PLANS FOR THE DEVELOPMENT OF THE IFR FUEL CYCLE*

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Background

The Integral Fast Reactor (IFR) is a concept for a self-contained facility in which several sodium-cooled fast reactors of moderate size are located at the same site along with complete fuel-recycle and waste-treatment facilities. After the initial core loading with enriched uranium or plutonium, only natural or depleted uranium is shipped to the plant, and only wastes in final disposable forms are shipped out. The reactors have driver and blanket fuels of uranium-plutonium-zirconium alloys in stainless steel cladding. The use of metal alloy fuels is central to the IFR concept, contributing to the inherent safety of the reactor, the ease of reprocessing, and the relatively low capital and operating costs. Discharged fuels are recovered in a pyrochemical process that consists of two basic steps: an electrolytic process to separate fission products from actinides, and halide slagging to separate plutonium from uranium.

The IFR concept has several important advantages over current light water reactor (LWR) and liquid metal reactor (LMR) designs. The self-contained facility in which fissile materials are only partially decontaminated is highly diversion and proliferation resistant. The reactor has been shown to be immune to several types of severe accidents, such as loss-of-coolant, loss-of-heat-sink, and transient overpower. In these accidents, damage to the reactor is prevented not by engineered safety systems but by the basic physical characteristics of the reactor itself. The inherent safety of IFR-type reactors was demonstrated in recent tests. With the automatic safety systems intentionally turned off, the primary sodium pump was shut down in the first test. Without operator intervention, the reactor power decreased smoothly from full power to near zero within a few minutes, and no damage to the reactor occurred. A similar result was obtained in a second test in which the secondary coolant pump was shut down simulating a "loss-of-heat-sink" accident.

The overall fuel cycle is also less hazardous than the LWR fuel cycle for several reasons. First, off-site shipping of radioactive materials is greatly reduced. Second, the IFR fuel processing facility is smaller, and thus easier to contain, and the process uses no neutron moderators. Third, radioactive releases should be very low, because all fission products can be easily contained within the facility. Finally, fuel is not directly handled in the fuel cycle operations, and so worker exposure should be lower.

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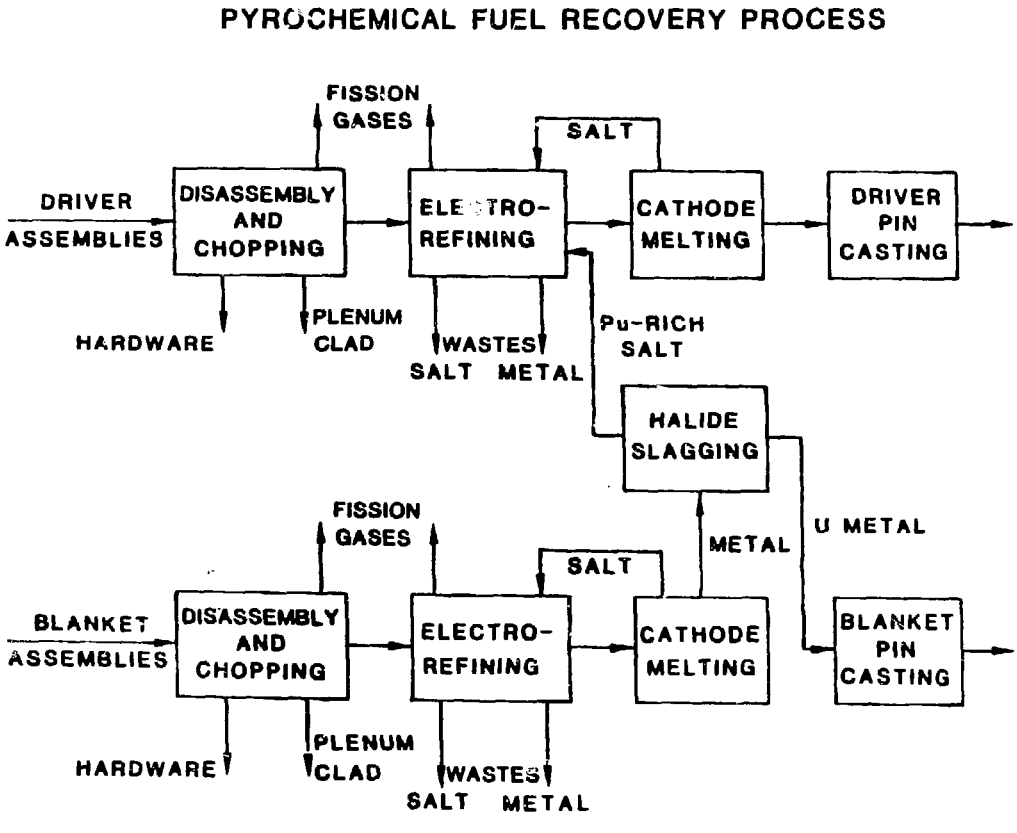
DISCLAIMER

Description of Pyrochemical Processes

The principal steps in the fuel recovery process are shown in Fig. 1. Spent driver and blanket fuel assemblies are brought into an argon-filled processing cell and dismantled. The separated driver and blanket fuel elements are sent through similar processing steps to remove most of the fission products. The elements are first chopped into short pieces, with the plenum cladding being segregated from the fuel-bearing sections. The chopped clad fuel is then loaded into steel baskets and immersed in the liquid cadmium anode of an electrorefining cell. Uranium, plutonium, and the other actinides, with the possible exception of americium, are transported electrolytically to the cathode. This step leaves electronegative elements (Fe, Zr, and noble metal fission products) in the anode and electropositive fission products (alkali metals, alkaline earths, and rare earths) dissolved in the electrolyte as chlorides. After most of the uranium and plutonium has been deposited on the cathodes and removed from the cell, the anode baskets and a portion of the electrolyte are removed to effect separation of the fission products.

Figure 1.



The cathode deposits are melted to consolidate the metallic actinide product and separate adhering salt, which is returned to the electrorefining cell. The consolidated driver fuel alloy is recast into fuel pins by injection casting. The blanket fuel is first sent to the halide slagging step in which the metal is melted in contact with a chloride salt containing UCl_3, thereby oxidizing the plutonium and transferring it to the salt. The plutonium-rich product salt is added to the driver-fuel electrorefining cell to re-enrich the driver fuel. The plutonium-depleted uranium metal is recast into blanket fuel pins.

Status of Pyrochemical Process

The IFR development work is based on the experience gained in operation of EBR-II and its integral fuel cycle. In the 1960s, the metal alloy fuel in EBR-II was successfully reprocessed by a pyrochemical technique. Many of the operations envisioned for the IFR fuel cycle facility, especially the head-end and fuel refabrication steps, are similar to those used earlier.

Laboratory experiments with 10 to 100 g of actinides demonstrated the chemical feasibility of the pyrochemical process. Halide slagging experiments demonstrated an adequate separation of plutonium from uranium. More than 90% of the plutonium can be extracted from discharged blanket fuel corresponding to a Pu/U ratio in the salt of at least 0.6, which is sufficient to re-enrich the driver fuel. Any plutonium left in the uranium metal is returned to the blanket and, thus, is not lost. Beryllia crucibles proved to be very good containers for halide slagging and for other operations in which fuel alloy is melted.

Electrorefining experiments showed that uranium and plutonium can be electrotransported from a liquid cadmium anode and deposited on a steel cathode. By controlling conditions in the electrorefining cell, these actinides can be deposited separately or together. The separation of key fission products from the actinides was found to be adequate, with the decontamination factor for rare earths being at least 100 and greater than 1000 for noble metals, alkali metals, and alkaline earths. The cathode deposits can be coalesced and the adhering salt separated by melting them in BeO crucibles.

The primary process wastes are the chloride salts and the spent anode baskets removed from the electrorefining cells. Contacting the waste salt with a Cd-Li alloy can reduce the alpha activity in the salt to less than 100 nCi/g, thus making the salt easier to dispose of.

Plans for Developing Pyrochemical Process

The laboratory-scale experiments will be continued to obtain additional information on the behaviors of actinides and fission products in the process. Of particular interest are the co-deposition of americium and curium with plutonium and the behavior of zirconium in the electrorefining step. The effects of various operating conditions on mass transfer rates, product yields, cathode deposit characteristics, etc., will be determined in order to improve the performance of the electrorefining cell. Increased

efforts will be devoted to developing methods for converting pyroprocessing wastes to disposable forms. Studies will also be made of pyrochemical methods to separate actinides from all process wastes so that only wastes with the transuranics removed will be produced by the IFR fuel cycle.

The main problem areas primarily involve engineering design of the electrorefining cell. Key problems are (1) determination of mass transfer rates of uranium and plutonium between the electrodes; (2) design of the anode to allow rapid dissolution of chopped, clad-fuel alloy while the cladding and other insolubles are retained; and (3) design of apparatus to charge anodes and discharge products and wastes. These problems will be addressed in an engineering-scale (10 kg U, no Pu) facility expected to begin operation by January 1987. This size is about one-half that required for a facility servicing a 1000 MW(e) reactor park. The cell is intended to demonstrate that uranium metal can be transported from a cadmium anode and deposited on cathodes at a rate of 10 kg/day, as required by the commercial facility.

The next step in the development of the IFR fuel cycle is to demonstrate the complete IFR fuel cycle with fully irradiated fuel from EBR-II. The equipment needed for this demonstration will be installed in the existing facilities at EBR-II and will be put into operation by 1991. Conceptual designs are being devised of this equipment, and preliminary work is under way to upgrade the EBR-II Fuel Cycle Facility.

Goal

The goal of the IFR Program is a commercial facility in which the power reactors and fuel-recycle/waste-handling facilities are integrated at one self-contained site. Argonne National Laboratory has prepared a conceptual design of such a facility integrated with either the General Electric PRISM or the Rockwell SAFR reactors. For a 1000 MW(e) plant, the main process cell, in which all fuel recycle operations are performed, would be 17 m by 10 m by 4.3 m high. The estimated capital cost of the total facility, including the maintenance cells, waste handling/storage building, analytical cells, offices, etc., is about $50,000,000. In a comparable Purex facility processing oxide fuels, the processing/refabrication cells would have 18 times the floor area and 40 times the volume; the complete conventional facility would cost about $270,000,000. Operating costs for the pyrochemical fuel facility were estimated to be lower because of its greater simplicity and ease of operation. The ease of refabricating metal fuel pins as compared to reforming mixed-oxide fuel pellets was an important advantage of metal fuels. As a result, the cost of electricity produced by the IFR concept was projected to be competitive with present LWRs. It also appeared economical to build a relatively small fuel cycle facility to service several reactors having a total electrical output of about 1000 MW.

Although a great deal of research and development effort is needed to reach this goal, the results to date are very encouraging. The IFR concept has the potential to become the next generation of commercial power reactor. The capability to recover the metal fuels in a simple pyrochemical process will be one of the keys to the success of this reactor.