ADVANCED REACTOR DEVELOPMENT: THE LMR INTEGRAL
FAST REACTOR PROGRAM AT ARGONNE

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The Integral Fast Reactor concept is so named because all the elements of a complete breeder reactor system are developed and optimized as a single entity and could in fact, if desired, all be made an integral part of a single plant.

The IFR is based, in one way or another, on the earlier Argonne directions made newly relevant for two basic reasons. First, new discoveries had been made within the Argonne program that indicated new possibilities in fuels, safety, and fuel cycle technology. Second, when factors now affecting nuclear power are recognized, reactor system properties not thought to be important before now seemed very important indeed.

In the summer of 1984 the IFR program was started. The program was governed from its inception by four overriding requirements:

- Passive or inherent safety characteristics.
- Economically competitive.
- Environmentally sound.
- Proliferation- and diversion-resistant.

For the concept to be feasible, three basic developments were needed: a specific metal alloy was required; establishing concomitant improvements in reactor safety was essential; and showing the feasibility of the new metal-based fuel cycle was perhaps the most important of all.

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FUEL

The fabrication of any metallic fuel alloy promised to be cheap, and readily adapted to remote operation. The EBR-II fuel had been made at Argonne for years, with one simple casting operation instantly producing enough fuel for one assembly. In the period 1964-69, fuel had been made remotely for EBR-II.

Yet the standard EBR-II metal fuel then available would not do, outstanding in-reactor though it was, because it didn't use plutonium. In a closed cycle breeder system, plutonium is the bred material, so any IFR alloy had to include plutonium.

The alloy selected was a (Uranium-Plutonium)-Zirconium alloy that had very limited trials in the late 1960s, but appeared to have the basic characteristics needed. It used plutonium; it had a high melting point and a high eutectic point with stainless steel, even higher than those for EBR-II fuel.

But would the U-Pu-Zr alloy provide adequate burnup? In the fall of 1984, a new plutonium fuel fabrication capability was put in place. The Experiment Fuels Laboratory, or EFL, was created in just four months, once again demonstrating the simplicity of the fabrication process. Early in 1985, three lead assemblies of the new IFR fuel were put into EBR-II.

The fuel development has been a remarkable success. Over eighteen atom percent burnup has been achieved in these first assemblies. The data base with IFR fuel will now grow at a significant rate, for as of the beginning of 1989, EBR-II was com-

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pletely fueled with prototypic IFR alloys.

SAFETY

It was important to demonstrate the unique safety properties made possible in the IFR with the use of metallic fuel. On April 3, 1986, two carefully planned tests were carried out. From full power in EBR-II, with the normal safety systems temporarily bypassed, the power to the primary pumps was shut off, simulating station blackout, or loss-of-flow without scram. The reactor shut itself down without safety-system or operator action, because of the reactivity feedback characteristics of the IFR. No damage occurred to either the fuel or to any of the system structures. Later in the day, the reactor was brought back to full power and a loss-of-heat sink without scram test was also carried out. The result again was without harm of any kind. These tests dramatically demonstrated what is possible for incorporating passive safety features in IFR plants.

Parenthetically, later in that month, the Chernobyl accident occurred and the stark contrast between the consequences of these two loss-of-flow events in the same month gave much added impetus to IFR development.

EBR-II is an electricity-generating power reactor, which although small (20 MWe), has a power density typical of that in larger fast reactors. The features of EBR-II which allowed it to shut itself down in these two tests, are typical of larger IFR plants as well.

The third of the classical fast reactor Anticipated Transient-Without-Scram (ATWS) events, the transient overpower (TOP) accident, is also reduced in consequence because of the metal fuel. The higher core conversion ratio offered by the higher fuel atom densities achievable with metal gives rise to reduced reactivity swings during a cycle. This in turn reduces the control requirements, allowing lower-worth control rods. The initiator of TOP events is the control

rods, and the transient initiated by control rod withdrawal can be made much less severe than would otherwise be the case. The goal is to limit the available excess reactivity contained in control rods to levels which would cause no damage if inadvertent rod runout at power were to occur.

The safety case is further strengthened by the fact that significant margin exists before fuel failure would occur in fast reactivity transients. Tests in the TREAT reactor have demonstrated that linear power can be increased by about four times above normal before cladding failure occurs, and that during these excursions the metal fuel is expanding axially within intact cladding, driven by entrapped fission gas pressure, which provides a strong negative reactivity feedback. Tests at EBR-II addressing other plant transients, such as overcooling associated with a sudden increase in the speed of coolant pumps or a rapid depressurization of the steam system, have also been done and show that they can also be accommodated without safety system action.

FUEL CYCLE

Metal fuel opens up the possibility of using a much different process for reprocessing spent fuel, and this process is described more fully elsewhere. Electrorefining, instead of solvent extraction, can be used. Electrorefining has very different properties, and some of them are very advantageous.

The basic process is electrochemical. The fuel to be processed forms the anode of an electrolytic cell. The electrolyte is a molten salt and the product heavy metal is collected on a cathode. Proper selection of the voltage draws uranium and plutonium from the spent fuel, leaving the fission product waste behind. The separation is done in this single step, at relatively low temperatures (about 500°C) and the device in which this is done is very small and compact; a 1.5 m diameter module would be sufficient for a CRBR-size plant.

The process separates uranium and plutonium from the fission products adequately for fast reactor purposes, but leaves a highly radioactive diversion-resistant product.

Development began on a few-gram scale, and both a uranium-only process (necessary to recycle uranium for the breeder blanket) and a uranium-plutonium process (for the core) are now proven. The two processes differ only in cathode design. The uranium-only process has now been scaled up and operates routinely at plant scale, about 10 kg per cathode. The U-Pu process scale-up awaits the completion of our Idaho fuel cycle demonstration facility.

In tests conducted recently, fuel segments sheared from a fuel element irradiated to 10% burnup have been successfully dissolved in an experimental apparatus. This was done electrolytically, essentially the reverse of electrorefining. We found that the heavy metal could be driven quantitatively from the cladding (only 0.04% of the heavy metal remained) in a one hour period. We thus have evidence that within a single electrorefiner, fuel can be successfully dissolved electrolytically, and electrotransported selectively to cathodes. The key reprocessing steps of dissolution and separation are thus achievable in a simple, compact, piece of equipment.

Importantly, also we have found that the transuranics go with the product, so the waste product radiological toxicity is dramatically reduced, since the transuranics are recycled and burned in the reactor. In an IFR reactor, with the high-energy neutron spectrum unique to a metal-fueled fast reactor, these elements are efficiently fissioned, and essentially provide more fuel, not waste.

FUTURE IFR PROGRAM ACTIVITIES

The basic feasibility of all elements of the IFR have now been proven. The next important step will be to close the fuel cycle at EBR-II. EBR-II is our prototype. It is sodium-

cooled; it is a pool-type reactor configuration; it is now completely fueled with IFR fuel; and when we have the new processes in operation, we will have the complete prototype -- integral cycle and all. It will demonstrate each of the essential features of the IFR: Passive safety, ease of operation, fuel performance, reprocessing and recycle, and transuranic burnup to improve the waste form.

Modifications are in progress to fully demonstrate the new fuel cycle at the EBR-II Fuel Cycle Facility. Following its use in the 1960s, this facility was converted to an examination facility (and renamed the Hot Fuel Examination Facility/South). The facility is being modified to bring it up to today's level of standards and regulations for such a facility. The facility modifications are detailed elsewhere. Briefly, they are: (1) confinement improvements, (2) provision of a new class 1-E emergency power system, (3) installation of a new safety-class exhaust system, and (4) construction of a new area within the facility in which to repair contaminated equipment. All of the work associated with these four areas is scheduled for completion in June 1992.

The process equipment is now in fabrication. There are nine items of main equipment (all quite compact, in all cases able to pass through a 2 m diameter, 2.5 m tall transfer lock):

- assembler/dismantler machine
- element chopper
- electrorefiner
- cathode processor
- injection casting furnace
- pin processor
- element settling furnace
- element welder
- leak-detection module

The Fuel Cycle Facility will have a dual mission: produce all the fuel needed for EBR-II, and serve as a test bed for optimization of the process.

There is still basic development to be done, and this will be going

on simultaneously with fuel cycle operations and experiments in FCF. But through the early 1990s, the IFR prototype will be recycling fuel; the recycled fuel will be tested and proven and the whole system (fuel, fuel cycle, and waste process) optimized.

All of this will be done on the ANL-Idaho site, which has all the necessary facilities, and all done without large expenditures.

And what does the IFR promise?

- In safety, fuel with larger overpower margins, resilience to transients, completely nonreactive with the coolant; a reactor with built-in ability to survive both loss-of-heat sink and loss-of-flow without scram events.
- In breeding, metallic fuel is the best possible. In addition to the obvious resource conservation reasons, this also allows the limited control rod worths that help in Transient Overpower (TOP) situations, adding again to safety.
- A simple closed fuel cycle, with recycle, and reuse of uranium, plutonium, and the other transuranics as well. All transuranics go with the fuel product, and are not left in the waste.
- Recycled plutonium fuel always accompanied by uranium, always carrying the other transuranics, and some small amount of fission products as well, removing diversion concerns, and adding nothing incremental to proliferation risk.
- No transportation of fuel, or spent fuel, and if desired on-site storage of wastes for the life of the plant.
- A waste product that has all long-lived transuranics removed, such that the carcinogenic risk from the waste is greatly

reduced. A change in the kind of risk, not just in degree, and in the product the public is asked to accept in waste disposal.

Although no one attribute may make the case by itself, taken together all its attributes make the IFR system a truly revolutionary improvement in fission energy for the 21st Century.

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