elements could initiate a process known as intergranular stress corrosion cracking, or IGSCC. The result would be cladding failure and potential release of fission products, fuel, and bond sodium. This lack of assured physical integrity, an end-of-life enrichment exceeding 50%, the presence of a regulated reactive metal, and a potential for long-term pyrophoric hydride formation following cladding breach make direct geologic disposal an unlikely option for the EBR-II fuel.

A substantial quantity of other spent nuclear fuel in the DOE inventory includes fuel that can be categorized as "at risk." This includes fuels that (a) have seriously degraded during storage; (b) are highly enriched in fissile isotopes; (c) are chemically reactive or contain reactive materials; (d) or cannot be expected to retain their integrity or remain stable over an extended period of wet or dry storage. Both the EBR-II driver and blanket elements represent spent nuclear fuel material that can be classified as "at risk." In addition to the EBR-II fuel elements scheduled to be processed in the demonstration, there are another eight tonnes of elements in storage on the Argonne National Laboratory-West (ANL-W) site. There are also approximately two tonnes of spent earlier-generation EBR-II driver fuel stored at the Idaho National Engineering Laboratory (INEL). Another 215 kg of IFR fuel irradiated in the Fast Flux Test Facility (FFTF) are being stored at the Hanford site. Among other at-risk metallic fuels are 38 tonnes of spent FERMI-1 assemblies stored at the INEL and 2100 tonnes of degraded N Reactor fuel at Hanford. *(4)*

Non-metallic spent fuels, including hydrides and some ceramics, *(5)* also fall into the at-risk category. The feasibility of process modifications for treatment of other fuel types will be tested at ANL-East using unirradiated materials. *(6)* These development activities are a part of the Electrometallurgical Technology Program within the ANL Redirected Nuclear R&D Program that replaced the IFR.

ELECTROMETALLURGICAL TREATMENT TECHNOLOGY

Objectives for treatment of EBR-II spent fuel include stabilization of the reactive bond sodium; emplacement of fission products in waste forms that have very high probability of acceptance for geologic repository disposal and that can be safely stored for the period of time until a repository is available; recovery of the highly enriched uranium as a low-enrichment (less than 20% ^{235}U) metallic product that can be stored in a conventional surface storage facility; and isolation of transuranic elements in a stable form that can safely endure long-term interim storage until acceptable means are available for their effective immobilization in a disposable waste form.

A block diagram of the electrometallurgical treatment flowsheet is shown in Figure 1. The equipment used for driver fuel treatment differs slightly from that used for blanket processing. This is necessitated by two considerations: precautions must be taken to ensure criticality safety of the highly enriched driver fuel under even the most highly unlikely conditions of operation; and the quantity of blanket material is very large compared to the quantity of driver fuel, but the fissile content of the blanket material is insignificant by comparison. Therefore, even though the process chemistry is identical, the operations with driver fuel must be limited to relatively small batches, while the much greater quantity of blanket material requires a much larger batch size, made feasible by the substantially lower fissile content of the blankets.

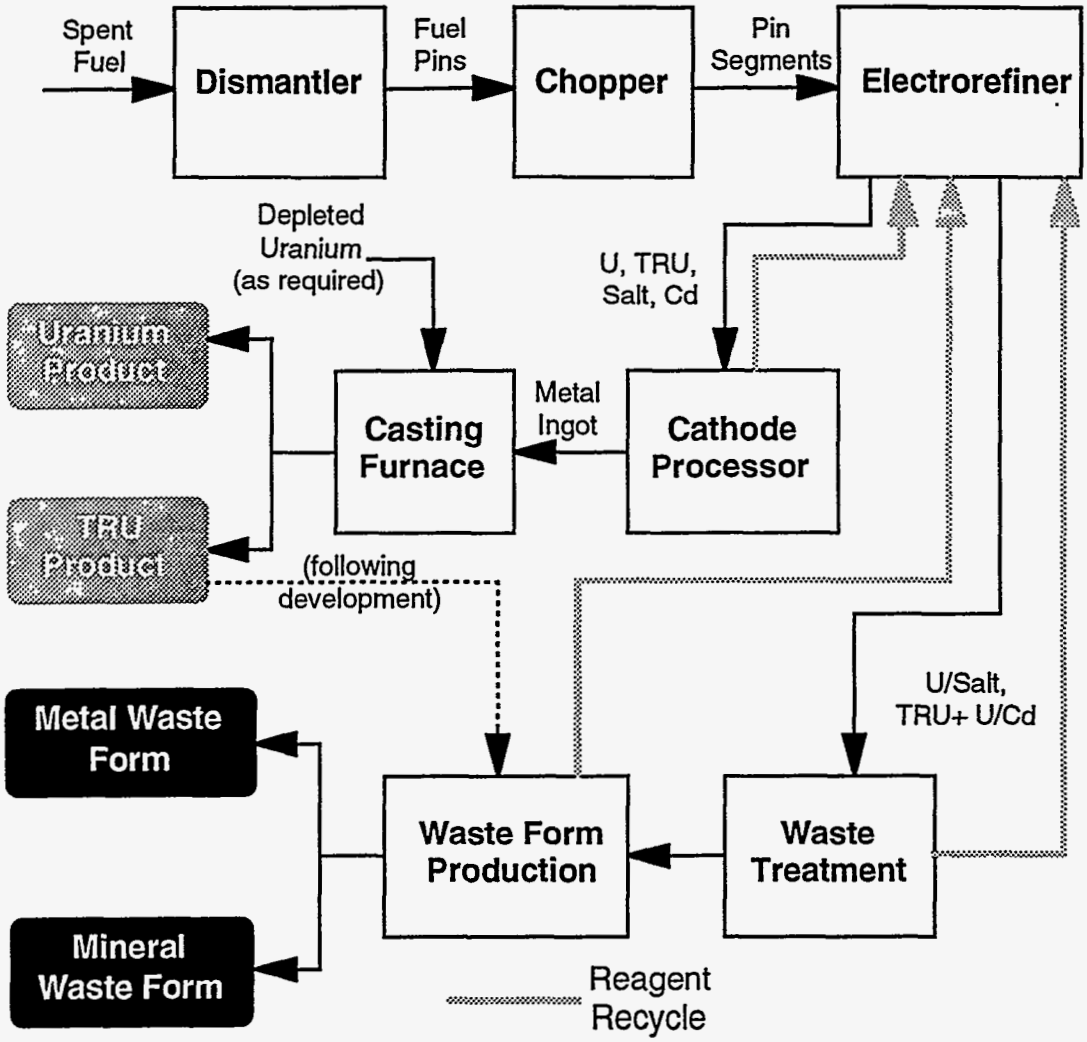

Fig. 1. Simplified Block Diagram for EBR-II Fuel Electrometallurgical Treatment

The treatment process begins with dismantling fuel assemblies. The stainless steel assembly hardware is set aside for disposal as low-level waste. The individual fuel elements are transferred into an argon-atmosphere cell, where they are loaded into magazines and inserted into the element chopper. Stainless steel baskets collect the elements as they are chopped into short segments. The baskets containing the fuel segments are inserted into an anode fixture and loaded into the electrorefiner.

The electrorefiner is a fused-salt electrotransport system containing a salt electrolyte that is a mixture of lithium and potassium chlorides at the eutectic composition. The electrolyte salt, in the case of driver fuel treatment, overlies a pool of liquid cadmium at the operating temperature of 500°C. The cadmium pool provides a prudent additional measure of criticality safety for the first-time electrorefining of high-fissile-content, highly irradiated fuel. In the unlikely event that an unexpected high concentration of fissile material in the salt phase were collectively reduced to the metallic state, the metal would become distributed in the cadmium in a criticality-safe configuration. A cadmium pool is not required in the case of blanket processing, nor in the electrometallurgical treatment of any low-enrichment fuel.

In the electrorefiner, the spent fuel is oxidized at the anode, placing the actinide elements and many fission product elements in solution in the electrolyte salt in the form of metal chlorides. Simultaneously, an equal amount of actinide elements are selectively electrotransported through the electrolyte to suitable cathodes, where they are reduced and collected as metallic deposits. Two forms of cathodes are used, as dictated by the relative stabilities of the actinide chlorides. Uranium, relatively free of fission products, is collected on a steel cathode. Because the transuranic chlorides are more stable than uranium chloride, they will not deposit on the steel cathode. Instead they are collected in a liquid cadmium cathode as dissolved metals and a

commingled collection of intermetallic compounds with cadmium (e.g., $PuCd_6$), together with about 30 weight percent uranium metal. When anodic dissolution of a basket of fuel material is completed, the cladding hulls remain in the basket together with the noble metal fission products such as Tc, Rh, Ru, Pt, and Pd.

The solid cathode deposits contain entrained salt in the amount 5-15 weight percent. Salt removal and recovery is accomplished by melting the deposit at reduced pressure in a distillation system called the cathode processor. In this process, the uranium is consolidated into a compact ingot and the salt is readily volatilized and collected in a condenser region for recycle to the electrorefiner. In the case of driver fuel, the consolidated uranium is blended down to less than 20% ^{235}U with depleted uranium metal. The uranium product is then transferred to a container for interim storage in a monitored facility. It is not expected that heavy radiation shielding will be required. The total volume of uranium product derived from electrometallurgical treatment of the combined EBR-II spent driver and blanket assemblies will be approximately one cubic meter.

As batch after batch of the fuel material is processed, fission products such as Cs, Sr, and the rare earth elements build up in the electrolyte salt. At the completion of driver fuel processing, the electrolyte salt will be removed for waste treatment. Because the salt will contain a substantial amount of actinide elements that are not to be sent to a waste stream until immobilization development has been completed, the actinides must first be removed from the salt. This is done in a reduction step that can be conducted either in the electrorefiner vessel or in a high-temperature centrifugal contactor known as a pyrocontactor. Initial operations in FCF will utilize the in-vessel reduction process; later operations will be carried out in a multi-stage pyrocontactor because of its high throughput capacity and greater efficiency. The reduction reaction in the pyrocontactor is accomplished by contacting the actinide-bearing electrolyte salt with a liquid alloy of Li in Cd. The in-vessel reduction involves placing a solid alloy of Li in Cd into the anode baskets and selectively electrotransporting the actinide elements to either solid or liquid cathodes. The cathode deposits can then be returned to condition the electrorefiner for the next campaign, or they can be consolidated in the cathode processor.

The liquid cathode deposits consist of uranium, transuranic element intermetallic compounds with Cd, and trace amounts of rare earth fission products. These are treated in the cathode processor to remove all traces of the readily volatile cadmium, which is recovered in the condenser and recycled to the electrorefiner. At the end of a campaign, the final reduction step will be done with solid cathodes to reduce the uranium concentration in the electrolyte salt to the point that the concentration ratio, $[PuCl_3]/[UCl_3]$, is slightly greater than three. At that point, the remaining uranium and transuranics will be collected in a liquid cathode. The liquid cathode deposit will be treated in the cathode processor to remove all traces of cadmium, consolidating the transuranics and uranium together with a small percentage of rare earth fission products in a compact metallic ingot. Owing to the presence of the rare earth fission products and the higher transuranics such as americium and curium, the small ingot will be highly radioactive. Because the total transuranic content of the combined driver fuel and blankets is relatively low, the volume of the transuranic product from the treatment of these elements will be rather small, approximately 0.01 m^3. Once development of a qualified transuranic waste form is assured, the transuranic product will be blended into the appropriate waste stream.

The mineral waste form is produced by first passing the withdrawn electrolyte salt through a multi-stage pyrocontactor, where the salt is reacted with a dilute liquid alloy of depleted uranium in cadmium for extraction of residual transuranic elements. The extracted salt, free of transuranics, is then passed through a zeolite bed, where the fission products are absorbed in the zeolite structure by a combination of ion exchange and molecular occlusion. The loaded zeolite consists of discrete pellets with a concentration of about 15 weight percent total fission products, an extremely efficient loading that is limited only by the heat generation rate in the resultant waste form. The pellets have a surface coating of fission product-bearing waste salt, which is absorbed by crushing the pellets and combining the resultant powder with anhydrous zeolite powder in a ratio sufficient to accommodate the excess salt. Glass frit is added to the powder mixture, and the aggregate is then hot isostatically pressed to produce a solid monolith, the final mineral waste form. The mineral waste form is placed into inerted containers for

interim storage pending loading of the containers into an acceptable overpack for repository disposal. The volume of the mineral waste form from driver fuel treatment will be about 0.4 m^3. Treatment of the much larger quantity of blanket material will produce a waste form with approximately the same fission product content, and a volume of slightly less than 2.5 m^3.

The metal waste form is produced by combining the stainless steel cladding hulls with the noble metal fission products retained in the anodic dissolution baskets and with loaded stainless steel filter cartridges from the bulk fluid handling system. This collection of materials will be melted together with a small amount of zirconium added to produce a low-melting point eutectic composition that permits operation of the melting furnace within a reasonable temperature range. The metal waste form production operations in FCF will be carried out in the casting furnace originally intended to produce fuel slugs for EBR-II. The metal waste form produced from treatment of the EBR-II spent driver and blanket fuel will have a total volume slightly less than 0.2 m^3. There are no secondary process waste streams associated with electrometallurgical treatment.

PROCESS EQUIPMENT

Due to high radiation levels, the process operations will be performed within shielded cells in FCF. Operations including maintenance, minor repairs, and process operations are performed using overhead cranes or remote manipulators. Equipment is designed and built to allow remote installation, replacement of modules, and removal while processing activities continue. *(7)* This equipment design philosophy has been demonstrated at the Hot Fuel Examination Facility, where the inert-gas cell has not had human entry since its commissioning in 1975.

The process equipment has been designed, built, and qualified to meet ASME NQA-1 requirements. Equipment is qualified in three phases: assembly, out-of-cell remote handling, and in-cell. During assembly qualification, the equipment is put together and tested for functionality by the equipment design personnel. Out-of-cell qualification, performed by operations technicians, verifies that assembly, operation, and maintenance can be done remotely. The FCF mockup shop enables testing of the equipment in the same configuration as in the cell. The in-cell qualification assembles the equipment in its final location and tests its functions.

Individual elements are removed from the assemblies using the Vertical Assembler/Dismantler (VAD). The VAD was an existing machine that has been refurbished and improved. Final equipment checkout and operator training has been completed.

The fuel element chopper uses a small, commercially-available electromagnetic punch press to chop individual fuel elements into segments approximately 6 mm long. The elements are fed from a 44 position magazine into a standard machine tool collet. The collet advances the element into the shear, and the individual segments fall into electrorefiner anode baskets or sample containers positioned on a turntable located below the shear. The shear blades, remotely replaceable without machine disassembly, are capable of more than ten thousand cuts.

The principal apparatus, the electrorefiner, consists of a process vessel with its associated heater/insulator assembly, cover, and support stand; the electrode assemblies (anodes and cathodes) and their associated handling and placement mechanisms; ancillary materials service systems connected directly to the electrorefiner (i.e., for cover gas circulation, stirring, materials addition, sampling, measurement, etc.); and an instrumentation and control system. A staging or support station is provided to attach and remove anode and cathode parts, remove the product from the cathodes and empty the cladding hulls from the anode baskets. The process vessel is approximately 1.0 m in diameter by 1.0 m deep, made with a 2 1/4% Cr, 1% Mo steel alloy. It is heated by thermal radiation from a furnace assembly consisting of resistance heaters embedded in low-density ceramic insulator blocks. Circular ports in the steel cover and thermal radiation baffles provide access for four electrodes and one stirrer. Other smaller ports allow material additions, sampling measurement, and cover gas control.

The electrode assemblies are independent structures consisting of a long shaft with an adapter for either an anode or a cathode bottom, a rotation motor, rotating electrical contacts, a port cover, a containment housing and various instrumentation components. The containment housing mates with a slide valve mounted on the electrorefiner cover and maintains isolation of

the cover gas from the general cell atmosphere. The electrode assemblies are maneuvered into and out of the process vessel by elevator/rotator mechanisms mounted on the support structure.

The major features of the cathode processor are the vessel, the induction-heated furnace region inside the vessel at the top, and the condenser region inside the vessel at the bottom. The furnace region uses a passively cooled induction coil and a graphite furnace liner that acts as the susceptor. The liner heats the cathode charge contained in the charged crucible by thermal radiation. The vessel is made of type 410 stainless steel to eliminate the potential for damage to the vessel from the process cadmium and salts, and because it has acceptable strength at the operating temperatures. The induction coil and power supply are similar to that used in the injection casting furnace. Because the cathode processor is bottom-loaded, it is supported in an elevated position within the cell. An elevating mechanism raises the crucible assembly and bottom flange into position to seal the furnace prior to the heating cycle. When in the lowered position, a trolley moves these components to an adjacent window for crucible handling operations.

The design of the casting furnace is similar to that of a machine operated from 1987 to 1994 in the EBR-II Fuel Manufacturing Facility. The casting furnace vessel provides confinement for the casting operation. It is a cylindrical shell approximately 711 mm OD. and 1.27 m long with a 260 mm ID. top hat. A top flange is removed for loading and unloading the furnace. The furnace crucible is machined graphite. To measure melt temperatures, a thermocouple is fed through a curved tube, through the bottom flange, and into the center thermocouple-well in the bottom of the graphite crucible. Furnace atmosphere control is provided by an external high-purity argon source to minimize pickup of argon cell atmosphere contaminants. There is a vacuum pump for use immediately before casting, and an accumulator with a fast-acting valve to supply rapid and repeatable pressurization of the furnace necessary for casting representative samples.

Design activities for several pieces of new equipment have been started and schedules reflect this progress. Other equipment, such as the pyrocontactors, requires results from further research and development. The high-throughput electrorefiner is being designed to process almost 200 kg of heavy metal per batch. The improved throughput will result from larger area electrodes, increased uranium collection efficiency, and improved fluid flow. Anticipated improvements in the density of the actinide products would result in more compact products that require less operator handling. A new anode and cathode design will be needed for the high-throughput electrorefiner. These will be fitted to a new head for the spare FCF electrorefiner vessel. Testing is being performed at both the bench and engineering scale.

Some higher-throughput support equipment will also be required for operation of the new electrorefiner at its intended rates. This includes a high-throughput element chopper, high-throughput cathode processing equipment, and assorted handling equipment. A non-destructive assay system is being developed to quantify the fissile content of the blankets before they are processed, and the fissile content of the waste containers before they are removed from the facility.

Required new waste equipment includes the bulk fluid handling system, metal waste form furnace, and a mineral waste form hot isostatic press. This initial waste equipment is well along in the design process and should be available in 1996. For higher throughput rates, a multi-stage pyrocontactor, a production furnace for the metal waste and a larger hot isostatic press for the mineral waste may be needed.

STATUS

FCF and the associated support facilities are ready for hot operations. The ANL internal and DOE operational readiness reviews have been completed. Permission for startup of hot operations should be received from DOE no later than June 1995. Process equipment will be ready on the same schedule.

The element chopper has been installed in the argon cell since 1991. The final step of remote qualification will chop 20 kg of depleted-uranium/zirconium sodium-bonded elements for the electrorefiner startup operations.

In June 1994, the electrorefiner was installed in the argon cell. Integrated tests with an empty

vessel at 400°C have been completed, the process chemicals have been added, and the temperature of the device has been raised to the operating temperature of 500°C, and the vessel has been charged with depleted uranium.

Because the vessel configuration and size were different from previous experience, two cathode processors were built. The prototype unit, which was installed in an argon glove box in Illinois, has been operational since late 1993. This unit has been used to distill salt and cadmium, and to consolidate depleted uranium. Support testing for FCF operation will continue to ensure that any unforeseen problems can be addressed quickly because the operations are hands-on. The FCF cathode processor completed its out-of-cell remote qualification in February, 1994. Installation in-cell was completed in June. In-cell qualification tested the equipment without process chemicals to its design temperature of 1370°C. Distillation operations were then carried out using material simulating a cathode. Depleted uranium solid cathodes will be processed to complete the startup operations.

The casting furnace completed its out-of-cell qualification in late 1992, and was installed in the argon cell in early 1993. The first depleted uranium casting was completed in October 1993. Three additional castings have been completed and the homogeneity of the melt has been demonstrated. The third and fourth castings were also used to demonstrate the FCF mass tracking system for special nuclear material control. No modifications will be necessary to obtain representative samples or metal ingots for storage of the actinide products. Minor modifications will allow this equipment to produce metal waste form samples for testing.

Development of the electrometallurgical technique has been carried out with unirradiated fuel materials containing representative non-radioactive fission product elements. Operations with transuranic elements have been limited to laboratory-scale electrorefining experiments. All unit operations steps in the flowsheet, however, have been established in the course of the development program. The process chemistry has been verified thoroughly, and tests have been conducted to confirm that the FCF equipment meets functional and operating requirements.

Experiments with the electrorefining process have been carried out with an engineering-scale electrorefiner having the same dimensions as the FCF unit, but without the capability for remote operation in a hot cell. These experiments have been done with depleted uranium and with binary uranium-zirconium fuel that is adequately representative of the bulk of the EBR-II spent driver fuel and blanket material. Electrorefiner operating parameters and procedures have been established and are reflected in the operating procedures for the FCF unit. More than 150 major electrorefining experiments have been conducted in the course of testing and include the production of normal uranium deposits and the conduct of actinide reduction operations associated with electrolyte salt cleanup. A laboratory-scale electrorefiner has been used for the development of the liquid cadmium cathode concept, and the high efficiency of this design has been confirmed in more than 50 separate runs. The behavior of plutonium-bearing fuel materials has been the subject of intensive characterization with this device. A prototype of the high-throughput electrorefiner electrodes for use in treatment of blanket material has been tested successfully, with processing rates exceeding expectations. Further development work will be centered on optimizing design parameters for integrated high-throughput.

A bulk fluid handling system has been developed and tested for use in the transfer of electrorefiner fluids (salt and cadmium) between the electrorefiner and various waste treatment operations. The system incorporates a centrifugal pump for transferring these fluids through a heated transfer line to the appropriate equipment. Tests of the pump have proven successful. A filter cartridge integral to the pump housing has been developed and tested, and has been shown efficient in the removal of particulate materials from both salt and cadmium. The FCF bulk fluid handling system, based on these developments, is in the final design stage. Development efforts are now being directed toward the incorporation of a zeolite-bearing filter element in the pump housing, for use in initial experiments with the zeolite system in FCF.

A single-stage pyrocontactor has been successfully tested with surrogate materials representing uranium and plutonium and with a representative fission product element. Functioning of the pyrocontactor design was in accordance with requirements, and separation efficiency achieved was excellent. A multi-stage pyrocontactor is required in order to attain the target actinide extraction level of >99.9% from the spent electrolyte salt, so a four-stage prototype

pyrocontactor has been built and is ready for testing.

Mineral waste form samples have been produced to date with laboratory-scale experiments, using a simulated salt waste stream that includes representative non-radioactive fission product elements. Early experiments were performed in the batch processing mode with zeolite A powders. Recent emphasis has been on the use of zeolite pellets, which will be required for operation of a zeolite column absorption bed.

Mineral waste form performance testing has centered on two variants of the mineral waste form: the glass-zeolite composite, and sodalite. The latter is produced in much the same manner as the composite, but the quantity of glass added is considerably less and the hot-pressing operation is conducted so as to convert the zeolite to the sodalite form. A hot isostatic press has been installed for development testing of hot-pressing operations and establishment of FCF process parameters (temperature, pressure, hold times, etc.).

Performance testing of the mineral waste form has utilized conventional leach-testing methods as established by the ASTM subcommittee on high-level waste form performance testing. The test results have been highly satisfactory, with leach resistance being at least as good as the reference borosilicate glass waste form. Radiation resistance of the glass composite version has been demonstrated to very high gamma dose levels, with no evidence of radiolysis other than the production of color centers in the zeolite crystal structure. The mineral waste form falls within the established qualification envelope of the standard borosilicate glass waste form, so acceptance of this material for repository disposal is likely. Considerable further work remains to be done in compiling a comprehensive database on waste form performance under a reasonable range of repository environmental conditions. Preparation of sample materials with actual fission products may be expedited at FCF, possibly using the bulk fluid handling system centrifugal pump with zeolite cartridge to produce initial samples.

Metal waste form development has similarly been carried out to date with laboratory-scale equipment and samples, using non-irradiated materials and representative noble metal fission products. Waste form composition envelopes have been selected, and numerous samples have been melted to provide material for corrosion testing and metallography. Initial corrosion test results are promising, with extremely small corrosion rates observed in simulated Yucca Mountain well water. Accelerated corrosion tests are in progress, including studies of the propensity for galvanic corrosion with these materials and their containers. Equipment for production of large-scale samples has been placed into operation, with the installation of a tilt-pour induction melting furnace capable of producing 20-kg sample batches.

PLANNED TREATMENT OPERATIONS

EBR-II spent fuel treatment in FCF will start with the highly enriched assemblies. *(8)* Three electrometallurgical treatment campaigns of approximately one year each will be employed for the driver fuel. During the first series, 60 assemblies will be treated; approximately 90 assemblies will be treated during each of the next two series. Fewer assemblies are scheduled during the first year because of problems typically encountered with the startup of any new process and because startup operations with depleted uranium will be required initially to bring the electrorefiner into steady-state operating conditions. *(9)*

All recovered enriched uranium will be blended down to less than 20% ^{235}U by adding depleted uranium in the casting furnace. An option exists to perform the blending operation in the cathode processor, but the casting furnace should permit more efficient operation. The resultant material, having minimal security requirements will be stored as metal in canisters in a suitable location to be selected on the basis of external radiation level. Early testing will provide input to the final canister designs and validation of storage requirements.

Treatment of spent EBR-II blanket assemblies will begin after about two years of driver fuel processing. There are approximately 14.3 tonnes of heavy metal in some 323 EBR-II blanket assemblies to be treated in the termination program. The development and prototype testing of high-throughput equipment will proceed in parallel with the driver fuel processing and will make use of experience gained in these operations.

Approximately 140 kg of transuranic elements will be collected in the course of blanket processing. Pending selection of a final disposition option, this material will be recovered in

liquid cathodes and processed into an interim storage metal alloy containing uranium, plutonium, the minor transuranics, and lanthanide fission products. Ingots in criticality-safe geometries will be stored in adequately shielded canisters, and the canisters will be placed in suitable interim storage. Final determination of the on-site storage facility will be made after measurements of radiation levels are established and shielded containers designed. Processed depleted uranium from the blankets will be formed directly into ingots in the cathode processor for interim storage.

The schedule for the IFR termination program calls for completion of treatment of spent fuel from EBR-II shutdown by the end of October 1998. The final qualification of the mineral and metal waste forms is expected to take several more years. Production of these waste forms will continue into 1999 and beyond as part of the transition of the ANL-W site.

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REFERENCES

(1) Y. I. Chang, "The Integral Fast Reactor," *Nuclear Technology, Vol. 88,* p. 129 (1989).
(2) C. E. Stevenson, *The EBR-II Fuel Cycle Story*, p. 5, American Nuclear Society, La Grange Park, IL (1987).
(3) M. J. Lineberry, J. J. Laidler, R. D. Phipps, R. W. Benedict, J. E. Battles, and W. E. Miller, "Fuel Cycle and Waste Management Demonstration in the IFR Program," *ANS/ASME Nuclear Energy Conference*, p. 57, American Nuclear Society, La Grange Park, IL (1992).
(4) Eddie C. Gay and William E. Miller, "Electrorefining 'N' Reactor Fuel," *Proceedings of DOE Spent Nuclear Fuel — Challenges and Initiatives*, 13-16 December 1994, Salt Lake City, p. 267, American Nuclear Society, La Grange Park, IL (1994).
(5) C. C. McPheeters, R. D. Pierce, T. P. Mulcahey, "Pyroprocessing Oxide Spent Nuclear Fuels for Efficient Disposal, *Proceedings of DOE Spent Nuclear Fuel — Challenges and Initiatives*, 13-16 December 1994, Salt Lake City, p. 275, American Nuclear Society, La Grange Park, IL (1994).
(6) James J. Laidler, "Pyrochemical Processing of DOE Spent Nuclear Fuels," *Proceedings of DOE Spent Nuclear Fuel — Challenges and Initiatives*, 13-16 December 1994, Salt Lake City, p. 188, American Nuclear Society, La Grange Park, IL (1994).
(7) R. H. Rigg, "IFR Fuel Cycle Process Equipment Design Environment and Objectives," *Proceedings of the ANS Fifth Topical Meeting on Robotics and Remote Systems*, 25-30 April 1993, Knoxville, Tennessee, Vol. II, p. 817, American Nuclear Society, La Grange Park, IL (1993).
(8) H. F. McFarlane and M. J. Lineberry, "Spent Fuel Pyroprocessing Demonstration," *Proceedings of the Fuel Management and Handling Conference*, 20-22 March 1995, Edinburgh, UK, p. 149, British Nuclear Energy Society, London (1995).
(9) K. Michael Goff, Robert W. Benedict, and David Levinskas, "Spent Fuel Treatment at ANL-West," *Proceedings of DOE Spent Nuclear Fuel — Challenges and Initiatives*, 13-16 December 1994, Salt Lake City, p. 267, American Nuclear Society, La Grange Park, IL (1994).