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IFR FUEL CYCLE DEMONSTRATION IN THE EBR-II FUEL CYCLE FACILITY

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ABSTRACT

The next major milestone of the IFR program is engineering-scale demonstration of the pyroprocess fuel cycle. The EBR-II Fuel Cycle Facility has just entered a startup phase which includes completion of facility modifications, and installation and cold checkout of process equipment. This paper reviews the design and construction of the facility, the design and fabrication of the process equipment, and the schedule and initial plan for its operation.

I. INTRODUCTION

Since 1986, Argonne National Laboratory has been engaged in activities leading to demonstration of the unique Integral Fast Reactor (IFR) pyroprocess fuel cycle. The last major conference where these activities were reported occurred in 1987.[1] At the present time, both the process equipment and the Fuel Cycle Facility (FCF) at Argonne's EBR-II test facility complex in Idaho are in the final stages of preparation. A nine-month startup period began in September 1991. Demonstration of the pyroprocess is the next major step in the IFR program.

The FCF was originally constructed in the early 1960's along with EBR-II, and was used from 1964 through 1969 to demonstrate an early and incomplete version of the pyroprocess.[2] In subsequent years the facility was used for examination of irradiated fuels and materials, and was then known as the Hot Fuel Examination Facility/South. Last year the facility was given back its original name in anticipation of the new demonstration.

II. PROGRAM OBJECTIVES

FCF will provide complete fuel cycle service for EBR-II. In addition, it will serve as an experimental facility where process alternatives and advanced concepts can be developed. The substantial R&D program in progress at Argonne's main laboratory in Illinois since 1983, principally involving the reprocessing and waste processing portions of the fuel cycle, will continue and is expected to result in experimental campaigns in FCF.

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DISCLAIMER

A primary program objective is to establish the reactor performance of IFR metal fuel remotely refabricated in FCF. In pursuing this objective, the feasibility of utilizing extraordinarily compact facilities for the pyroprocess will be established; and costs, safety record, and reliability and maintainability of the equipment and facility systems will be quantified.

As will be discussed below, the key process equipment has significant capacity beyond the ~250 kg/yr needed to serve EBR-II. This is being done so that no significant scale-up of the equipment will be needed in any follow-on project. Moreover, by the time that hot operations commence (expected in June 1992), about 100 spent EBR-II fuel assemblies with IFR metal fuel will be in storage. This backlog of assemblies will permit the process to be run for brief periods at throughput rates significantly higher than that associated with steady-state service to EBR-II.

III. FACILITY DESIGN AND CONSTRUCTION

Early in the IFR program, it was clear that any demonstration of the IFR fuel cycle process would need to be achieved at minimum cost. Fortunately, the process is very compact and demonstration requires only a small hot cell facility. This led to the plan to modify the original FCF. However, to meet the current safety standards for facilities processing nuclear fuels, especially plutonium, many improvements to the facility were needed. These confinement improvements were discussed in the 1987 paper.

FCF has two shielded hot cells, one with an air atmosphere and the other containing argon. Together they comprise a floor area of about 240 m^2. FCF is a U.S. Department of Energy (DOE) facility, and will not be licensed by the Nuclear Regulatory Commission (NRC). Safety design criteria for DOE facilities are contained in DOE Order 6430.1A "General Design Criteria", and the codes and standards it incorporates by reference.

During the preliminary design phase of the modifications to FCF, a revision to Order 6430.1A was issued which resulted in a substantial addition to the scope of modifications reported in 1987. The principal new systems are the Safety Exhaust System (SES), and a safety-class emergency diesel power system, both housed in a new Safety Equipment Building (SEB).

The SES is a nuclear-safety-class ventilation system. It is designed to provide an assured filtration path for gas-borne radioactive particulates which might result from any of the design basis accidents. The SES also mitigates the consequence of over-pressurization and under-pressurization of the argon cell.

The SEB is a 15.2 m by 15.2 m concrete building located adjacent to FCF. Five rooms in the SEB house essentially all of the safety-class equipment for FCF. This includes redundant trains of the SES, redundant emergency diesel generators, and stack monitoring equipment. Under all design-basis abnormal conditions coincident with the loss of preferred power, including the design basis earthquake, the emergency power system provides power to the SES and to the other safety-related systems.

The process equipment is being designed, to the extent possible, for repair in place. When this is not possible, modules or components (or in a few instances, entire pieces of equipment) will be brought to a new repair area for repair or disposal. This new hot repair facility (HRF) will include provisions for remote transfer of equipment from either cell, remote decontamination, and shielded glovewall and special purpose glovebox access to equipment. Direct access to equipment will be available if needed by personnel in protective clothing. A special pit area for crane trolley and electromechanical manipulator carriage repair is included, as is the

capability for bag-transfer of equipment and low-level contaminated waste into or out of the area.

Equipment can be transferred between the air cell, the argon cell, and the new HRF using carts and a hydraulic ram system being installed in an equipment transfer tunnel. Hydraulic rams at either end of the tunnel elevate a flat metal plate to the air cell, or to the bottom of the argon cell transfer lock. An orthogonal transfer path is provided to move components on the plate into or out of a decontamination spray chamber.

IV. PROCESS EQUIPMENT

The pyroprocess itself is described in detail elsewhere.[3][4] In application to the specific case of EBR-II, the main process is as shown in Figure 1:

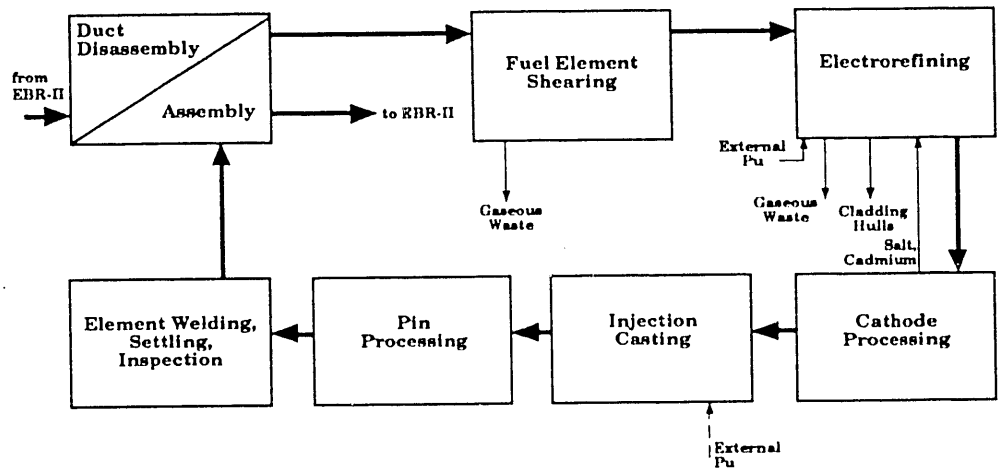

Fig. 1 Basic Pyroprocess in EBR-II Application

Each of the boxes shown above is a function involving one machine with the exception of element welding, settling and inspection, which will be done on three separate machines. Thus nine machines comprise the basic process. When one considers that most of these devices will pass through an argon cell airlock which permits a maximum size envelope of just under 2 m in diameter and 2.5 m long, the compact nature of the pyroprocess is further illustrated. Note that for EBR-II application, there are no blankets to be processed. Plutonium instead is introduced from an external source at the electrorefiner (or, less desirably, at the injection casting furnace). All fuel processing occurs in the argon cell, while element inspection and assembly/disassembly occur in the air cell. In sections below, each piece of process equipment is discussed, starting with the three key machines.

A. Electrorefiner

Electrorefining is the central step in the reprocessing portion of the pyroprocess. In this single device, spent fuel is removed from cladding; and separation of uranium, plutonium, and minor actinides from fission products is accomplished. Spent fuel is sheared (see below) and introduced in the form of element segments (~6 mm long) contained in perforated metal baskets and suspended into molten chloride salt. The fuel is electrolytically removed from the cladding, with the heavy metal being partially dissolved in the cadmium, or plating out on the vessel internals. Heavy metal ions are then subsequently electrodeposited onto a solid cathode mandrel or into a crucible of liquid cadmium, either of which is also suspended in the salt. The product cathode is then either a ~10 kg dendritic uranium deposit with adhering electrolyte salt, or a cadmium-uranium-plutonium-minor actinide mass (~6 kg heavy metal). Either type of cathode is then passed to the cathode processor for retorting. Fission

products remain in either the salt or in the cadmium layer, and are removed periodically.

The principal apparatus for the electrorefiner (Fig. 2) 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.

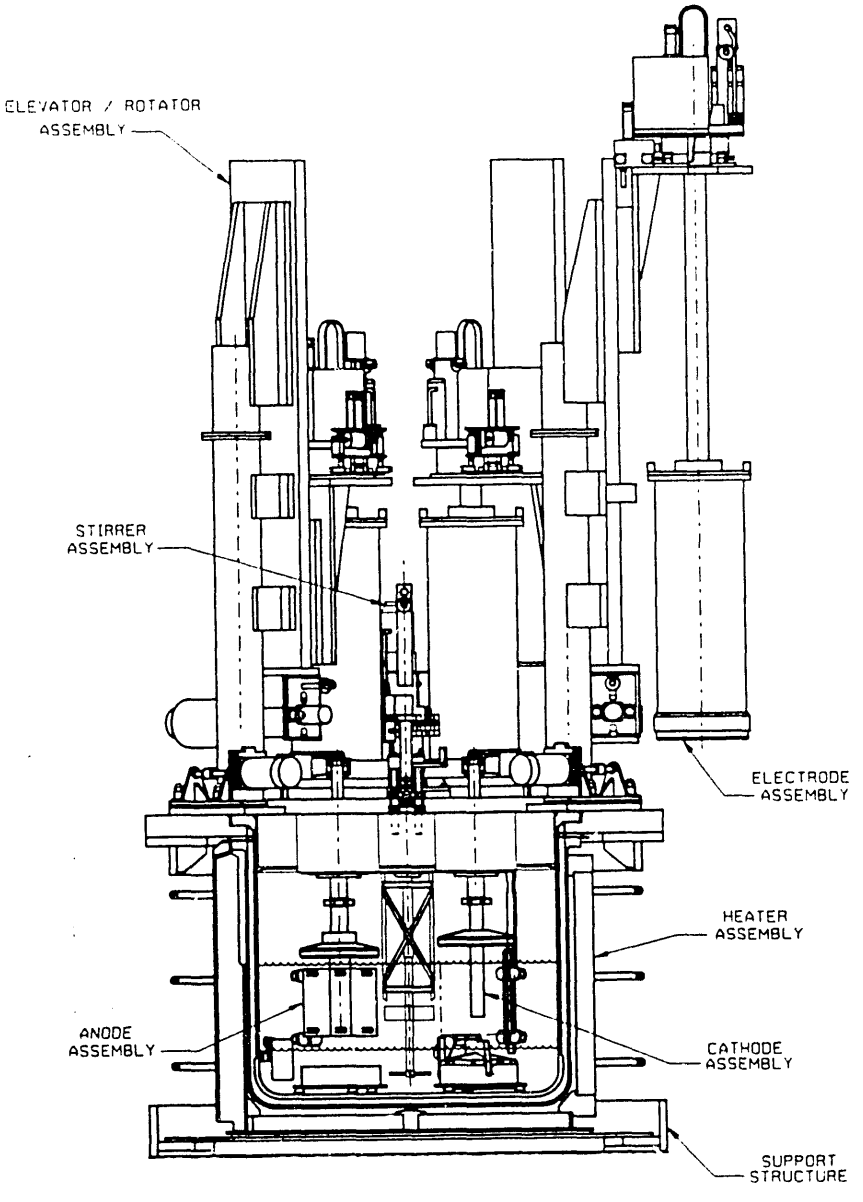

Fig. 2 Electrorefiner

The design is based on a device of roughly the same size that has been in service at the main laboratory in Illinois since 1987, and which has been routinely used for depleted uranium experiments at 10 kg per cathode.

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. The device operates at a temperature of 500°C. It contains a 15 cm layer of molten cadmium and a 30 cm layer of molten salt. 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 (28 cm in diameter) and one stirrer (20 cm in diameter). 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.

Spent fuel element segments are put into baskets and attached to anode assemblies. The anodes and the cathode assemblies are then inserted into the electrorefiner. At the end of an electrotransport run, the electrodes are removed, and transferred back to a support station for removal of the cladding hulls from the baskets, the dendritic solid cathode deposit or the ingot from the cadmium cathode. The cathode products are sent on for further processing, the cladding hulls are retained for later waste treatment, and the electrode assemblies are prepared for the next batch.

Based on results from the R&D program, it appears that 10 kg solid uranium cathodes can be deposited in 24 hours. The liquid cadmium cathodes containing ~6 kg heavy metal now are expected to require a 48 hour deposition period.

B. Cathode Processor

Cathodes from the electrorefiner include the recovered heavy metals with some salt and/or cadmium. Hence, further treatment is required prior to injection casting. This is accomplished at the cathode processor. The cathode processor functions are to: (1) separate the cadmium and salts from the solid- and cadmium-cathode products, and (2) consolidate the purified metals into ingots of acceptable size, shape, and composition for casting.

A cathode is loaded into a process crucible, and the crucible is loaded into the cathode processor. The crucible is then heated under vacuum to temperatures which causes the sequential evaporation of cadmium, decomposition and evaporation of cadmium from various cadmium and heavy metal intermetallic compounds, and finally evaporation of salts. During the heating, the distillate is transported from the process crucible to the condenser region, where it condenses and runs down into the receiver crucible. Then the heavy metal in the process crucible is heated to melt and consolidate it into fuel ingots in shaped recesses in the bottom of the crucible.

The major features of the cathode processor (Fig. 3) 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 charge crucible by thermal radiation.

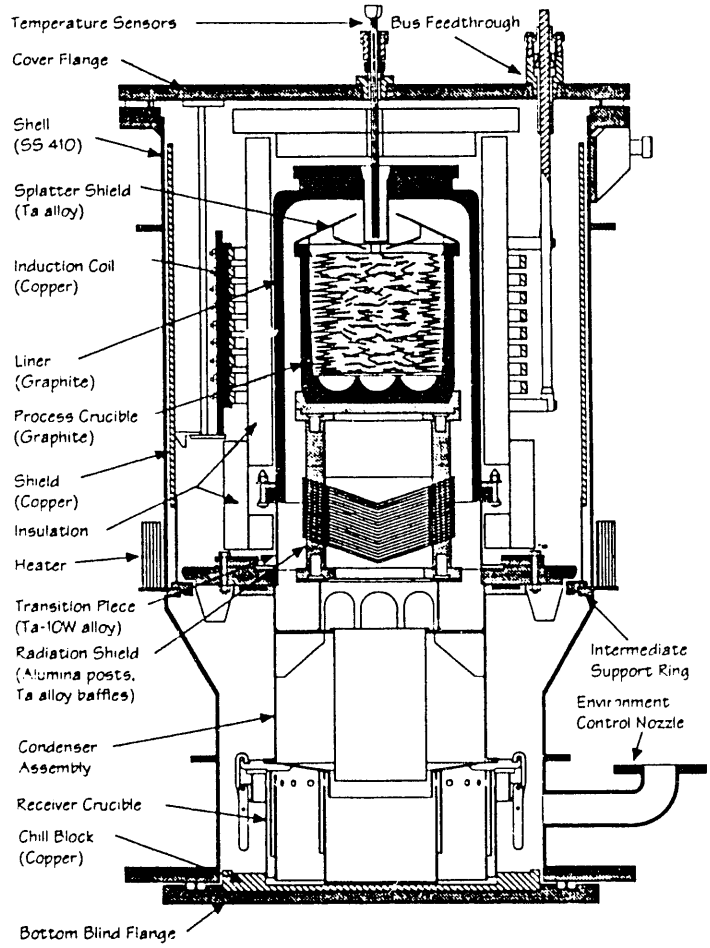

Fig. 3 Cathode Processor

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.

The cathode processor is bottom-loaded. It is, therefore, supported in an elevated position within the cell. An elevating mechanism raises (and lowers) 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.

It is anticipated that the process time will be about 8 hrs. to purify and consolidate either type of cathode, but the entire cycle time is longer because of the time required to cool the vessel and its contents. Two cathode processor machines are being fabricated, one for use in FCF and the other for ongoing R&D (with depleted uranium and other surrogate materials) at Argonne's main laboratory in Illinois.

C. Injection Casting Furnace

The function of the casting furnace (Fig. 4) is to blend uranium, plutonium, alloying metals, and recycle materials in the proper proportions to achieve a homogeneous and uniform fuel composition. The design batch size is a 25 kg charge (22.5 kg heavy metal), set by criticality-safety constraints. About 12 kg of useful fuel pins will result from an 8 hr. casting cycle. The remaining heavy metal (heels, and ends of pins) are routed to another casting batch. The alloy charge is heated inductively until fully melted, held at a temperature for a prescribed period to ensure homogeneity, and then injection cast into closed-end quartz molds.

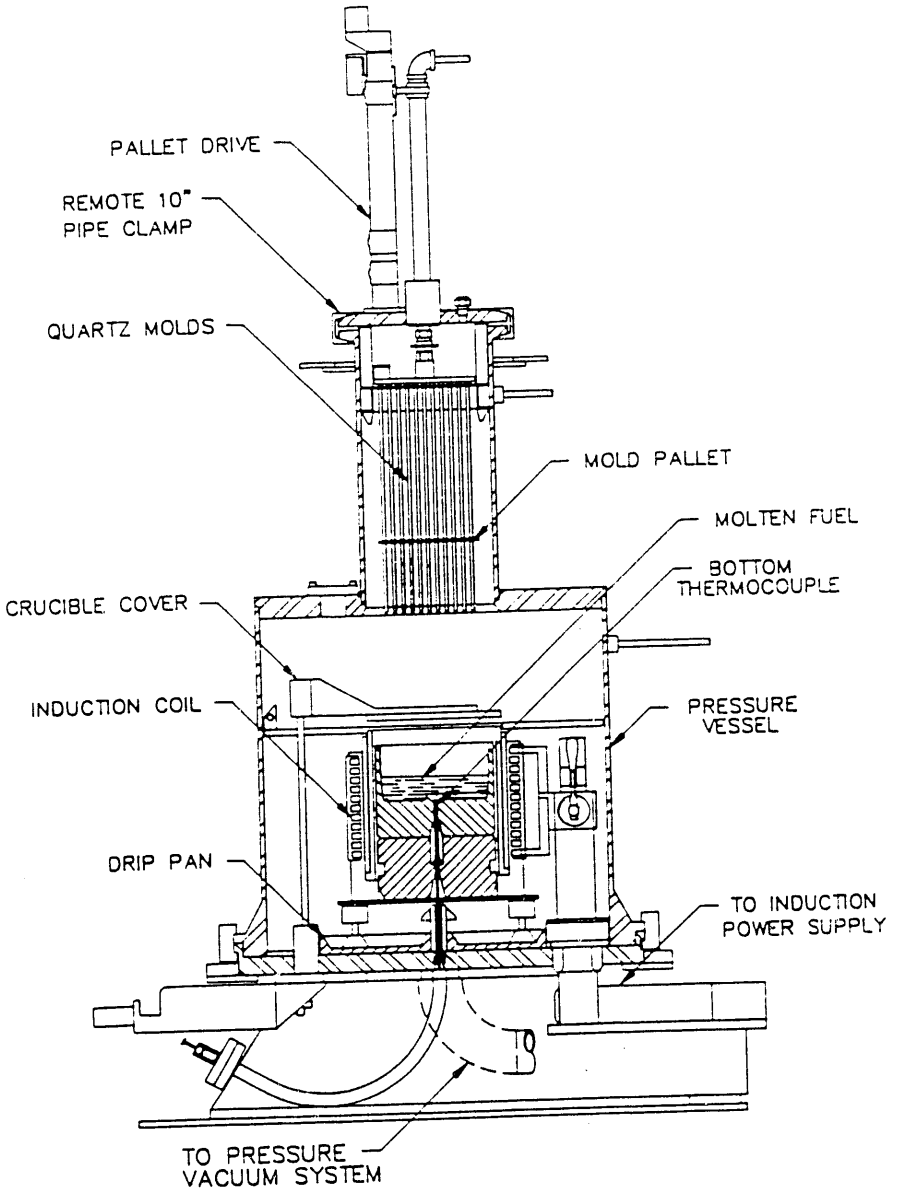

Fig. 4 Casting Furnace

To inject the alloy into the molds, the furnace is evacuated by a vacuum system, and the molds (open end down) are lowered into the charge. The furnace is rapidly pressurized, injecting the molten alloy into the evacuated molds. Argon gas from a mold cooling system then flows over the molds to expedite freezing the alloy.

The design of the furnace is similar to that of a machine operated since 1987 in the EBR-II Fuel Manufacturing Facility, also located in Idaho. The casting furnace vessel provides confinement for the casting operation. It is a cylindrical shell approximately 711-mm O.D. and 1.27 m long with a 260 mm I.D. 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.

D. Fuel Pin Processor

After fuel pin casting and removal from the mold pallet, the pin processor removes the quartz molds from the cast fuel pins, shears the pins to length, and inspects them for length, diameter, straightness, and weight. Acceptable pins are then inserted into sodium-loaded fuel element jackets positioned in an element fabrication magazine. Fuel element jackets are fabricated, loaded with sodium which acts as a thermal bond, and installed in the magazine in a clean, out-of-cell environment. Reject pins and sheared end pieces will be collected in separate trays and returned to the casting furnace workstation.

E. Element Welding, Settling, and Inspection

The element welder is an automated device that loads and welds top-end plugs onto fuel element jackets which are previously loaded with fuel slugs and bond sodium.

The element welder functions are to: (1) load element end plugs into the top of fuel element jackets, (2) for specific fuel elements, fill the plenum with unique isotope mixtures of identifying tag gas (3) weld the end plugs to the element jackets, and (4) perform automated visual inspections of the welded fuel elements. Once the fuel elements have been welded and inspected, they are transferred to the settling and bonding station which is adjacent to the element welder.

The settler machine ensures that the fuel is seated at the bottom of the element and that the bond sodium is relatively free of voids in the annulus between the fuel and the cladding. The element fabrication magazine is lowered into a heater cavity and rests on an impact plate. Following fuel element heatup, a motor driven cam lifts and drops the plate and magazine every 2 s. The maximum temperature of the fuel elements during this operation will be 500°C.

The element inspection station verifies (1) by x-ray imaging that the fuel pin is settled and that the bond sodium level is acceptable, and 2) by leak testing that the closure weld integrity of the fuel elements meets specifications.

F. Assembly and Disassembly

A single machine is used to assemble and dismantle fuel assemblies coming from and going back to EBR-II. It is located in the air cell and is an existing machine that was refurbished and improved. Fuel elements are installed on or removed from a support grid with master-slave manipulators, and fuel bundle ducts are installed on or removed from the assembled bundle with a drivescrew mechanism and load cell.

G. Fuel Element Shearing

The fuel element shear 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 are remotely replaceable without machine disassembly, and are capable of more than ten thousand cuts per set.

H. Process Control and Accountability

A control system is being installed to monitor and log data from instrumentation from the different facility and fuel processing systems, control the equipment operations, track the movement of fissile materials and maintain an archival record of selected data. Three different types of computers are used in this system: programmable logic controllers (PLCs), personal computers for the operator control stations (OCSs) and engineering workstation computers for the mass tracking system (MTG). The PLCs operate the equipment and provide the input/output interface to the instrumentation. The OCSs provide the operator interface to monitor the process parameters, change control parameters for the equipment, interact with the MTG system and log data for transfer operations. The mass tracking system tracks the movement and location of fissile material in the FCF and assists operations personnel with process control, fissile material accountability, and compliance with the facility operating limits and criticality specifications.

The PLCs are standard industrial computer devices that communicate with many different types of instrumentation and control devices such as thermocouples, pressure transducers, resolvers, stepper motors, servo motors and solenoids. The PLC reads data from input modules, interprets data and commands from the OCS, manipulates the data as defined by the control strategy, and sets output values. Each major piece of equipment has a dedicated PLC to allow quick response to changes in the operations as indicated by the process instrumentation.

The mass tracking system provides nearly real-time bookkeeping of the location of all items, particularly nuclear material, in FCF. This information is used to calculate the mass balances within criticality zones of the hot cells and to estimate any inventory differences for later statistical analysis. The database also contains the limits for different containers, criticality zones and equipment operations.

V. WASTE PROGRAM

The objectives of the IFR waste program are to: (1) quantitatively recover and recycle plutonium and minor actinides from as much of the waste as possible; (2) develop practical and NRC-certifiable waste forms; and (3) ensure a disposition path for all wastes generated in FCF.

Actinide recovery will first be demonstrated from the two principal high-level waste streams, the electrorefiner electrolyte salts and cadmium. R&D activities to accomplish this are at the laboratory scale, and more work is needed. There is, however, time available to complete this work, since at the earliest it will be sometime in 1993 before sufficient waste materials accumulate. Design work and laboratory-scale development is proceeding on a salt stripper to remove actinides and rare earth fission products from the electrolyte, a salt extractor to separate TRU elements from rare earths, and a metal retort to recover cadmium from various streams.

The development of licensable and practical waste forms is an important part of the IFR fuel cycle program. Work thus far in the laboratory has centered on licensable forms of (1) electrolyte salt waste, and (2) cadmium, cladding hulls, and other metal forms. For the electro-

lyte, adsorption in a zeolite matrix appears promising.[5] For metal wastes, alloying the metal matrix with copper and then encapsulating in copper is the favored approach. When these technologies are more advanced, they will be brought to engineering scale in FCF.

During the initial operations with irradiated fuel, the waste streams will be stored in storage pits in the argon cell or in a separate Argonne facility which can store radioactive materials on a temporary basis. Wastes will be stored under passively cooled conditions and in a manner that allows remote recovery of the material. The principal focus of this early stage of operations is to gather information on actual irradiated fuel processing, accumulate sufficient materials for the actinide recovery phase, and to determine waste characteristics.

VI. STATUS AND PLANS FOR OPERATION

The FCF project has entered a startup phase, with the goal that spent fuel operations will begin in June 1992. Milestones achieved thus far include:

Preliminary Safety Analysis Report (SAR) submitted to DOE	January 1988
Start of limited construction	July 1988
Authorization for full-scale construction	May 1990
Final SAR submitted to DOE	July 1991
Startup phase began	September 1991*

The startup activities include installing the process equipment identified above into the hot cells, and conducting pre-operational testing using depleted uranium or other surrogate materials. Meanwhile, the final facility modifications are being completed. Equipment installation started with the fuel element shear, and will be completed in June 1992 with installation of the electrorefiner. At that time, operations are scheduled to begin.

Because the electrorefiner and cathode processor are among the last of the process equipment to be installed, operation of this equipment with spent fuel and extracted cathodes, respectively, will lag the initial facility operation by 3-4 months. Meanwhile, ternary fuel (U-Pu-Zr), fabrication operations will start immediately with externally-supplied plutonium and uranium.

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