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STATUS OF IFR FUEL CYCLE DEMONSTRATION

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ABSTRACT

The next major step in Argonne's Integral Fast Reactor (IFR) Program is demonstration of the pyroprocess fuel cycle, in conjunction with continued operation of EBR-II. The Fuel Cycle Facility (FCF) is being readied for this mission. This paper will address the status of facility systems and process equipment, the initial startup experience, and plans for the demonstration program.

I. INTRODUCTION

Argonne National Laboratory's Fuel Cycle Facility (FCF) has been undergoing refurbishment since 1988 in order to demonstrate the pyroprocess fuel cycle technology that is key to the success of the U.S. Integral Fast Reactor (IFR) program. Global '93 coincides with an advanced startup phase of FCF. This paper reports on the startup experience, the status of the facility systems and process equipment, and plans for the fuel cycle demonstration program.

Demonstration of the pyroprocess fuel cycle[1] is the next major step of the IFR program. The FCF program directly supports the U.S. Department of Energy advanced reactor development program milestones to (1) determine IFR technical and economic feasibility by the end of FY 1995, and (2) reach an implementation decision on an IFR demonstration project, reactor and fuel cycle, by the end of FY 1998. Thus the FCF program is the vital activity which might lead to a U.S. fast reactor demonstration project. This possibility has been jeopardized by the Clinton Administration's FY 1994 budget proposal, but both the Administration and DOE support completion of the fuel cycle demonstration. The overall fate of the IFR program is in the hands of the U.S. Congress.

Japan joined the FCF program in late 1992, and is participating both technically and financially. The Japanese role is led by the Japan Atomic Power Company, with participation from Japanese utilities, CRIEPI, and Japanese industry.

When in full operation, FCF will recycle metallic U-Pu-Zr fuel for the Experimental Breeder Reactor-II (EBR-II), collocated with FCF at Argonne's fast reactor test facilities in Idaho. In addition to this production mission, FCF will be used for process optimization. Waste processing equipment aimed at maximizing recovery of transuranics will be a later addition.

The main economic potential for the pyroprocess lies in its relative simplicity and compactness. A small number of process machines can be deployed in limited process cell space. In the case of FCF, nine machines are needed for the main process steps. These are deployed in cells with floor area of about 250 m^2. The demonstration program is aimed at establishing this potential. The pyroprocess is depicted in Figure 1.

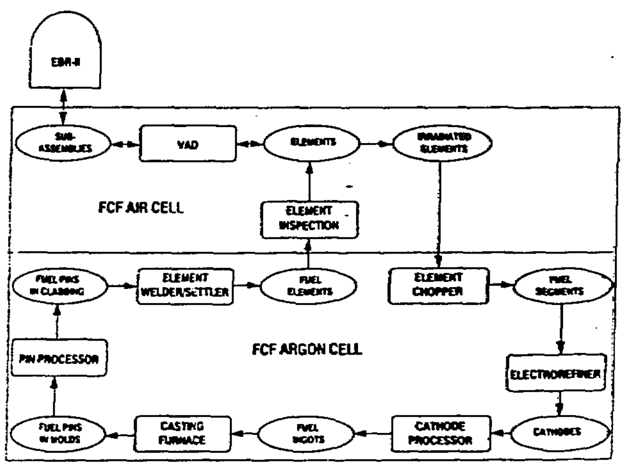

Figure 1 - Process Flow In The Fuel Cycle Facility

Disassembly of spent fuel assemblies and reassembly of recycled fuel is accomplished on the Vertical Assembler/

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Dismantler (VAD). This is an existing device being refurbished for the demonstration. At the chopper, fuel elements are sheared and the segments are loaded into anode baskets for electrorefining. The chopper is operable today in the FCF argon cell.

The heart of the pyroprocess is the electrorefiner. Here fuel is dissolved electrolytically and electrotransported to one of two types of cathodes. A KCl-LiCl electrolyte is used in a vessel operating at 500°C. The basis for separation of fission products is the difference between the free energies of their chlorides and those of uranium and transuranic chlorides. The separation is not perfect, but more than adequate given the high energy spectrum of the neutrons in the metal-fueled IFR. The electrorefiner for use in FCF, shown in Figure 2, has been fabricated and shipped to Idaho.

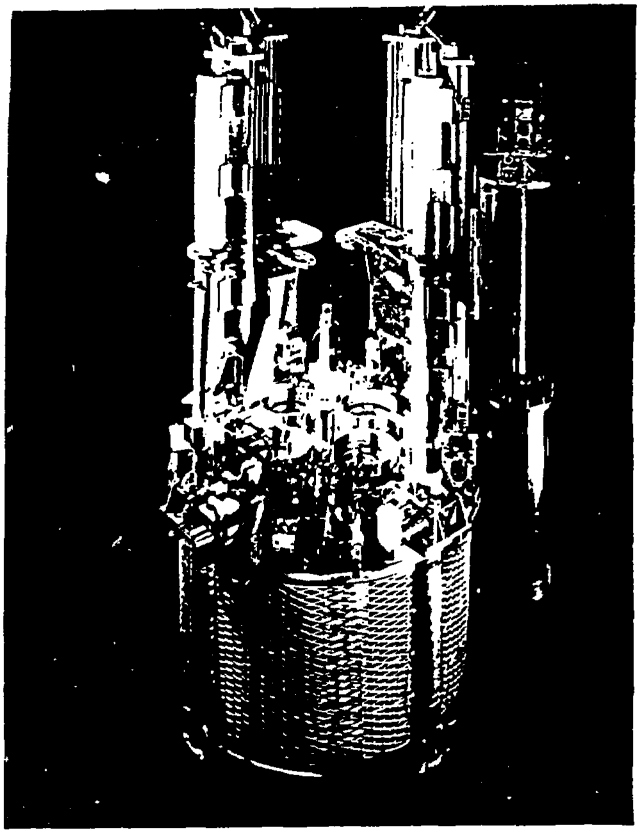

Figure 2 - Partial Assembly Of The FCF Electrorefiner

Cathodes, with 4-10 kg of heavy metal each, are further processed in the Cathode Processor. This machine carries out a high-temperature retort operation wherein the electrolyte and process cadmium in the cathodes are retorted and the heavy metals are consolidated into ingots. Fabrication of the Cathode Processor is complete. The device is being assembled for remote qualification in the FCF mockup shop, as shown in Figure 3. An identical unit is being assembled for out-of-cell testing and continuing R&D, beginning in July of 1993.

Injection casting of metal fuel is the technology used for manufacturing EBR-II fuel since the reactor began operation in 1964. A new injection casting furnace has been constructed

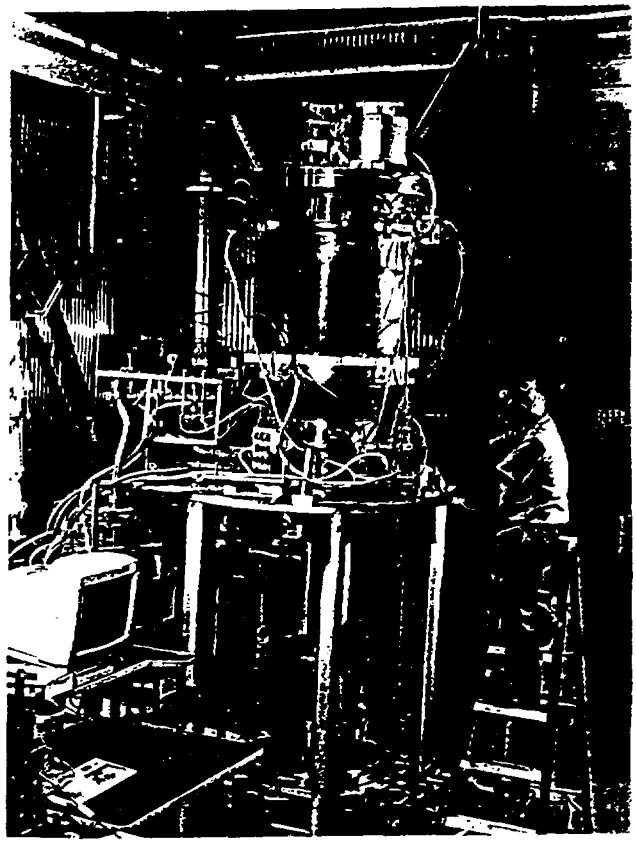

Figure 3 - Installation of the Cathode Processor In The Mockup Shop

and installed in the argon cell. Figure 4 shows the casting furnace prior to installation in its permanent location.

The pin processor is a multi-module device which will strip the molds from the cast fuel pins, shear them to length, provide quality control checks and insert accepted pins into fresh cladding tubes which will have been pre-loaded into a magazine. The pin processor has now completed its remote qualification phase, where like all equipment destined for hot cell use, its remote operation, maintenance, and repair capability was verified.

The welding station is where an end cap is inserted in the cladding, a TIG weld is made to seal the element, and a visual (TV) inspection is performed. A module is also included which can provide a Xe-Kr tag gas, if needed. The welding station has been fabricated and is undergoing remote qualification. Next a relatively simple low-temperature "settler" furnace is used in order to settle the fuel slug down through a small amount of metallic sodium pre-loaded into the cladding. This provides an efficient thermal bond between fuel pin and the reactor coolant. The settler is also being remotely qualified.

The final fuel element inspection occurs at a station which, by x-radiography, assures that the fuel pin has settled to the bottom of the cladding. An image enhancement feature permits viewing the bond sodium level, which assures that the sodium

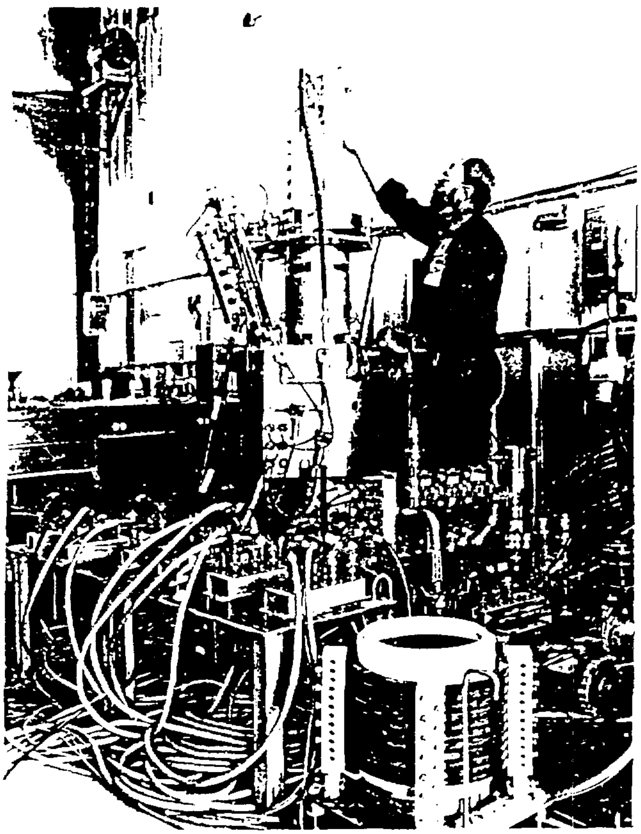

Figure 4 - FCF Injection Casting Furnace

has wetted the fuel pin and cladding. The fuel element inspection station is in final design. Several components have been received and tested.

II. FACILITY MODIFICATIONS

Extensive modifications to FCF were needed both from a programmatic and a regulatory perspective. An example of a programmatic change is a new contaminated equipment repair area that has been added to the facility basement for repair of equipment contaminated during the demonstration program. But most of the facility modifications have been done as a result of changes in DOE safety requirements since FCF was originally constructed in the early 1960s. These safety modifications have included numerous confinement improvements as well as installation of a safety-class exhaust system and a 360 kW emergency diesel system in a new interconnected 240 m^2 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 is expected to be completed before the end of August 1993.

In order to facilitate as early a start as possible for the demonstration program, the facility modification activities and process equipment are being completed in four stages that will allow a phased startup of facility operations. Each stage has a set of modification requirements that are determined by the added degree of radiological risk associated with the facility operations that will follow. The four phases of facility startup are defined as follows:

Phase 1:	Facility Ready for First Transfer of Process Equipment into the FCF Argon Cell
Phase 2:	Facility Ready for Operation of Process Equipment Using Depleted Uranium
Phase 3:	Facility Ready for Operation with Unirradiated Enriched Uranium and Plutonium
Phase 4:	Facility Ready for Processing Irradiated IFR Fuels (Hot Operation)

Phase 1 was completed in September 1991 when the element chopper was transferred into the argon cell, initiating remote process equipment checkout. A significant program milestone was achieved in April 1993 when DOE approval was granted for Phase 2 operation. The first depleted uranium casting with the FCF injection casting furnace took place in early summer. Phase 3 startup operations are scheduled to begin in September 1993, with Phase 4 following in February 1994.

For startup Phases 2 through 4, the project activities have been organized into 32 discrete work packages. Each work package represents a logical grouping of tasks for a given system, or related systems, that assures the necessary hardware and software are in place, operability of the equipment has been demonstrated, documents have been reviewed and approved, and personnel are trained and ready.

A major advantage of the work package approach is that it allows the facility review and approval process to run somewhat concurrently with construction. As a work package is completed, it is turned over to an ANL evaluation team which independently confirms the status of hardware, procedures, and personnel. On-site DOE personnel also have the option of reviewing each completed work package. When the complete set of work packages for a startup phase is finished, an operational readiness review is conducted by an independent board. This process, which worked well for Phase 2 startup, is now being applied to the much more complex set of activities that must precede plutonium operations.

A complete description of the work packages and their status is too lengthy to present here, but a look at the work package titles for Phases 3 and 4, shown in Table I, gives a fair hint at what systems are involved. The work packages for Phase 2 included Facility Systems, Safety Assessment, Environmental Documents/Notifications, and Administrative Documents. There are 11 additional work packages which will be completed after Phase 4 startup that do not affect the safety of hot operations.

Figure 5 shows the installation of the new safety exhaust system (SES) that is a requirement for Phase 3 startup. Figure 6 shows the new transfer tunnel, which needed to have limited functional capability for Phase 2 but must be completed and approved prior to the Phase 4 startup.

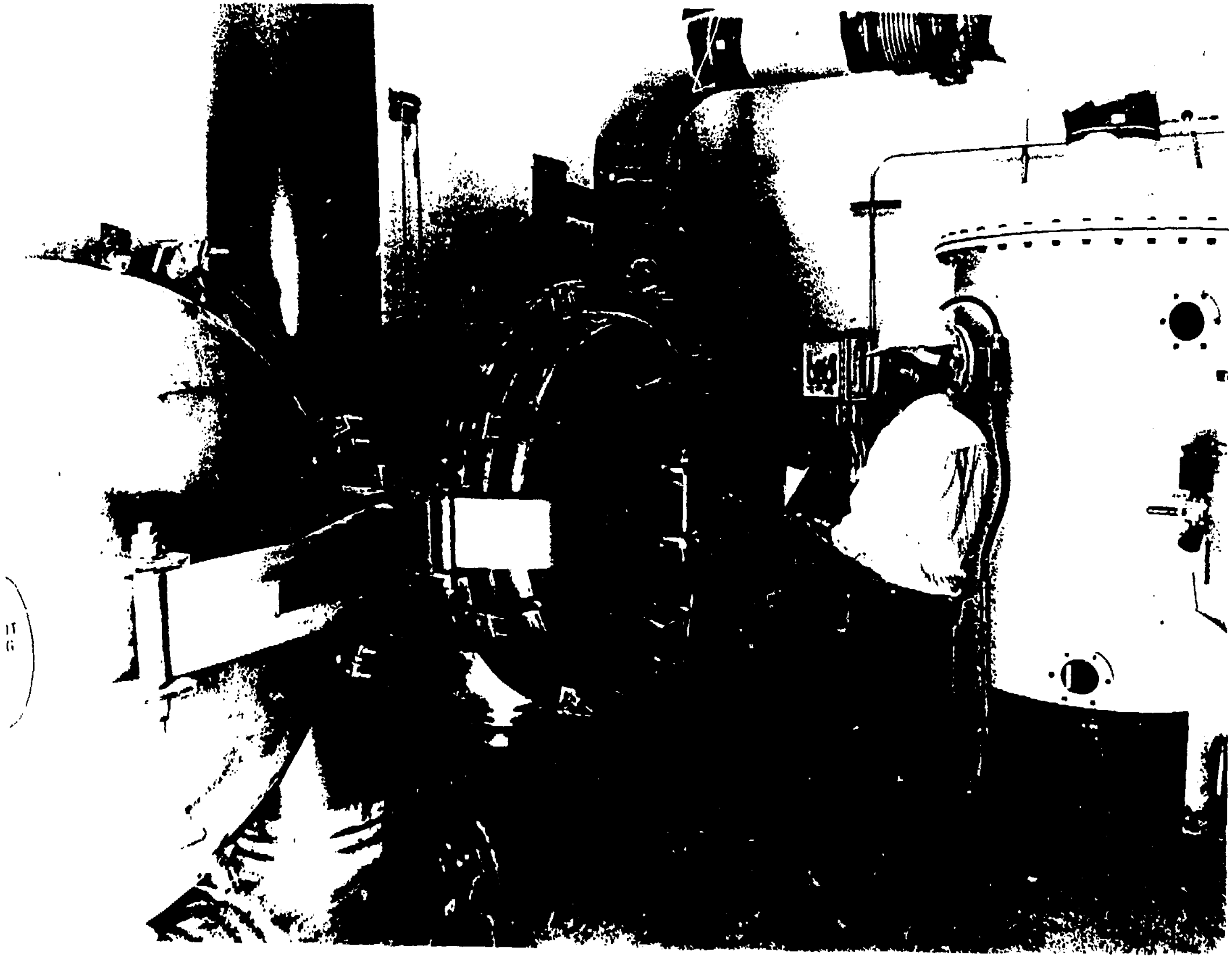

Figure 5 - Part Of The New Safety Exhaust System
In The Safety Equipment Building

Table 1 - Work Package Titles For Phase 3 and 4 Startup

PHASE 3 WORK PACKAGES	PHASE 4 WORK PACKAGES
Argon Cell Confinement Boundary	Cask Transfer System
Confinement Boundary for the Contaminated Air Enclosure	Highbay Modifications
Modifications/ of Secondary Confinement Boundary	Radioactive Liquid Waste
Argon Cell Atmosphere Systems	Hot Repair Facility and Air Cell Systems
Safety Exhaust System	Electrorefiner
Safety Equipment Building	Cathode Processor
Air Cell Exhaust System	FCF Shield Test
Stack, Stack Fans and Building Supply and Exhaust Systems	
In-cell Handling and Lighting Systems	
Intercell Transfer Systems	
Facility Support Systems	
Security Systems and Documents	
Radiation Monitoring	
Normal Power	
Emergency Power	
Control of Special Nuclear Materials	
Safety Documentation	
Environmental and Waste Notification	
ANL-W Site-Wide Procedures	
Injection Casting Furnace	
Integrated Acceptance Test Plan for Pu Operations	

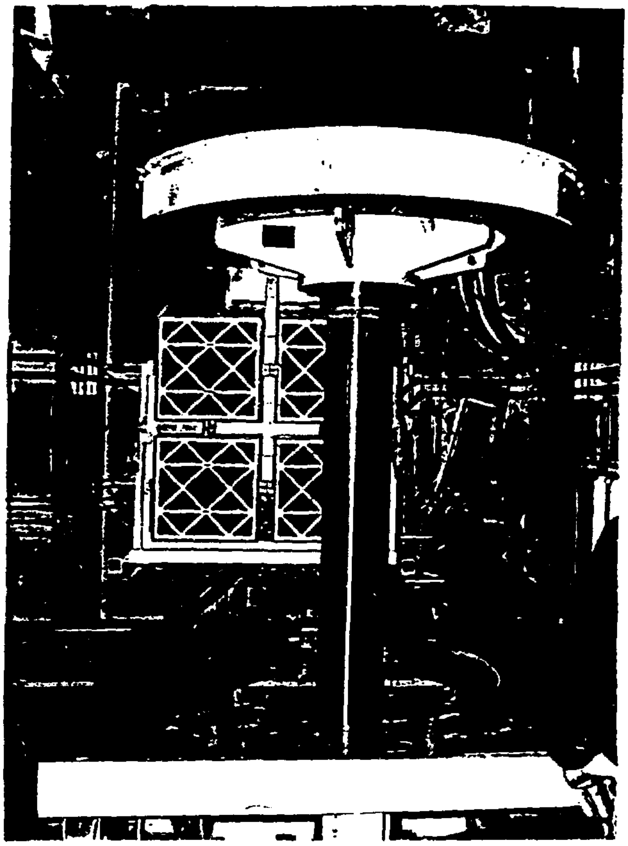

Figure 6 - Transfer Cart and Platen With Ram In Up Position For Final Phase 2 Checkout

III. DEMONSTRATION PROGRAM

The fuel cycle program will demonstrate processes that previously have been carried out in glovebox operations. Technical feasibility of pyrometallurgical reprocessing has been developed and demonstrated at engineering scale for depleted uranium and at bench scale for plutonium-uranium alloy. Extrapolation from the present database to the fuel cycle demonstration will include larger batch sizes, irradiated fuel, remote operation and maintenance, recycled (Mark-V) fuel for EBR-II, and large scale retorting.

The program will contain elements of research and development in addition to demonstration of scaled-up processes. With new equipment and process flowsheets that have not been tested under the FCF operating conditions, the occasional need for modifications is anticipated. Plans are already being made for new or improved process equipment and components, particularly in the waste operations.

In order to evaluate the commercialization potential of the IFR closed fuel cycle, operational and institutional data will be taken in addition to measurements of parameters needed to characterize the processes. A sound nuclear materials safeguards system and a record of safe operation will be needed to demonstrate institutional acceptability. Detailed operational records will be maintained for use in an eventual economic evaluation of reliability and maintainability. Once FCF is in full-scale operation, it will provide all the driver fuel required by EBR-II.

The products recovered from irradiated fuel refining during the initial operations will be used to produce Mark-V subassemblies, which contain a ternary alloy of enriched uranium, plutonium, and zirconium. The plutonium will be initially provided from cold plutonium feedstock. Later in the demonstration these subassemblies, produced in FCF and returned from the reactor, will be available for processing. Typically, two years of in-reactor time will be required to reach the design burnup limit (approximately 10 atom percent) for these subassemblies. A few subassemblies will be removed after partial burnup to provide early and varied data for fuel pyroprocessing.

For the first two years, the majority of the actinide processing experience with irradiated fuel will be obtained by refining subassemblies that are currently in the reactor or that have recently been discharged. The EBR-II core primarily contains subassemblies which are composed of a binary fuel alloy with enriched uranium and zirconium. The characteristics of the currently available subassemblies are shown in Table II. In addition, some 200-400 experimental pins, containing from eight to twenty-eight weight percent plutonium, will be available for processing.

Prior to the availability of irradiated Mark-V fuel, plutonium feedstock will be added to the electrorefiner to demonstrate large-scale transuranic processing with and without fission products present. By mixing in the appropriate amounts of plutonium with the EBR-II binary driver fuel, a very good simulation of dissolved commercial IFR fuel can be achieved, as shown in Table III.

Table II - Irradiated Subassemblies Available for Processing

Characteristics	Mark-IIC	Mark-IICS	Mark-III	Mark-IIIA
Presently Available[a]	9	29	58.5	12.5
Projected Available[b]	13[c]	42[c]	62[c]	84.5[c]
Peak Burnup[d] (at %)	6.4 & 8.9	6.4	10	10
Average Burnup[d] (at %)	4.8 & 6.9	4.8	8.2	8.2
Number Cooled <1 Yr[e]	4[c]	13[c]	3.5[c]	72[c]
Number Cooled >1 Yr, <2 Yrs[e]	5	8	28	12.5
Number Cooled >2 Yrs[e]	4	21	30.5	0
Decay Power at 180 days[d] (W/SA)	142 & 202	142	337 & 277	337 & 277
Decay Power at 1 year[d] (W/SA)	72 & 107	72	189 & 159	189 & 159
Decay Power at 2 years[d] (W/SA)	t.b.d.	20	49 & t.b.d.	49 & t.b.d.
Activity at 180 days[d] (Ci/SA)	38682 & 55219	38682	92491 & 76040	92491 & 76040
Activity at 1 year[d] (Ci/SA)	19678 & 29251	19678	51835 & 43535	51835 & 43535

[a]Subassemblies available as of February 1, 1993.
[b]Total Number of subassemblies expected to be available on February 1, 1994.
[c]These values include an estimate of the number and types of subassemblies to be removed from EBR-II between 2/1/93 and 2/1/94.
[d]Mark-IIC includes control and safety rods, Mark-IICS includes HW control rods, and Mark-III and Mark-IIIA include core drivers and inner blanket drivers.
[e]Cooling times are estimated for February 1, 1994.

Table III - Simulated Ternary Fuel Compared With IFR Fuel[a]

Chemical Element	EBR-II Binary Driver Fuel (grams)	Simulated Ternary Fuel (grams)	Typical IFR Driver Fuel (grams)
uranium	9959	7760	7760
plutonium	37.5	2210	2211
americium	0.00012	0.44 to 46	16.3
neptunium	3.9	3.9	12.0
lanthanum	29.6	23.0	40.8
neodymium	93.4	72.5	120
cerium	62.4	48.4	76.3
sodium	270	210	174
barium	31.4	24.4	49.5
cesium	86.0	66.7	136
strontium	26.4	20.5	16.4
zirconium	1291	1002	1337
niobium	0.11	0.085	0.005
other noble metals	213	165	356

[a]normalized to 10 kg charge of actinides from 10% burnup fuel discharged from 900 MWt commercial IFR

For planning purposes, the fuel cycle technology demonstration program has been broken into 10 distinct operational categories: startup fabrication operations, cold plutonium fabrication operations, refined fuel fabrication operations, startup refining operations, irradiated refining operations, equilibrium operations, process stream characterization operations, fission product separation operations, waste form testing, and advanced separation operations. Basically, these are just fabrication, refining, and waste operations during different phases of the demonstration. Equilibrium operations refers to the collective set of operations once irradiated Mark-V fuel is available for processing. *Startup fabrication operations*, which involve just depleted uranium, have begun. Startup refining operations initially involve depleted uranium, then follow with processing of unirradiated plutonium. Separate program plans are being developed for each of the 10 categories. The relationship of these program categories to facility readiness is shown in Table IV.

Table IV - Relationship Between Program Demonstration Operations and Facility Readiness

Program Demonstration Operations	Expected Starting Time	Required Facility Readiness Phase (Project Date**)	Process Equipment Requirements
Startup Fabrication Operations	May 1993	Phase 2 (April 1993)	Casting Furnace, Pin Processor, Element Welder/Settler, & D.O.E approval for operations*
Cold Plutonium Fabrication Operations	October 1993	Phase 3 (September 1993)	Casting Furnace, Pin Processor, Element Welder/Settler, & D.O.E approval for operations*
Refined Fuel Fabrication Operations	May 1994	Phase 4 (February 1994)	Casting Furnace, Pin Processor, Element Welder/Settler, Element Inspection & VAD plus product from refining operations*
Startup Refining Operations	March 1994	Phase 2	Element Chopper, Electrorefiner Startup*, Station 3, & Cathode Processor
Startup Refining Operations with Cold Plutonium	May 1994	Phase 3	Element Chopper, Electrorefiner, Station 3, Liquid-Cadmium Cathode*, & Cathode Processor
Irradiated Refining Operations	July 1994	Phase 4	VAD, Element Chopper, Electrorefiner*, Station 3, & Cathode Processor
Equilibrium Operations	June 1996	Phase 4	All Fabricating and Refining Equipment

* Indicates the critical path item for each operational category.
**The project date is the time when the project asks DOE for permission to commence operations

Fuel refining operations involve the element chopper, the electrorefiner, and the cathode processor. The key goal for fuel refining, and in fact for the whole demonstration, is the quantitative recovery of plutonium together with uranium and the minor transuranic elements in the presence of a high concentration of fission products. Other than waste processing, this is the only process step that requires a significant extrapolation from the laboratory results or past EBR-II fuel experience.

For the retorting step in the cathode processor, the goal is to obtain a high-purity actinide ingot with minimal loss of product. A secondary goal is to collect the volatized salt or cadmium for recycling to the electrorefiner.

The goal for the element chopper operation is simply to provide fuel element segments for the electrorefiner anode at a rate sufficient for the demonstration. This piece of equipment, designed for EBR-II fuel elements, is not meant to be prototypic of a commercial operation. However, the key performance parameter, lifetime of the die used to shear sodium-bonded ternary fuel elements, will be demonstrated.

Fuel fabrication equipment is comprised of the casting furnace, the pin processor, the element welder, element settler, and the element inspection station. The main goal is to fabricate acceptable Mark-V fuel for EBR-II with feedstock obtained from processed spent fuel.

The FCF injection casting furnace is a close relative of previous casting furnaces that have been used to manufacture EBR-II fuel for almost 30 years. The goal is to cast commercial-size batches (~20 kg) of ternary fuel pins that will meet EBR-II Mark-V series fuel specifications. Previous ternary fuel production has been a glovebox operation for batch sizes of less than 1.3 kilograms. A secondary goal is to demonstrate routine fabrication of metallic fuel containing a significant fraction of minor transuranic elements, americium in particular.

Goals for the pin processor operation include demonstrating an effective process for shearing the fuel pins to length, loading pins into sodium-bearing cladding, and providing acceptable elements and pin data to the remainder of the fabrication process. Another important goal is to demonstrate that pin measurements of length, diameter, and weight, combined with compositional data, are sufficient to control fuel reactivity.

The FCF element welder, although sized for EBR-II, is a robotic device that will demonstrate some advanced fabrication features. The main goal of the welding operation will be to demonstrate automated tungsten-inert gas (TIG) welding of type 316 austenitic stainless steel and type HT9 ferritic/martensitic stainless steel to reactor fuel quality standards. A second important goal will be to demonstrate quality control using automated weld inspection based on a vision system. A third goal will be to tag individual subassemblies with a unique krypton-xenon gas mixture in order to determine the location of any failed pins within EBR-II.

The element settler is a relatively simple device used to establish an effective thermal bond of sodium between the fuel pin and the cladding of an EBR-II fuel element. The goal for this operation is simply to establish the parameters needed for adequate bond quality.

The element inspection station introduces new technology for the application of examining finished fuel elements. An x-ray system is being used to examine the fuel position and sodium bond in each element. Because the fuel has a high gamma field from fission products carried over in the refining process, x-ray inspection techniques are a challenge. But they offer a rapid and effective inspection technique if the problems with the gamma background can be overcome.

Much support for the IFR program arises from its promise to deal effectively with the issue of nuclear waste. In addition, environmental regulations require strict waste management practices in the facility. Accordingly, the program goals for the IFR fuel cycle waste operations[2] are ambitious. The key goal of the FCF waste operations is to produce licensable low-volume waste forms with a minimum of TRU content. The first operations involve separating fission products from useful process materials. Fission product separation operations will be delayed for approximately two years, allowing sufficient materials to accumulate from the fuel refining operations. Separation flowsheets and equipment will be developed specifically to meet FCF requirements and the pyroprocess development needs.

The initial goal is to characterize the process streams in the facility and to provide safe storage of the materials pending further treatment or disposal. The categories of streams include direct process waste, gas-borne waste, indirect process liquid waste, indirect process solid waste, and non-radioactive waste. Materials will be characterized according to radioactivity, TRU content, and the presence of hazardous materials. Characterization protocols will be developed as a part of the program. A key parameter in safe storage is the heat load of the material.

The direct process streams include principally salt and cadmium from the electrorefiner, used fuel element hardware, and subassembly hardware. For these streams, the objective is to produce two waste forms suitable for permanent regulated disposal, one form containing the salt and another containing the metal. A major thrust of the IFR program is to make these permanent waste forms as free as feasible of all transuranic elements in order to reduce the required isolation time, and thus possibly ease the requirements on a geologic repository. The initially developed waste forms will provide the baseline for future TRU minimization.

After approximately a year of processing, the fission product buildup in the electrorefiner will reach a thermal limit, requiring a separation operation to remove a substantial fraction of the fission products. Initially, the demonstration of separation operations is planned to take place in the electrorefiner itself. Later, advanced extraction equipment will be demonstrated to provide a more prototypic database for commercial equipment design and operation.

The ultimate goal of the waste operations will be to produce the salt and metal waste forms that can be made available for testing at ANL and, most likely, other laboratories. Production of acceptable waste form samples is a major technical hurdle that must be cleared before full commercialization of IFR fuel cycle technology is possible.

Although the FCF process is not designed for continuous high-volume operation, its overall technical operability will be essential to evaluation of the commercialization potential. A goal of the demonstration is to develop a comprehensive database covering the details of facility operation during the program. This database should include maintenance and repair records in addition to process records and records for the facility support activities. This database should provide information needed to establish a baseline for processing rates, although process improvements and more automated equipment would be expected to increase rates in a commercial facility by more than an order of magnitude in some cases.

Another goal of the overall facility operation is to demonstrate a level of safety commensurate with the robust reactor safety already demonstrated in the IFR program. Safety experiments are not specifically planned for the fuel cycle program, but at the end of the demonstration the record of operation is expected to show an adequate margin of safety.

The current schedule for the FCF demonstration program is shown in Figure 7.

To summarize, a major FCF milestone, approval for operation with unirradiated plutonium and enriched uranium, is expected to occur around the time of the Global '93 conference. By February of next year, facility modifications and process equipment will have reached a state of readiness for irradiated fuel operations. Completely recycled U/Pu/Zr fuel is expected to be provided to EBR-II in 1996.

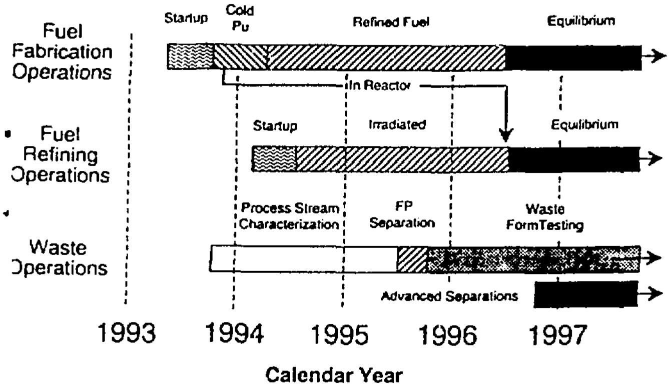

Figure 7 - Schedule For The IFR Fuel Cycle Demonstration

IV. ACKNOWLEDGEMENTS

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