European Breeders (1): France Leads the Way

Marcoule. As it begins to appear likely that the world will face uranium shortages before the end of the century, the performance of a prototype breeder power station here in the south of France is being watched closely by energy experts from many nations. The technical performance of the French breeder reactor has been outstanding during its first year of operation, which indicates that at least for the present, France has the lead in developing a new energy technology with potentially enormous implications for the worldwide availability of energy, the future of the nuclear industry, and the degree of energy independence of many industrialized countries toward the end of the century. Even sooner, breeders are likely to affect international trade, since the first nation to have a proved breeder technology ready for export is likely to find many customers ready to buy it.

The breeder reactor—so named because it produces more nuclear fuel than it consumes—is one of the major energy technologies that could replace fossil fuels in the long-range future. As a source of nearly unlimited energy, it falls into the same category as solar energy and thermonuclear fusion. There is great concern, especially in the United States, that the breeder—using the fuel cycle favored by all the major countries developing it—is not the safest new energy source, since it is based on the conversion of uranium to plutonium. But the breeder is undeniably the most advanced new energy option, since it is the only one that has a working example of a 250-megawatt power plant open for inspection.

Breeders were a natural outgrowth of nuclear power development because they provide a way to utilize most of the 99 percent of natural uranium that is nonfissionable and therefore cannot be used to fuel the current generation of reactors. Instead, the breeder converts nonfissionable uranium (^{238}U) to plutonium, which is fissionable, by absorption of neutrons from the reactor core. Thus, by extracting energy from most of the uranium that is unused by the present generation of reactors, the breeder technology has the effect of multiplying the energy content of uranium resources at least 60-fold.

Plutonium breeders differ in several respects from the current reactors. Since energetic or "fast" neutrons are needed for efficient uranium-plutonium conversion, plutonium breeders are called fast reactors. For a coolant, the major developers have selected liquid sodium to optimize cost and performance. The development projects discussed in this and subsequent articles are all tests of the concept of the liquid metal fast breeder, which has cornered 95 percent of the available breeder support in the United States and virtually all the support in Europe. More complete technical details and economic discussions of the concept have been given previously [*Science* **174**, 807 (1971); **184**, 351 (1974)].

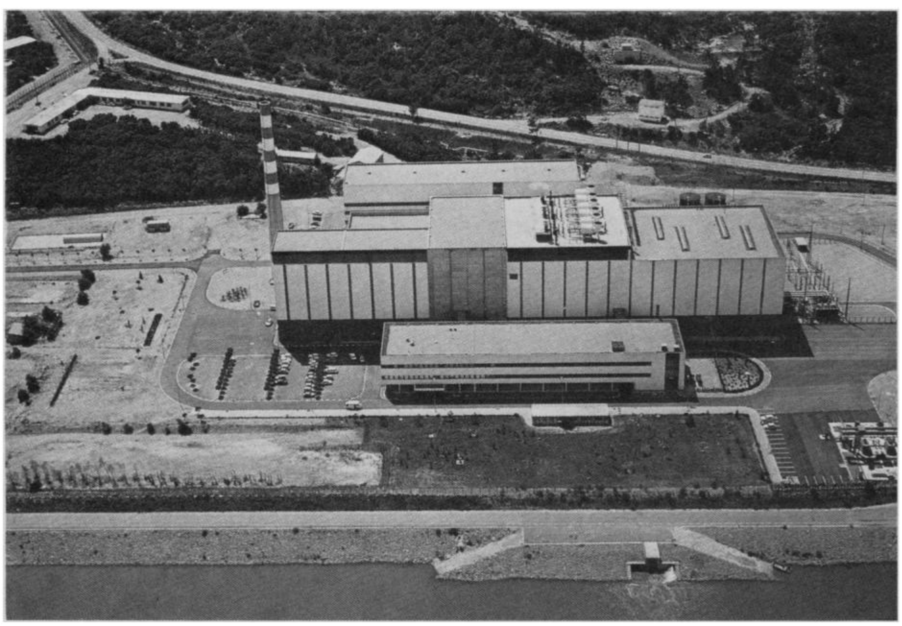

Fig. 1. The 250-megawatt French fast breeder reactor, on the Rhone river near Marcoule.

The French reactor at Marcoule (Fig. 1) has been unusually successful, almost matching the standard of excellence implied by its name, which is Phenix. Although the reactor is a prototype, in its first year of operation it was more reliable than many commercial reactors. After being completed on schedule in late 1973, 5 years after construction began, the Phenix began generating 250 megawatts of power for the national electrical grid in July 1974. Since that time it has been producing full power 80 percent of the time, a record considerably better than the 60 percent figure that is typical for light water reactors in the first year of operation. Many of the features of the Phenix are being incorporated into a full-scale breeder with a 1200-megawatt rating, scheduled for the early 1980's.

Great Britain has also just completed a 250-megawatt breeder reactor, which was beset with a number of problems that kept it from producing much electricity during its first year. But the British breeder began producing electricity at 30 megawatts power in late October and is scheduled to reach full power in the spring of 1976. Located at the town of Dounreay, on the northeasternmost point of Scotland, the British Prototype Fast Reactor (PFR) is an impressive engineering accomplishment, more nearly approaching a realistic commercial plant design than the Phenix in several respects. The United Kingdom is also in the process of extrapolating its prototype reactor design to a commercial-sized plant.

The Soviet Union has a prototype breeder plant, which was completed almost a year before any other but has not yet started regular power production because of a number of serious pipe ruptures in the steam-producing equipment. Visitors to the 350-megawatt plant at Shevchenko on the Caspian Sea report that the nuclear design is good, but that the manufacturing processes and quality control used for the Soviet breeder appear to be crude.

The United States, in spite of its advanced manufacturing techniques and long history of successful reactor development, has no prototype breeder power station operating now and no prospect for testing one before the 1980's.

The successful engineering of breeder reactors is a difficult job. The liquid sodium coolant is a very corrosive material, for which there was no previous experience in other industries to rely on, and the behavior of nuclear fuels in fast reactors turned out to be much different from the response of fuel to irradiation in conventional reactors. A whole new technology of handling liquid sodium had to be developed, including ways to purify it of oxides and carbonates, which tend to clog small passageways in the plumbing. At the temperatures in a fast reactor liquid sodium burns spontaneously in air, so breeder programs have devoted much effort to developing ways to contain sodium in case of a plumbing rupture, detect leaks when they occur, and put out sodium fires if they erupt. Enormous resources have been put into fuel development, since the swelling of fuel rods in a fast reactor is a crucial factor in the design of the reactor core and the principal limitation on the amount of power that can be extracted before the fuel has to go through a costly recycling process.

The fuels for the British and French breeders are combinations of oxides of plutonium and highly enriched uranium, called mixed oxide fuels. They are used with a "pot" type reactor, in which most of the large nuclear components are immersed in one large vessel along with the reactor core. This is quite different from the U.S. design—a "loop" type reactor—where the reactor core is in a small separate tank connected to the other components by pipes. More complete details of the design and operation of the PFR and the Phenix, and the related research on advanced fuels, will be discussed in two additional articles.

Because power production from breeder reactors would come quickly to a halt without a steady flow of spent fuel products through a properly working fuel cycle, Britain is mounting a large program to make sure that the reprocessing technology for breeders keeps pace with reactor development, and France is pursuing the same goal by a different route. At the same site as the PFR reactor at Dounreay, the U.K. Atomic Energy Authority is constructing a moderately large reprocessing plant for fast reactor fuel, which is due to be completed in late 1976. The plant will be able to reprocess between 15 and 45 kilograms of plutonium per day, an amount sufficient to maintain the fuel cycle of two 250-megawatt breeders such as the PFR. France is not building a separate reprocessing plant for the Phenix, since officials of the Commissariat à l'Energie Atomique estimate that the proper size for the first plant would accommodate seven to ten commercial-sized reactors. But an experimental reprocessing plant is available to extract 1 to 2 kilograms of plutonium per day from breeder fuels, and the French plan to reprocess considerably more fuel at a new light water reactor reprocessing plant due to start operation this month at the CEA complex on La Hague, a small land point that juts into the English Channel near Cherbourg.

The French now use about 80 percent plutonium in the core of the Phenix. The initial charge of fuel was made of plutonium derived from existing reactors, which are also plutonium producers, but generally produce only half as much new fuel as they consume. Within 6 months, the French plan to convert the Phenix to operation on 100 percent plutonium oxide fuel. So far, the CEA has not recycled any of the plutonium actually produced in the Phenix as fuel to keep the reactor going, but there are plans to do so within a year.

Although the Phenix appears to be a technical success, the reactor falls very far short of the cost and fuel production rate generally set as goals for commercial breeder programs. The doubling time of the Phenix—the time needed for it to double its original inventory of fuel—is 50 to 60 years, too long for a commercial power sector based on breeders to expand at a reasonable rate. The doubling time of the PFR is about 30 years. Ten or twelve years is the goal of breeder development. The cost of the Phenix itself is high, about $1000 per kilowatt of generating capacity, and the major factor that controls the cost of the breeder fuel cycle—called the percentage "burnup" of the fuel—falls short of the economic goal by at least a factor of 2. The Phenix does prove quite nicely, however, one of the advantages of breeder reactors. Since it operates at a higher temperature than light water reactors, the breeder can well exceed their thermal efficiency of 33 percent. The thermal efficiency of the Phenix is 43 percent.

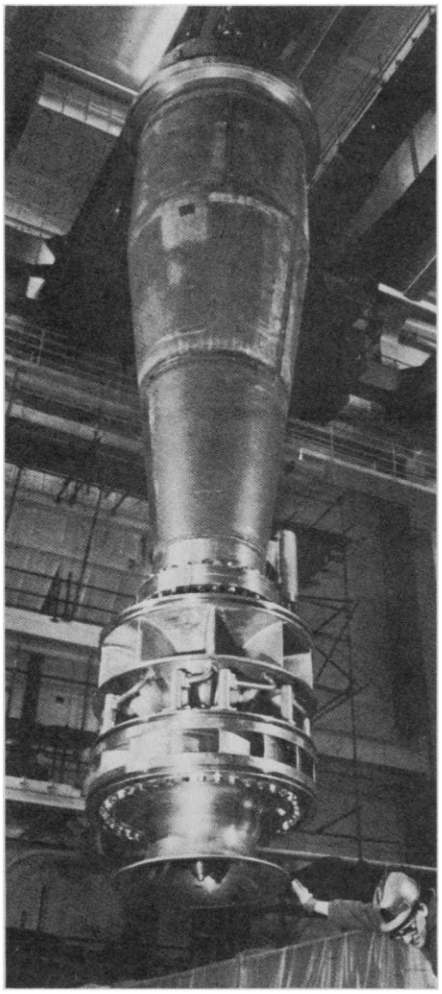

Fig. 2. One of three primary sodium pumps installed in the reactor vessel of the British 250-megawatt Prototype Fast Reactor.

Officials at the CEA emphasize that the Phenix was not intended to meet commercial design goals, and its successor, the Superphenix, will also be a conservatively designed reactor. "For Superphenix as well as Phenix, the major emphasis was to achieve a technical success," said M. Villeneuve, deputy director of the CEA reactor division. "Surely it won't be economic, but today we are confident of our technology, and after Superphenix we'll go to an economic reactor."

The aggregate experience of the Europeans has put them far ahead of the United States, probably as much as 10 years ahead. Construction of the first American prototype is just now beginning, at a site located on the Clinch River near Oak Ridge, Tennessee, and it will not be completed before 1982 or 1983. At 350 megawatts the Clinch River Breeder Reactor (CRBR) will be slightly larger than the present European plants, but its role in the reactor development program—as experimental prototype—will not be appreciably different. The commercial-sized French plant is due to be completed at about the same time. Thus, the Europeans are now a full step ahead of the United States.

There are many ironies in the present situation. The American nuclear industry leads all others in the design, manufacture, and export of light water reactors. The first reactor to produce electricity in the United States was a liquid metal fast breeder. In 1964 a small but advanced U.S. breeder, EBR-II, was the best facility for testing breeder design, and many Europeans were coming to the United States for their training, both at it and at the Fermi reactor. Then, in the words of one European observer, the U.S. program "hiccuped" and never quite recovered its breath.

France, Britain, and the Soviet Union proceeded directly from small test reactors to the prototypes that are now operating. The United States, on the other hand, devoted its considerable resources to the exploration of all conceivable problems and their solutions. The next step after

EBR-II was not a power reactor, but an equivalently large and expensive reactor designed to test the effects of irradiation on a wide variety of components, but not those designed for any specific reactor. The project, named the fast flux test reactor (FFTF), has required at least as much money and effort as the prototype power stations in Europe. Officials defending the U.S. program argue that it will pay off in the advanced stages of breeder commercialization. But the FFTF is still not completed, 12 years after the previous big step in U.S. breeder development.

"If I had had the immense industrial resources of the United States, where you have two large corporations capable of the whole job," said one British official who has long been associated with nuclear power development, "I would simply have taken out my pen and written a check."

France and Britain found the need to develop a breeder more urgent than the United States did, because they have been more dependent on foreign oil and only have access to limited amounts of uranium. The situation is most acute for Great Britain, which has no domestic uranium reserves and had not discovered the North Sea oil fields when it made a national commitment to develop breeders. "We have long taken the attitude that only a foolish industry throws away 99 percent of its raw material," said T. N. Marsham, the deputy director of reactor development for the UKAEA, referring to the nonfissionable uranium left over from light water reactors. "In the United Kingdom we had a greater need," said Marsham, "and—let's face it—everyone does what he has to do."

British planners think that the country could just get by with 5 percent of the world's uranium supply, commensurate with the fraction of electricity it uses, if breeders are introduced quickly. Thus, Marsham comments, "I would hate to be a U.K. representative going into a conference to bargain for more than our fair share of uranium if I didn't have the capability of the breeder in my negotiating portfolio."

The French national commitment to develop breeders stems not so much from uranium impoverishment—since France has 2 to 3 percent of the world supply within her borders and has special arrangements with former colonies in Africa, such as Gabon and Niger, that control an additional 10 percent—but from a desire for energy independence. Officials at the CEA refer to the day when Phenix began commercial operation, which happened to be 14 July, as "our independence day." France is now in a position to export uranium, but breeders are absolutely essential for the country to become energy independent, which could occur by 2025 according to the CEA estimate. Short of total independence, French officials point out that the breeder can insulate their economy from the disruption that a geopolitical crisis in uranium distribution could cause.

Both France and Britain are planning to proceed quickly to build commercial-sized breeders based on their prototype designs. According to CEA officials, a contract for construction of the 1200-megawatt Superphenix is only being delayed by organizational changes in the energy authority, and should be completed within months. It will be built at Creys-Malville in southeast France by a combine of French government and industry, CIRNA, and paid for by Europe's three largest electrical utilities—EdF in France, RWE in Germany, and ENEL in Italy. The price will be slightly less than $1000 per kilowatt.

Before Superphenix is finished, which could be as early as 1982, the French national generating company, EdF, is planning to start two more 1200-megawatt breeders, to be ordered between 1978 and 1980. During the same period, Britain plans to start construction of a 1300-megawatt plant, already named the Commercial Fast Reactor (CFR). The designs of these plants are already in the final stages, and at least one of them could be completed before the U.S. prototype plant.

The leadership in breeder technology has clearly passed to Europe, and with their plans for early construction of commercial-sized reactors the British and French programs have enormous momentum. Public opposition to breeders is not nearly as strong in Europe as in the United States, and the economic imperative for their development is much stronger. The impressive record established so far indicates that Britain and France can probably meet their goals of installing a substantial number of breeders by the end of the century. If they are not limited by their industrial capacities, they will probably export breeders to other countries as well.

—WILLIAM D. METZ

Diabetes Therapy: Can New Techniques Halt Complications?

Insulin therapy has prolonged the life of diabetics by many years. But the quality of life for many diabetics, particularly those who develop the disease at a young age, is less than satisfactory. More than 60 percent of juvenile diabetics may have serious impairment of vision, kidney function, or peripheral blood flow. Many suffer from more than one such impairment.

These complications are now often thought to result from the lack of continuous control of blood glucose concentrations. The healthy pancreas, in response to increases in the blood glucose concentration, releases small quantities of insulin throughout the day and thereby maintains the concentration within physiological limits (normoglycemia). But the diabetic generally receives only one large dose—or, at best, a few doses—daily. The diabetic's blood glucose concentration can thus fluctuate greatly during the interval between doses, and it has been suggested that the complications result from the periods of high concentrations of blood glucose (hyperglycemia). Many investigators thus believe that restoration of normoglycemia might halt the progression of such complications in severely debilitated patients and perhaps even reverse them.

There are three primary techniques that have been investigated for restoration of normoglycemia. They are: transplantation of healthy pancreases; transplantation of islets of Langerhans, that portion of the pancreas that actually secretes insulin; and implantation of artificial pancreases. Each of these techniques has been so publicly discussed that many diabetics have built up false hopes about the possibility of soon being "cured." There has, in fact, been a great deal of success in the development of these techniques and each seems, on the whole, promising. Nonetheless, it will undoubtedly be many years before any one of them is accepted as a treatment for diabetes.

To many people, the obvious approach would seem to be simply to transplant pancreases from cadavers in the same manner that kidneys and other organs are routinely transplanted. That was the rationale on 17 December 1966 when Richard C. Lillehei and his associates at the University of Minnesota Medical School performed the first recorded pancreas transplant. Since then, there have been 46 pancreas transplants in 45 other patients in the United States and five other countries. But only one of these patients is still alive with a