Description of the ALMR/IFR Program 3

The Department of Energy (DOE) has been funding the development of an advanced liquid metal reactor under a program within the Office of Nuclear Energy. Recent budgets for this program were between $40 million and $43 million per **year** for FY 1992 and 1993, and $30 million for FY 1994. Most of the budget has been directed toward research work at the Argonne National Laboratory. During FY 1992 and 1993. some $10 million per year was directed toward research at the General Electric Company (GE).

The current DOE concept of the advanced liquid metal reactor/ integral fast reactor (A LMR/IFR) system includes a liquid metal-cooled nuclear reactor and associated nuclear fuel reprocessing, manufacturing. and waste processing facilities. The system combines many discrete components operating together at a single site. The complete system can be divided into three major parts:

1. an advanced li quid metal reactor.
2. a fuel reprocessing system for transforming ALMR spent fuel into new fuel and processing its radioactive waste fox- disposal, and
3. alight-water reactor (LWR) spent fuel reprocessing system for the recovery of plutonium, uranium, and related act in ides from the spent fuel from conventional U.S. nuclear reactors to make new ALMR/IFR nuclear fuel.

Figure 3-1 illustrates these major components and shows the stage of development for each. For example, the current reactor part of the test system is a prototype that has been operating in various tests for more than 30 years. Many of the fuel reprocessing components. such as the electrorefiner, have been tested but have yet to be tested as a prototype system. Many of the waste and spent fuel processing components are still in the design stage.

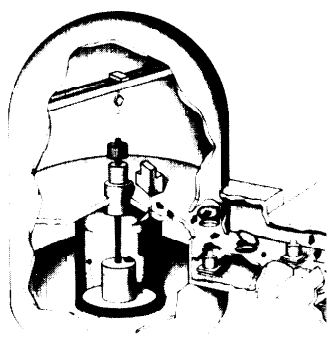
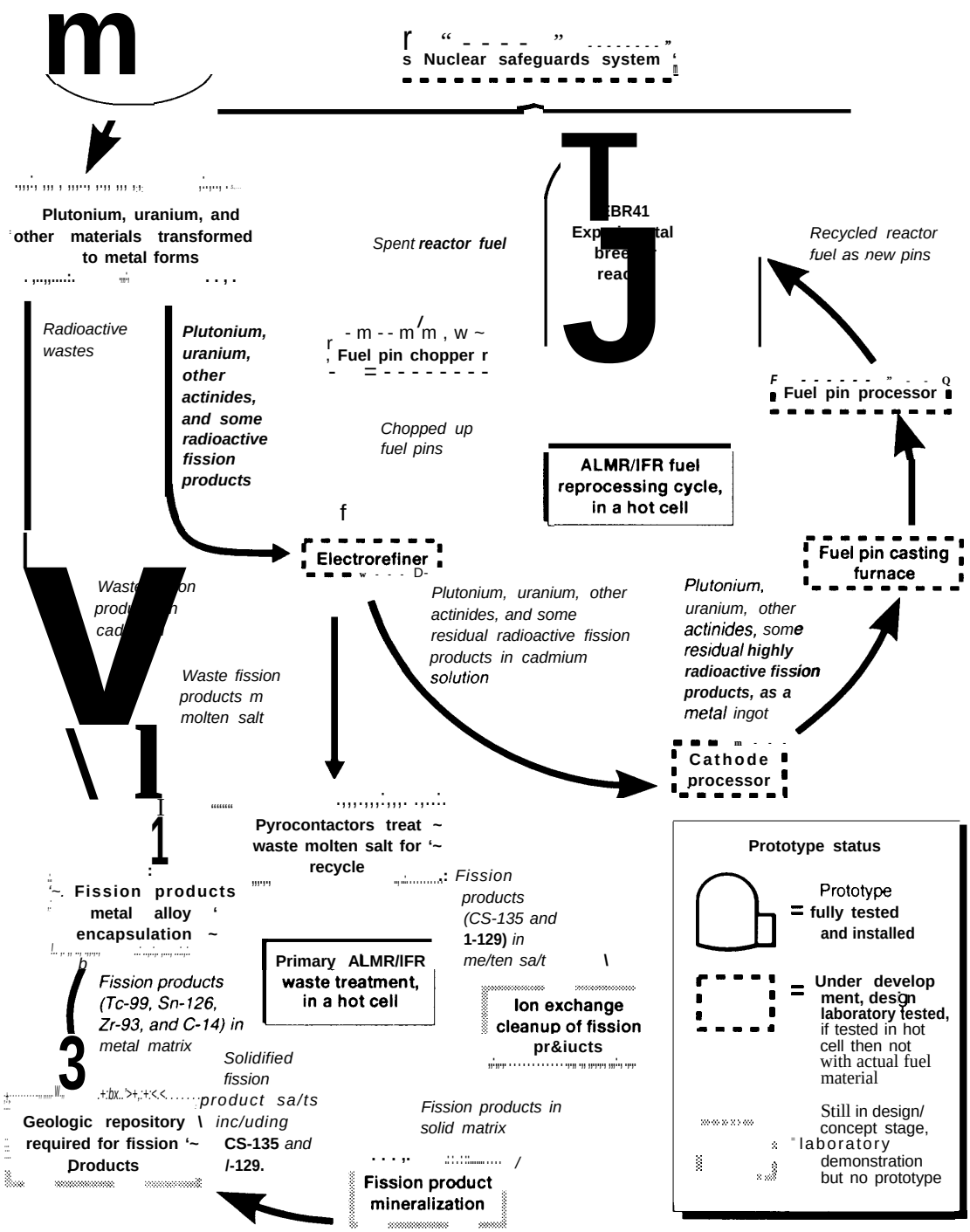


FIGURE 3–1: Planned ALMR/IFR Prototype at Argonne West, Idaho



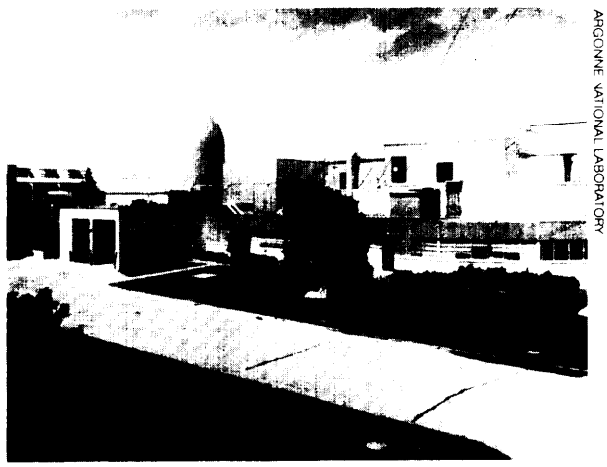
NOTE The system would involve many interlinked components, including a nuclear reactor and facilities for fuel reprocessing and fabrication, for reprocessing conventional reactor spent fuel into new ALMR/IFR fuel, and for handling the resulting nuclear wastes

SOURCE Argonne National [Laboratory

Argonne National Laboratory and GE are partners in research and development for the ALMR/IFR program. Argonne has taken the lead in developing the ALMR metal fuel reprocessing technology, while GE is focusing on developing the full-scale nuclear reactor. At present, the 30-year-old Experimental Breeder Reactor II (EBR-II) at Argonne West is serving as a prototype reactor for testing ALMR/IFR nuclear fuels (43). However, since the EBR-II is scheduled to be decommissioned at the end of 1994, its role in ALMR/IFR prototype development will be ending. DOE partly funds the GE reactor design project—at about $10 million per year over the last few years (43). GE also takes an active role in the ALMR/IFR fuel reprocessing development, via regular-meetings and consultation with Argonne National Laboratory researchers.

Figure 3-2 shows the 5-year schedule announced by DOE in 1991 for the development of a prototype ALMR/IFR at Argonne West(51). The total costs (shown by year and including nongovernmental contributions) over 5 years were projected at the time as $976.4 million.

Although the exact dates will change as work proceeds, the status of development of each component shown in figure 3-1 and the schedule shown in figure 3-2 illustrate that substantial developmental work remains to be done, and many of the individual components are in only the concept or early prototype stage. Some components have been demonstrated in the laboratory, but prototypes have not yet been constructed or tested. Thus any description of the ALMR/IFR system must be based partially on plans, rather than on actual hardware. This description also will have to be revised as the system is designed and developed. The schedule shown in figure 3-2 is for a prototype facility only (which was planned to be constructed at Argonne West), not for full commercialization of the technology. Although this schedule is already out of date, it serves as a general indication of the amount of development work ahead. It will require revision, for example, after the recent decision to suspend development of the nuclear reactor portion of the program and concentrate only on development of the prototype fuel reprocessing system (3).

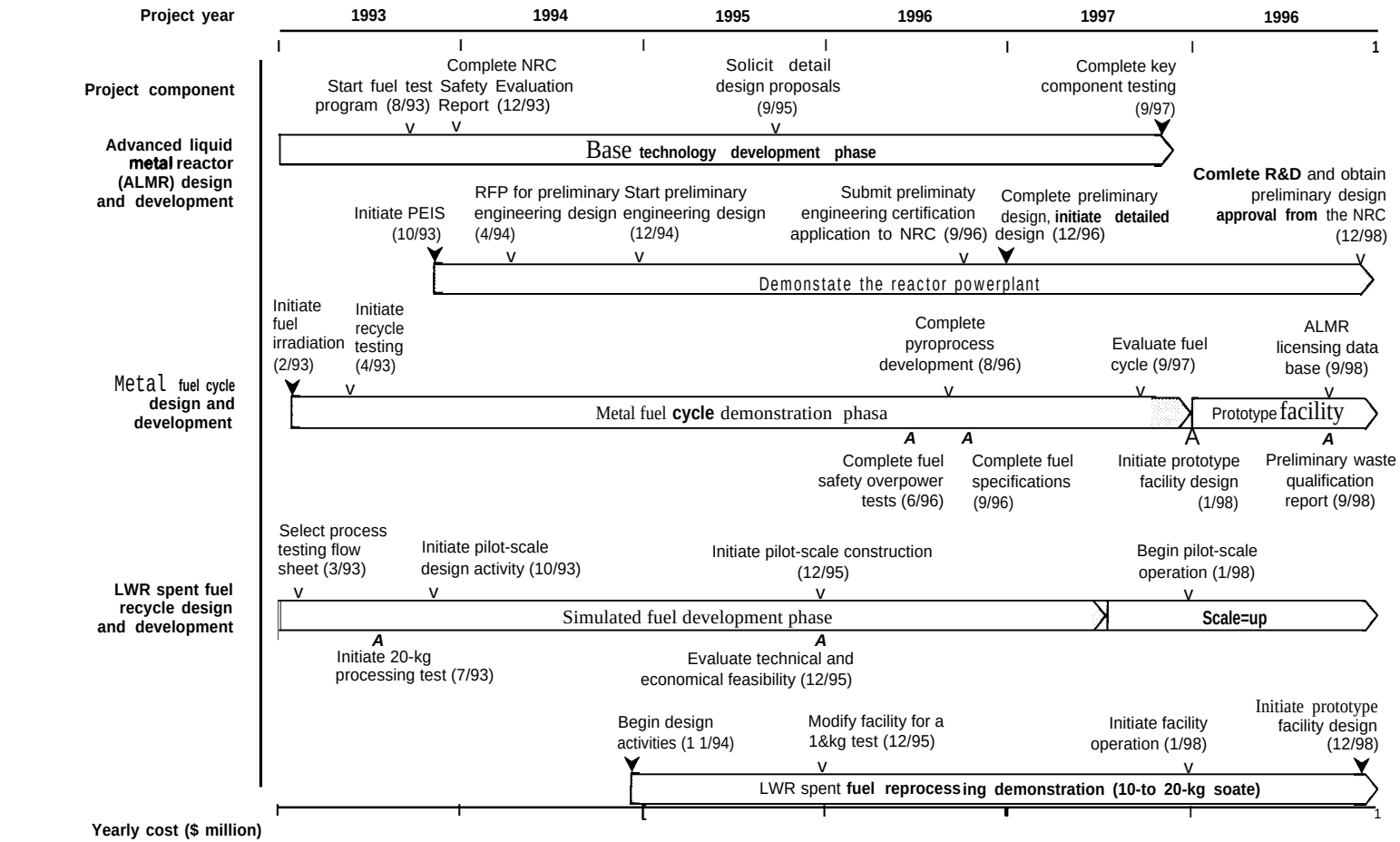


The EBR-II and fuel processing facility at Argonne West are prototype scale facilities. The reactor portion (left) has been in operation for several decades.

FUTURE FULL-SCALE COMMERCIAL DEVELOPMENT

If the planned research and development work, followed by completion of a prototype, is completed by Argonne and GE, full-scale commercial development using part or all of this fuel cycle may be carried out by a private sector multiorganization team. Using this assumption, GE has projected the full-scale ALMR system as a 1.866-gigawatt electric ALMR/IFR modular design plant that could include an ALMR/IFR metal fuel reprocessing facility with a capacity of 22 metric tons per year. Alternative] y, a centrally located facility with a capacity of 180 metric tons per year might support eight separate ALMR plants (44). The complete facility could also include a 2,800-metric-ton-per-year LWR spent fuel processing and conversion facility (12, 34, 42). High-level and low-level waste processing facilities would be colocated with the reactor and fuel reprocessing facility. One reactor design proposed by GE would use a nuclear fuel breeding ratio of 1.05 (i.e., for every pound of plutonium consumed during a fuel cycle, 1.05 pounds of new plutonium would be produced) and would also have the ability to operate at a range of ratios from 0.6 (thus

FIGURE 3–2: Proposed 5–Year Schedule and Projected Costs for a Prototype ALMR/IFR



Yearly cost ($ million)						
ALMR	8.8	31.5	47.7	101.0	151.0	137.0
Metal fuel	26.4	32.6	53.7	56.9	60.1	62.2
LWR reprocessing	6.5	18.5	19.5	30.0	30.0	30.0
Nongovernment contribution	9.5	12.0	13.5	10.0	15.0	13.0
Total	**51.2**	**94.6**	**134.4**	**197.9**	**256.1**	**242.2**

NOTE Although it IS out of date the schedule shows the amount of developmental work that remains undone Any analysis of the ALMR/IFR system Will require revision as the system IS designed developed, and deployed

KEY NRC = Nuclear Regulatory Commmission PEIS = programmatic environmental impact statement RFP - request for proposals

SOURCE U S Department of Energy, 5-Year Plan, 1993

consuming plutonium) to 1.23 (thus breeding plutonium) (34).

As of the end of 1993, GE projected schedule was as follows" (34):

- by 1996, complete technical feasibility and economic potential studies, as well as key features test and qualification phases;
- by 1999, complete both a concept demonstration and metal fuel qualification, and a components and subsystems test phase;
- by 2010, complete design certification; and
- after 2010, begin commercial deployment.

GE also projected that reprocessing LWR spent fuel could provide a source of startup plutonium fuel necessary for commercial-scale deployment (34, 42). The low-enriched uranium that will be simultaneously recovered from the reprocessed LWR fuel might either be put back into existing LWRs or into recycled AL MR/IFR fuel as a fertile material for breeder operation, or be disposed of as actinide waste in a repository. As an alternative approach, GE projected the full-scale AL MR/IFR system also to be capable of using a more conventional mixed uranium-plutonium oxide fuel (MOX) without electrorefiner reprocessing (42, 45).[1]

The commercial full-scale ALMR as conceived of by GE is a breeder-capable nuclear reactor that uses liquid sodium as a coolant, and a metal nuclear fuel containing plutonium and uranium. The full-scale GE ALMR design is projected to be a bank of up to six modular reactors, each generating 311 megawatts of electricity (each approximately 16 times larger than the EBR-II prototype) (34). With nuclear fuel reprocessing the system would be capable of operating as a breeder reactor (making more plutonium than consumed). This design has not yet been built. By comparison, conventional LWRs used for commercial power generation today in the United States are water cooled, use uranium oxide nuclear fuel, and do not reprocess their spent fuel.

The ALMR/IFR system has generally been presented as easily convertible between plutonium breeding and burning. The full-scale ALMR system envisioned by GE is designed specifically to be converted easily between breeding and nonbreeding operation (42). According to its designers, "[b]y straightforward adjustments in fuel composition and arrangement, the system can be readily adjusted to meet any overall fissile demand scenario, from being a rapid consumer of fissile material (conversion ratio as low as about 0.6) to a net producer (breeding ratio as high as about 1.3)"2 (14). Figure 3-3 shows across section of the arrangement of fuel elements in a full-scale ALMR reactor in the breeding and nonbreeding configurate ion. As can be seen, both configurate ions use the same total number of elements in the reactor core. Only the arrangement of fuel, the fuel type, and the presence or absence of fertile material (for breeding) are different (21).

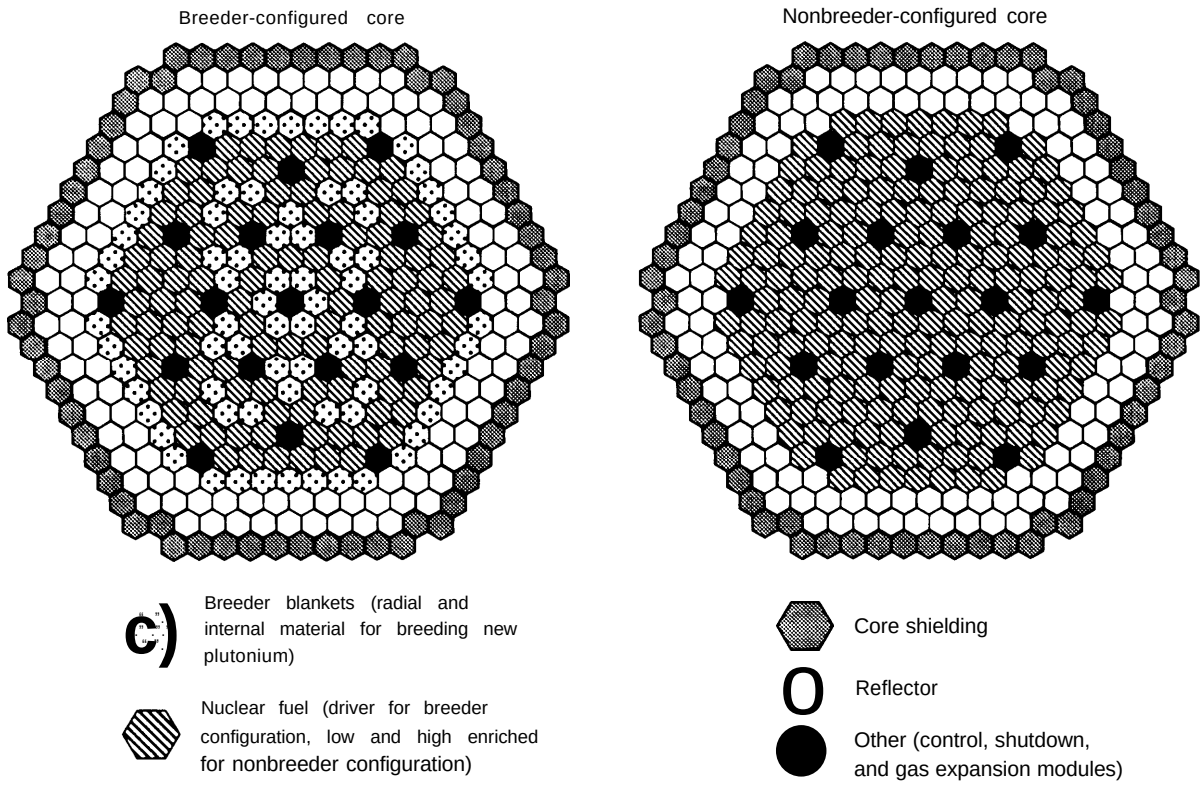
| The ALMR/IFR Fuel Reprocessing System

The ALMR/IFR fuel reprocessing system as currently envisioned by Argonne researchers will be a complex of equipment for handling spent fuel, chopping up the fuel elements, reprocessing to separate actinides from fission products, converting into new reactor fuel elements, inspecting and quality control, and handling and processing radioactive waste for disposal. Because of the intense radiation of spent fuel, reprocessed fuel, and

[1] Conventional LWRs fueled with uranium oxide w ill transform some of the uranium-238 (the bulk of the fuel material) contained in the fuel into plutonium as the fuel is irradiated in the reactor. This is the source of the approximately 1 percent plutonium contained in LWR spent fuel. The difference is that in LWR reactors the plutonium is left in the spent fuel for disposal. Breeder reactor operation requires that the spent fuel be reprocessed to recover the plutonium.

[2] At the end of each cycle of fuel fissioned in the reactor (approximately 18 months to 2 years), a conversion ratio of 0.6 means that about 60 percent of the original amount of plutonium in the fuel would remain, while a conversion ratio of 1.3 means that about 130 percent of the original amount of plutonium would be present.

FIGURE 3–3: Cross Section of ALMR Cores for Breeder and Nonbreeder Configurations



SOURCE Magee (GE), 1993

waste from the reprocessing of spent fuel, all of these operations would have to be carried out in a remotely operated hot cell.

Remotely Operated Hot Cell

The hot cell is an enclosed area surrounded by heavy shielding to protect workers against the intense radioactivity present from the fission products in spent and new reprocessed ALMR/IFR nuclear fuel. In addition, because of the extreme chemical reactivity with air or water of ALMW/IFR fuel materials and processing chemicals, processing is done in an inert atmosphere (the current prototype uses dry argon gas). Even new recycled ALMR/IFR fuel after reprocessing will contain sufficient amounts of highly radioactive fission products to require heavy shielding and remote manipulation by robotics or remotely operated manipulators. For radiation protection, a hot cell has walls made of several feet of concrete and 4-foot-thick special radiation-shielding glass windows for viewing. All operations would be done with remote manipulators or by automation. After startup with radioactive materials, no human would enter the hot cell.

Argonne researchers are in the process of transforming an existing hot cell facility at Argonne West for this purpose. The hot cell was originally built as part of the demonstration of an earlier version of the current design, with the EBR-II as part of a breeder reactor system integrated with onsite molten salt metallic fuel reprocessing from 1964 to 1969 (12, 31). It consists of two hot cells, one with an air and the other with an argon atmosphere, and a passageway connecting them to the EBR-II reactor building for transfer of spent fuel

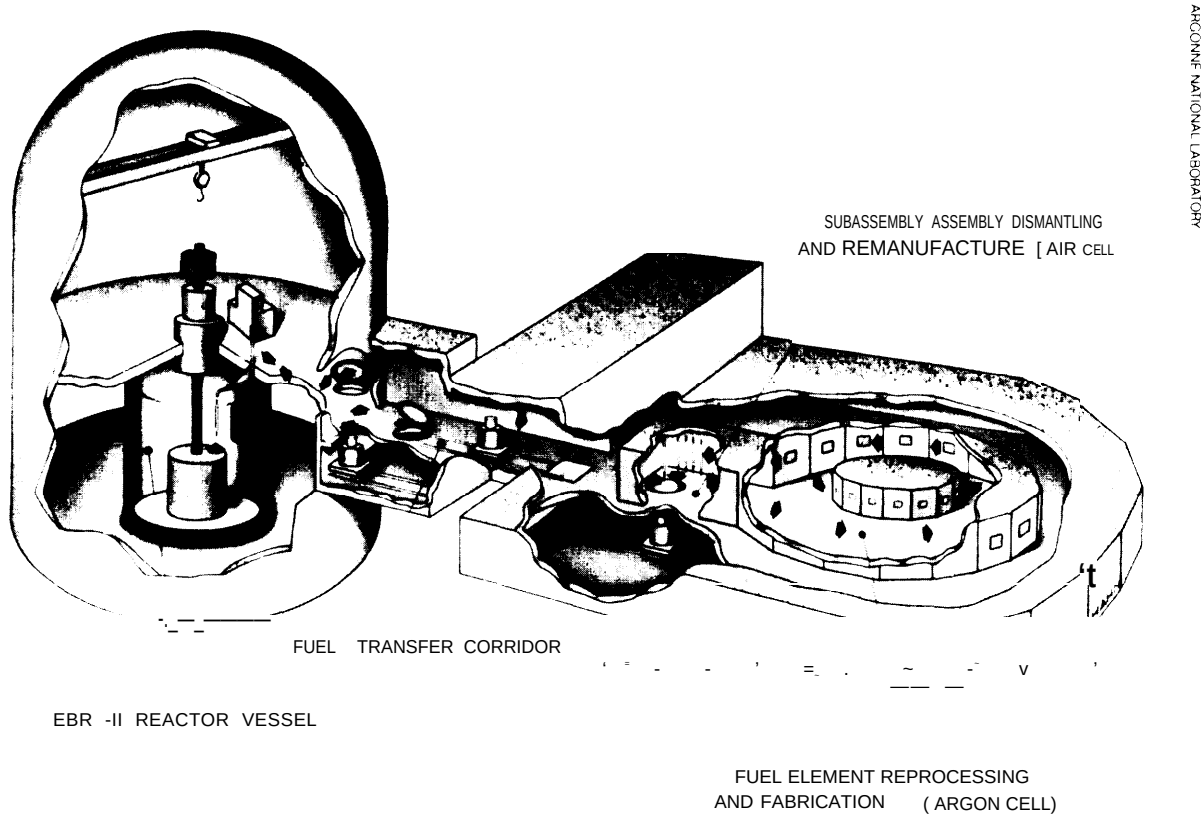


Diagram showing plans for converting the existing EBR II and Fuel Cycle Facility to an ALMRIIFR prototype system The system would contain the nuclear reactor (EBR II on the left) and the fuel reprocessing facility (rfght).

containers. Argonne researchers expect that the ALMR/IFR demonstration equipment to be constructed and installed in the hot cell will be of a scale appropriate for a full commercial-size ALMR/IFR installation.

Electrorefiner Fuel Reprocessor

The electrorefiner, now under development at Argonne West, would be used to dissolve, reprocess, and divide spent fuel from the reactor into new fuel material and spent fuel fission products (see box 3-1). With some process modifications, the electrorefiner might also be used to reprocess spent fuel from existing commercial U.S. light-water reactors, Irradiated fertile (breeding) elements from an ALMR breeder configuration would be similarly processed using this equipment (14). Because of the intense radioactivity of the fission products, the electrorefiner must also be operated remotely in the hot cell.

The electrorefiner is a key part of the ALMR/IFR nuclear fuel reprocessing cycle, but it is still in the early stages of development. A full-scale prototype electrorefiner is being readied for testing with remote operation, before installation in the hot cell at Argonne West. This installation is expected to be completed in 1994(31). This prototype has yet to be tested with actual spent fuel material, although a similar unit has been tested with unirradiated fuel (17). *The* fuel element chopper for chopping the spent fuel pins has been installed in the hot cell for testing. The first test will be a qualification step that involves chopping metallic sodium-filled dummy fuel elements.

BOX 3–1: The Electrorefiner Fuel Reprocessor

The electrorefiner will be at the heart of both the ALMR/IFR fuel reprocessing technology and the possible reprocessing of spent light water reactor (LWR) fuel into new ALMR/IFR fuel. It WIII be a vat heated to 500°C (about 930°F), filled with molten mixture of lithium and potassium chloride electrolyte that contains both cathode and anode electrodes, resting above a liquid cadmium phase (see ftgure 3-4). The fuel IS mechanically chopped up, placed in the anode basket, and then broken up through electrochemical action to allow the plutonium, uranium, and other actinides, along with some fission products, to be dissolved in the molten salt. The chopped stainless -steel fuel cladding is not dissolved but IS left behind in the anode basket (16). Other materials from the chopped spent fuel that are less soluble in molten salt simply fall into the molten cadmium phase located below the molten salt phase. Selective distribution to the molten salt, rather than the liquid cadmium, results in the upper phase containing most of the highly electropositive fission products, including alkali metals such as cesium, alkaline earths such asstrontium, and some rare earths (lanthanides) (figure **3-4)** Noble metal fission products, including ruthenium, rhodium, molybdenum, palladium, technetium, and zirconium, and more rare earth (lanthanide) fission products along with zirconium from the fuel alloy move to the lower cadmium pool ***(14).***

After the spent fuel is electrochemically dissolved, passage of an electric current through the iron electrode causes the bulk of the uranium dissolved in the molten salt electrolyte from the spent fuel to become deposited as a metal on the iron cathode. ALMR/IFR designers hope to recycle this uranium to make new reactor core or fertile material (breeding) elements, Next, the plutonium, remainder of the uranium, and other actinides such as neptunium, americium, and curium from the dissolved chopped fuel are transported electrochemically to asecond, smaller liquid cadmium pool cathode contained in a ceramic crucible immersed in the electrorefiner molten salt (14). Some rare earth (lanthanide) fission products also inevitably end up codeposited with the actinides in this cadmium cathode, Both the salt and the cadmium phases would accumulate highly radioactive fission products and would require periodic processing to remove these waste products for disposal.

An electrorefiner large enough to support fuel reprocessing for a commercial-scale reactor such as the full-scale ALMR concept would be about 1 meter in diameter and would contain 1,000 kg of cadmium and 500 kg of salt (14). Argonne researchers expect that fuel reprocessing wiII be done in batches containing about 10 kg of uranium and 3 to 5 kg of fissile materials (mostly plutonium) (13).

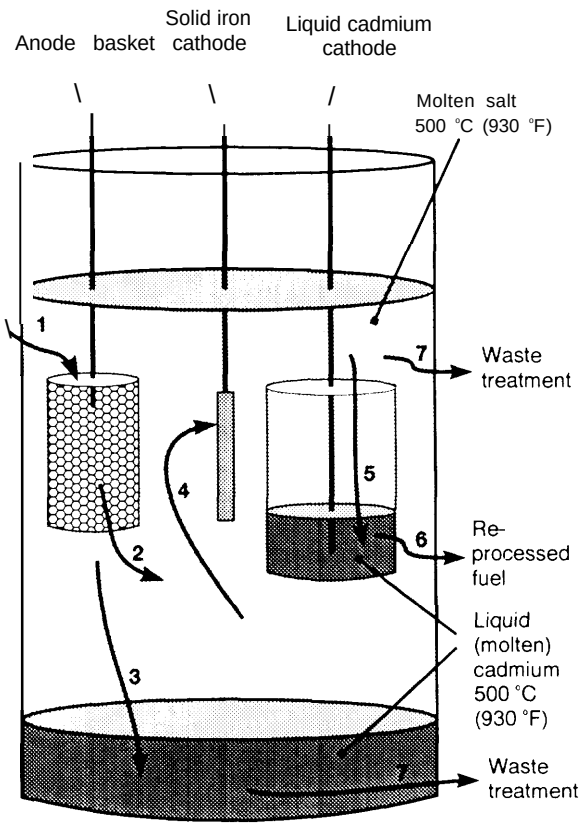
To adapt the electrorefiner processor LWR spent fuel reprocessing, the LWR spent fuel, which IS composed of the oxides rather than the metallic forms of uranium, plutonium, other actinides, and fission products, must first be chemically reduced to the metal (16), This reduction can be accomplished by treating the chopped LWR spent fuel with lithium metal m the molten salt solution (28). After conversion to the metal form, the material would be collected from the bottom of the molten salt bath and transferred to the anode basket of the electrorefiner, where spent ALMR/IFR fuel IS Introduced as described above, There it too could be processed into new fuel

The Cathode Processor

One of the key steps in the electrorefiner involves concentrating actinides collected at the liquid cadmium cathode (see figure 3-4). After processing, most of the actinides, including plutonium and uranium, along with some fission products, will be deposited in a molten cadmium pool contained in the liquid cadmium cathode. This cadmium pool will then be transferred to another piece of equipment called the cathode processor. After evaporation of the cadmium (which will be recycled), the plutonium, uranium, other actinides, and remaining rare earth (lanthanide) fission products will be recovered as a metal ingot at the bottom of the cathode processor.

This ingot will contain up to 70 percent plutonium and 30 percent uranium and other actinides, as well as a minor amount of rare earth (lantha-

FIGURE 3–4: Diagram of Current Electrorefiner Design



NOTE The electrorefiner would reprocess spent ALMR/IFR metal fuel into **new** fuel and highly radioactive waste fission products in a hot cell The operations described here have not yet been conducted with actual spent nuclear fuel A similar but physically separate system IS envisioned for reprocessing LWR spent fuel Into new ALMR/IFR fuel

SOURCE Argonne National Laboratory

Notes on figure 3-4

1 Spent metal fuel from an ALMR containing plutonium, uranium, and other actinides, and highly radioactive fission products, IS mechanically chopped up and placed in the anode basket Chopped fuel IS broken up electrochemically and its nuclear components are dissolved in the molten salt, leaving behind the old fuel cladding

2 The plutonium, uranium, and other actinides, and most of the highly electropositive fission products, are dissolved electrochemically in the molten salt This includes alkali metals such as **cesium, alkaline** earths including strontium, and some rare earths (lanthanides)

3 Noble metal fission products including ruthenium, rhodium, molybdenum, palladium, technetium, and zirconium are not transported electrochemically but settle as metal particulates m the molten cadmium pool at the bottom of the electrorefiner The cadmium pool accumulates radioactive waste fission products

4 Passing an electric current through the electrodes causes the bulk of the dissolved uranium to become deposited as metal on the iron cathode

5 The plutonium, remaining uranium, and other actinides, and some rare earth fission on products, are transported electrochemically from the molten salt to a cadmium cathode, made **of** a smaller cadmium **pool** in a ceramic crucible The material in the cadmium cathode IS as high as *70* percent plutonium and 30 percent uranium and other actinides, and less than 1 percent rare earth fission products Other highly radioactive waste fission products accumulate in the molten salt

6 After reprocessing and separation are complete, the molten cadmium from the cadmium cathode IS transferred to the cathode processor where cadmium IS removed, leaving a metallicing got that will be made into new ALMR fuel

7 Fission products from reprocessed fuel accumulate in the molten salt and cadmium Periodically these must be removed, and the waste materials processed, producing a highly radioactive waste form for disposal

nide) fission products. Although the lanthanides contribute less than 1 percent of the mass, along with certain more radioactive actinide isotopes, they generate the hazardous radioactivity responsible for what the developers consider the "self-protecting" proliferation resistance of the final recycled fuel product.[3] A significant amount of the total radioactivity of the final product from the cathode processor and of the radioactive decay heat comes from the minor transuranic isotopes that are retained through the separation process (17). One estimate is that without further purification this material would be about 10,000 times more radioactive than a similar product from conventional PUREX reprocessing (56). This radioactivity also means that the cathode processor must be placed in the remotely operated hot cell. The device is currently undergoing tests for re-

3 Self-protecting proliferation resistance originally referred to the intense radioactivity due to the fission products in spent nuclear fuel that makes it lethal to handle without extensive protection. This radioactivity "protects" the material from theft or diversion. The amount of fission products in ALMR/IFR reprocessed fuel is significantly lower than in LWR spent fuel and provides less self-protecting radiation. For this reason, radioactivity from the residual actinides becomes more important for the self-protecting aspect of ALMR/IFR reprocessed fuel compared with LWR spent fuel (17).

BOX 3–2: Fuel–Pin Casting Furnace

A prototype device for casting new fuel elements IS currently Installed in the Argonne West hot cell, It consists of a series of units for converting the metal ingot from the cathode processor into new fuel pros. The fuel pin injection casting machine IS similar to existing equipment used with the experimental breeder reactor (EBR - II), except that it IS designed to be operated remotely in the hot cell. After the metal ingot has been melted in a furnace, its composition IS Intended to be adjusted by adding zirconium and uranium in proportions appropriate for new ALMR/IFR fuel. Next, the metal IS cast into new fuel pins in precision quartz molds that resemble long drinking straws (54) After inspection, the newly cast fuel IS loaded into stainless-steel cladding along with sodium metal and an inert atmosphere to make anew fuel pin. Volatilization of the radioactive actinide element americium during casting may be a problem, In one experiment casting fuel pins with minor actinides, approximately **40 percent** of the americium charge was lost during casting due in part to evaporation **(54). Currently, the quartz** molds are broken off after casting and create a waste material. Argonne West researchers have done some experiments on replacing the quartz with direct casting into azirconium sheath that could be inserted into conventional stainless-steel cladding.

Argonne researchers have not yet tested actual recycled ALMR/IFR fuel in this system. The pin casting furnace has been installed in the Argonne West hot cell, and some experiments in casting depleted uranium have been completed. Experiments are planned for 1994 to fabricate experimental uranium-plutonlum-zlrconwm (ternary) fuel elements (31). As part of the research on fuel design, a full-scale ALMR prototype fuel containing uranium, plutonium, and zirconium has been Irradiated to high degrees of fuel burn up (fissioning of total fissionable materials) in the EBR-II (54). ALMR/IFR fuel from recycled light water reactor spent fuel will contain about 20 percent plutonium and 10 percent zirconium, along with 70 percent uranium (mostly U-238) (54).

As part of the equipment required for fabricating new fuel pins for the EBR - I I, a "welder/settler" IS also being tested Argonne expects to transfer it to the hot cell so it will be available in 1994. A "vertical assembler/disassembler'" for fuel pin fabrication IS being tested as well and will be installed in the hot cell when available. A "fuel element inspection x-ray system" IS also under development.

mote operation and is expected to be installed in the Argonne West hot cell in 1994 (31).

After the metal ingot material is removed from the cathode processor, it is transferred to a fuel pin casting furnace and then to a fuel pin processor. The function of these parts is to produce new fuel rods from the processed material that will then be recycled to the reactor, to complete the entire fuel reprocessing step. Box 3-2 describes the specific operations envisaged for the casting furnace and the status of its development.

ALMR/IFR High-Level Nuclear Waste Treatment Processes

During the electrorefining reprocessing of spent fuel, fission products and other materials will accumulate in the molten salt and the bottom liquid cadmium pool (figure 3-4). Eventually, these waste products will generate excessive heat and cause unacceptable contamination (by the accumulating rare earth fission products) of the reprocessed nuclear fuel deposited in the liquid cadmium cathode (16). Argonne researchers expect that a salt load might be used for several dozen fuel reprocessing cycles before requiring treatment. The intense radioactivity from the fission products means that all waste treatment will have to be performed in the remotely operated hot cell. Waste recovered from the molten salt and cadmium would have to be disposed as high-level radioactive waste in some suitable repository. Box 3-3 describes the steps involved in waste treatment and the development status of this subsystem.

It will also be necessary for the ALMR/IFR waste processing technology to meet current and proposed high-level waste packaging and storage

BOX 3–3: ALMR/IFR High–Level Radioactive Waste Treatment

Reprocessing ALMR/IFR spent fuel will separate highly radioactive fission products that must be processed for eventual disposal The molten salt containing waste fission products and small amounts of actinides from the electrorefiner would be transferred into a processing device called a pyrocontactor There it will be treated with a uranium-cadmium alloy to reduce the residual transuranic chlorides to their metal forms (1 6) This would recover residual plutonium, uranium, and other actinides (which are returned to the electrorefiner) from the molten salt Next, the molten salt would be treated with lithilum in molten cadmium to remove the rare earth fission products in a liquid cadmium phase that would be combined with the liquid cadmium waste stream coming from the electrorefiner (figure 3-4)

fission products still remaining in the molten salt will require further treatment to remove them Argonne researchers have performed preliminary experiments with nonradioactive fission product analogues, [1] showing how fission products remaining in the salt—Including cesium, strontium, rare earths, and Iodine 129—might be recovered by passing the molten salt through a zeolite (mineral)-based ion exchange column Two possible final waste forms (for placement in a geological repository) are under development one is a bonded zeolite" in which zeolite is permeated with a low-melting glass for mechnical strength and leach/d lf - fusion resistance the second is a sodalite mineral structure formed by pyrolysis of a blended zeolite material If the development of this technology is successful, the purified molten salt could be recycled back to the electroreflner

Flsslon products in the molten cadmium pool from the electrorefiner, including the transition metal fission products technetium, ruthenium, rhodium, and zirconium, after reduction to their metal forms, are expected to be placed in a stainless-steel matrix and cast into a metal ingot waste form, by using the remaining nuclear fuel cladding hulls as a source of stainless steel If the development of this technology is successful, cadmium would also be recycled to the electrorefiner

None of these processes has been tested with actual ALMR/lFR recycled fuel A single-stage pyrocontactor has been tested in a glove box, and initial flow tests with salt and cadmium have been conducted (16) A multistage pyrocontactor test apparatus (seven or eight stages will be required to meet target actinide recovery) is under design Some experiments reducing rare earth salts to their metallic forms with lithium in liquid cadmium have been completed, as well as the demonstration of the use of centrifugal pumps for the transfer of salt and cadmium between process vessels Argonne researchers are currently investigating the use of pumped filtration units for the removal of insoluble such as $U0_2$ (uranium oxide) from the process, the filters will then be sent to the metal waste stream (16)

[1] For example the Iodine Isotope I- 129 is a toxic radioactive fission product whereas another isotope I -127 is a naturally occurring nonradioactive form of iodine As an analog of the more toxic I-129, 1-127 has physical properties that are very similar to I- 129 and can be used more safely to test chemical process development

methods. Although experience with actual reprocessed spent fuel is lacking, salt waste generated from recycling spent ALMR/IFR fuel by these processes can be expected to be quite different from PUREX aqueous waste and will require the development of special treatment processes (56). Argonne researchers have experimented with various salt waste forms (17). However, if current plans for developing salt waste treatment are not successful, recovery and recycling of some types of waste materials may conceivably require processes that would generate aqueous waste forms (56). Experience suggests that several kinds of water-based separation processes could be used to recover some wastes that do not lend themselves to nonaqueous treatment (56). As another option, Argonne researchers are also considering the possibility of vitrifying ALMR/IFR waste (17).

| LWR Spent Fuel Reprocessing System

Argonne researchers are beginning to design equipment for reprocessing existing and future spent LWR fuel from U.S. commercial nuclear reactors to recover the actinides, including plutonium and uranium, for making new ALMR/IFR fuel. Recently, this feature has become a central goal of their research program and has been renamed the "ALMR actinide recycle system" to reflect this shift (35). The overall plan is that ALMR/IFR technology might be used to remove the plutonium, uranium, and other actinides in existing commercial reactor spent nuclear fuel by transforming them into radioactive fission products. Promoters of this idea think that this maybe a more acceptable waste form for repository disposal. In principle, over a period of centuries—with repeated reprocessing in many ALMR/IFR systems deployed around the world—much of the existing world's inventory of plutonium and other actinides in spent fuel could be transformed. Of course, in the process, quantities of plutonium would be contained in ALMR/IFR reactors or fuel reprocessing plants.

Argonne researchers hope to make the LWR process compatible with the electrorefiner designed for reprocessing spent ALMR fuel by using the same temperatures, reagents (salts), and waste forms and treatments. Plutonium and other transuranic actinides will be recovered for ALMR fuel, while uranium may be recycled for ALMR or LWR use, or disposed of (16). As with spent ALMR/IFR fuel, the reprocessing of spent LWR fuel inventories will require shielded hot cell facilities for handling the spent fuel, recovering actinide elements, and processing the resulting radioactive wastes, which will include highly radioactive fission products.

Officials at DOE and Argonne indicate that the research and development of the LWR spent fuel reprocessing system lags significantly behind that of other components of the ALMR/IFR fuel cycle system (11, 28) (figure 3-2). Others add that the use of electrorefiner technology for the conversion of spent LWR oxide fuel into new metal fuel may be very difficult. "The fact that LWR fuel is oxide and the [Argonne] conceptual process is a nonaqueous process requiring conversion of all of the oxide fuel material to metal poses process development problems that may not be easily solved" (56). According to Argonne researchers the process chemistry has been selected. The next step would be the design of a prototype system. During 1993, an experiment was conducted by Argonne using materials that resemble LWR fuel (without fission products), and a small quantity (20 kilograms) was transformed from the oxide to the metal (16). According to current plans, building a prototype of this system for demonstration purposes with actual irradiated fuel may be completed by FY 1997 (see figure 3-2).

Uranium is the most abundant material in LWR spent fuel. If it is to be eliminated by this process (i.e., completely converted to fission products), it would first have to be transmuted into plutonium, then reprocessed into new fuel, and finally fissioned in the nuclear reactor. This would require breeder operation and the production of plutonium over many decades before actinide elimination might be completed. It would also result in the wide deployment of ALMR/IFR nuclear reactor systems that would both require additional plutonium for continued operation, if for example they were to continue to generate electricity, and be capable of breeding more plutonium. Thus, the net effect may not be to decrease the world plutonium inventory, because plutonium would be contained in recycled nuclear fuel in ALMR/IFR systems spread around the world. These systems would also provide facilities and equipment that could be modified for small-scale plutonium purification, described later. Thus, from a long-term standpoint it is not clear whether large-scale ALMR deployment would be preferable to a plan that would place existing spent fuel in geologic repositories, should they become available (30).

Waste Management Issues

The potential impact of actinide removal on the long-term management of spent nuclear fuel has been the subject of a number of analyses. Some ar-

gue that the difficulty of developing geologic repositories cannot be **reduced** by merely making technical modifications to the waste because issues of siting, fairness, scientific uncertainty, and public trust override technical barriers (18). In any event, use of the AL MR/IFR technology for "actinide recycling'* of LWR spent fuel would in effect transform actinides into highly radioactive fission products that would have to be treated and disposed of in some suitable repository.

Argonne researchers expect that the most problematic waste fission products, such as iodine and cesium isotopes (because of their very long half-lives and water leaching potential), would be encapsulated in a mineralized form similar to a vitrified glass log for disposal in a geologic repository. Other fission products including technetium, strontium, zirconium, and carbon isotopes might be encapsulated in a metal ingot form. The researchers hope that these waste forms might prove to have equal or even greater groundwater-leaching resistance than the original LWR fuel rods (17, 28). It has been difficult for repository designers to prove the engineering reliability of safe spent fuel storage over man y centuries, and it is not clear that the new waste forms proposed by Argonne researchers will be any easier to evaluate.

Argonne researchers also think that by removing actinides from the LWR spent fuel, the wastes will be made more readily acceptable to the U.S. public for repository disposal. In part this is because the greatest amount of long-term radioact ivity is due to the actinides in the spent fuel, although some fission products are also long-lived. Others conclude that the impact on public acceptance will be minimal because although actinides contribute the majority of the total long-term radioactivity in spent fuel, they are much less water soluble than the fission products. Thus long-term *leakage* risks from a geologic repository come more from long-l ived, water-soluble fission products such as technetium-99 (half-life 210,000 years) and iodine- 129 (half-life 17 million years) than from actinides (5, 19, 46).

DOE officials are also quick to point out that they consider all such exposure risks from repositories, including leakage, to be extremely low (46). Some environmentalists argue that a lower environmental impact would result if all materials contained in spent fuel remained in the spent fuel rods they are presently in, and that any reprocessing will inevitably increase the risks of environmental releases due to increased handling and transportation during reprocessing (28).