Are humans more or less sensitive to hexachlorophene than rats? If a blood level of 1.2 ppm hexachlorophene causes gross brain damage in the rat, do lesser doses cause any detectable behavior change? What is the upper level of dioxin that could escape detection in hexachlorophene and yet still cause skin damage?

The FDA has had at least 18 months to answer these questions, but so far has neither acted against hexachlorophene nor set forth reasons for not doing so. Hexachlorophene may, in fact, be quite safe for most normal uses, but the longer the FDA delays announcing the reasons for supposing this to be the case, the greater the likelihood that political pressures rather than scientific data will decide the issue.

These pressures have already started to act, following the publication in August of the Atlanta scientists' work. The FDA has been working for 6 months on a second scientific review of hexachlorophene, the completion of which would, in normal circumstances, precede any regulatory action. Although the report is not expected to be ready for up to a month, the FDA announced last week, through the mouth of its press officer John T. Walden, that it will act "soon" to require warning labels on vaginal deodorants and liquid skin cleansers such as pHisohex. The industries concerned responded with the arrogance and strong-arm tactics that are known to pay off against the FDA. Leonard H. Lavin, president of the Alberto-Culver Company, which makes the market-leading FDS vaginal deodorant, fired off a telegram to FDA Commissioner Charles Edwards demanding that Walden be sacked for his "inaccurate, irresponsible and unauthorized statements about certain products containing hexachlorophene." (Walden's crime was to tell the Washington *Post* that there is no medical justification for hexachlorophene in vaginal deodorants.) Lavin demanded a meeting in Washington with Commissioner Edwards the next day. According to E. P. Doyle, Alberto-Culver's vice-president for public relations, "We had a meeting with Edwards on Friday afternoon and we feel satisfied that they will await more scientific evidence before taking any action. Our people feel the FDA doesn't have any good scientific information and was acting simply on the basis of generalized and somewhat biased articles," Doyle added.

The FDA's promise of further delay to Alberto-Culver may not be in either's interest, since countervailing pressure from Congress and consumers may rush the agency into a premature and unnecesarily harsh decision. And while the FDA makes up its mind, the public continues to bear whatever risk exposure to hexachlorophene may represent.—NICHOLAS WADE

RESEARCH TOPICS

Breeder Reactors: Power for the Future

The outcome of current efforts to develop breeder reactors will markedly influence both the configuration of the U.S. power industry and the cost of electricity to the consumer. Breeder reactors may offer lower thermal pollution, cheaper electric energy, and more efficient use of uranium reserves as compared to conventional light water nuclear power plants. The rapidly growing demand for electric power and forseeable shortages of high grade uranium ores make it likely that breeder reactors will constitute a substantial part of the world's electrical generating capacity by the end of the century. But development of breeder reactors on a commercial scale seems to be lagging behind in the United States amidst growing criticism of how the U.S. program is being run.

What is at stake in the development of breeder technology is nothing less than the future of the U.S. power supply. An error of judgment or execution could easily offset power rates to a degree that would, by the year 2000, result in additional expenditures of tens of billions of dollars per year for electricity. The timing of breeder development and the rate of fuel doubling in the breeders are crucial in determining how much uranium ore must be mined and what financial investment in new uranium separation facilities will be required before the breeders are self-sustaining.

Prototype generating stations powered by breeders, so called because the reactors produce more fuel than they consume, are nearing completion in France, Britain, and the U.S.S.R. Those in Britain and the U.S.S.R. are expected to begin producing electricity by the end of next year. Ambitious programs to develop breeder reactors are also under way in Germany, Italy, and Japan. Earlier this year, President Nixon announced long-delayed U.S. plans to build a demonstration plant, and has more recently indicated his support for a second such plant. But construction of such plants—which could take 6 to 7 years—appears unlikely to start before late 1973. Prospects for introduction of economically viable, commercial-scale plants are even more uncertain, although the announced intention of the AEC is to achieve this goal by the mid-1980's.

The future course of breeder development in this country depends heavily on AEC policy. What types of breeders will be built, how soon they will be available, and how economical they will be are closely connected to AEC decisions on research funding and reactor design—decisions that since 1965 have been made by Milton Shaw, head of the AEC reactor development and technology program. But despite the potential economic and environmental impact of this program, there has been relatively little public discussion of technical options or alternative policies for breeder development.

The U.S. breeder program as constituted at present is putting nearly all its hopes on one reactor concept—essentially the same as that being pursued in other countries. But this goal, and how it is being pursued, has aroused considerable disagreement within the U.S. nuclear community. Current designs, according to some critics, are so conservative that they may well be economically unattractive. Others have questioned the slow pace of the U.S. effort, despite relatively larger expenditures than, for example, those of Britain.

Research on possibly more economic fuels and potentially lower cost reactor concepts has been so cut back that it now receives only token support.

The attractiveness of the breeder reactor is that it can utilize thorium and the more naturally abundant form of uranium (^{238}U) and, thus, that its fuel costs might be substantially lower than those of conventional nuclear reactors. These attractions are enhanced if, as projected, the demand for electric power doubles more than twice before the end of the century and the cost of uranium rises as easily accessible ores are exhausted.

The energy released in a breeder reactor, as in other nuclear reactors, comes from the fissioning of uranium or plutonium. In the fission process, more than two neutrons are emitted (on the average) for each atom fissioned. The excess neutrons beyond those needed to maintain the chain reaction are used in breeder reactors to convert "fertile" isotopes of the heavy elements into new supplies of fissionable fuel. A similar conversion occurs in the light water reactors in commercial use today, although less efficiently, but even if the plutonium that is produced is recycled as fuel, these reactors can use only between 30 and 50 percent of the uranium that is mined. In contrast, breeder reactors, because of their greater neutron economy, will be able to use more than 70 percent, a saving that the AEC expects will reduce uranium needs by 1.2 million tons over the next 50 years.

Breeders burn either uranium or plutonium, and at the same time convert thorium (^{232}Th) or ^{238}U into, respectively, ^{233}U or plutonium (^{239}Pu), which are fissionable materials. In the conversion process, a neutron is captured by the nucleus of a fertile atom and beta particles (electrons) are subsequently released to form a fissionable product. The ^{232}Th-^{233}U cycle is feasible in a so-called thermal reactor, in which the neutrons are slowed by collisions with a moderating material (usually water or graphite) to energies of about 100 electron volts. The more efficient ^{238}U-^{239}Pu cycle can utilize essentially unmoderated neutrons with energies thousands of times higher, and reactors based on this concept are known as fast reactors. The absence of a moderating material in a fast reactor has the advantages that fewer neutrons are unproductively absorbed—so that the rate at which new fuel is created is higher—and that the reactor core can be considerably smaller.

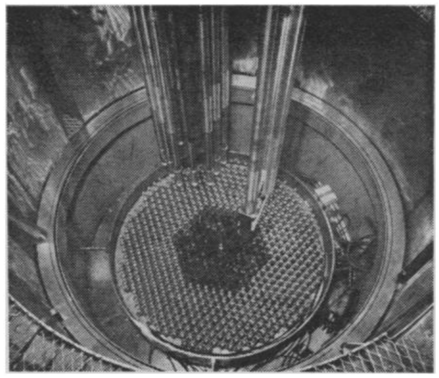

Fig. 1. Core and blanket of an experimental fast breeder reactor at the AEC National Reactor Testing Station in Idaho.

The more efficient a reactor's use of neutrons, the lower the potential cost of the power it produces. A measure of a breeder's neutron efficiency is its doubling time—the period required for the reactor to produce roughly twice as much fissionable material as was originally present. The theoretical doubling times of breeder reactors that have been proposed range from 6 to 20 years in different designs, although some nuclear experts believe that doubling times greater than about 10 years will not be economical. Neutron efficiency is not the only consideration in designing fast breeders, however, because other factors, such as the cost of fabricating and reprocessing fuel, safety features, and plant operating and construction costs also help in determining whether a given reactor is economically feasible.

The Sodium Cooled Breeder

The primary effort, both in the United States and elsewhere, is concentrated on a fast breeder design that will use liquid sodium as a coolant and heat transfer medium and plutonium oxide as a fuel. These features have necessitated the development of technology capable of handling the highly reactive sodium and considerable effort has been expended in the U.S. program to develop reliable heat exchangers, pumps, valves, and other hardware. New fuel fabrication and reprocessing techniques for the highly toxic plutonium fuel are also being developed. A large amount of data on the behavior of oxide fuels under intense neutron radiation has been gathered in experimental reactors.

Because the sodium becomes very radioactive in passing through the reactor core, an intermediate heat exchanger is necessary in the liquid metal cooled fast breeder reactor (LMFBR) design. The primary coolant "loop" transports the liquid metal through the reactor core. The heat is then transferred to a second, independent loop of nonradioactive sodium, which flows through the steam generator. The sodium throughout the system must be kept extremely pure because even small amounts of impurities can obstruct the sodium flow and can cause the mixture to become extremely corrosive and might therefore lead to a leak in the intricate sodium plumbing.

According to current designs, the fuel will be formed into pellets about 0.6 centimeter in diameter and about twice as long, which will themselves be packed into fuel rods made of stainless steel. Plutonium oxide, or a mixture of plutonium and uranium oxides, will constitute the fissionable material in the core of the reactor. The fuel may be diluted somewhat with ^{238}U, and additional fuel rods of this fertile material are located in the blanket around the core.

Breeder fuels must withstand extremely high rates of neutron irradiation and prolonged stays within the reactor—long enough for a fuel "burnup" corresponding to the fissioning of 10 to 12 percent of the total heavy atoms in the fuel. Only a few experimental fuel rods have been tested under these conditions. (Fuels in the current U.S. power reactors achieve a fuel burnup between 1/10 and ¼ of the projected amount before they are reprocessed). Plutonium carbide and other advanced fuels have also been studied and may ultimately be preferable to oxide fuels, although less is known about their behavior under heavy irradiation.

The fast neutrons in the core of a breeder reactor also have important effects on the stainless steel used as structural material and as cladding for the fuel rods. Radiation damage in the steel creates small voids that grow and cause the material to swell, become brittle, and finally fracture, an effect that was discovered only a few years ago.

No data is available on the amount of swelling that will occur at the neutron fluxes expected in commercial scale breeders (3×10^{23} neutrons per square centimeter), but AEC scientists have estimated that volume changes as high as 10 percent may occur. The swelling may increase the doubling time of breeders, because additional (unproductive) space must be designed into reactor cores to allow for the swelling

Management of U.S. Breeder Program Draws Criticism

The U.S. breeder program will eventually cost more than $3.9 billion in federal funds alone, according to AEC estimates, and will influence the way in which the utility industry will spend billions more per year on energy systems by the end of the century. The critical decisions concerning design are being made now, however, because 15 to 20 years are required to go from a demonstration plant to widespread commercial acceptance. But the present AEC breeder program, which is headed by Milton Shaw, has been strongly questioned by those who fear that important options are being overlooked and those who believe that Shaw's management has not produced results.

The AEC has so far officially spent about $650 million on developing breeder reactors. By comparison, this sum is about the same as that spent in the British breeder program. Actual resources committed in the U.S. program may be considerably higher, because Shaw has diverted much of the AEC's general reactor technology and safety programs to solving problems specific to the breeder. But despite these expenditures, and despite the progressive narrowing of the technical options under consideration, the U.S. program seems to be as much as 5 to 10 years behind that of some other countries. The British, French, and Germans are expected to start construction on full-scale commercial plants (1000 megawatts or larger) well before the first U.S. demonstration plant (300 to 500 megawatts) is completed. The U.S.S.R. is already building a 600-megawatt plant.

The strongest disagreement with Shaw's management of the breeder program appears to come from nuclear scientists and engineers within the AEC's own laboratories (see, for example, *Science* 1 Oct., 1971, pp. 36–37). Some of the disagreement concerns Shaw's goals; for example, his opposition to and near elimination of research on alternative breeder concepts and advanced fuels is opposed by some as an extremely shortsighted policy. But even given the goal of developing only a liquid metal cooled fast breeder (LMFBR), Shaw's critics —which include utility executives and industry reactor engineers as well as AEC scientists—believe that he overmanages the development effort, they question his technical judgment on major design decisions, and they dispute his optimistic claims for the economic performance of the LMFBR. They cite as evidence the delayed construction of the demonstration plant, which was originally scheduled to begin in 1970, then in 1972, and which now seems unlikely to start before late 1973 or 1974. The fast flux test reactor in Hanford, Washington, an elaborate and expensive facility that is key to Shaw's development strategy, is also 4 to 5 years behind schedule—a delay apparently occasioned in part by Shaw's insistence on design requirements that later proved unrealistic. Others cite Shaw's perfectionist attitude that leads him, according to this view, to place excessive emphasis on reliability rather than on economic performance.

There is no doubt that Shaw, who has had essentially undisputed control over the breeder program in recent years, has brought a needed measure of concern with practical engineering to the breeder program. Nevertheless, the question remains whether he has allowed a concern with test facilities and hardware development to delay the program unneedfully.

Shaw's approach has its supporters. One utility official, for example, told *Science* that it was indeed time to stop doing research and start building demonstration reactors, and others expressed support for Shaw's emphasis on reliability. Shaw himself discounts claims that the breeder programs of other countries are ahead, maintaining that their technology is still unproved. Shaw believes that the economics of the breeder will work out in the long run if reliable components are available; his approach, he told *Science*, is concerned more with making sure that there will be a strong breeder industry than with seeing how quickly or how economically the first breeders can be built.

There appear, however, to be substantial questions as to whether the breeder Shaw is designing will be economical enough to attract industrial buyers. The capital costs of the LMFBR are expected to be higher than those of the light water power reactors being built today, but the breeders would potentially have lower fuel cycle costs. But Shaw admits that the initial cores in the first few commercial scale breeders will be designed conservatively, that they will have relatively long doubling times, and that "somebody" will have to absorb the first-of-a-kind costs. Improved fuels, which could be substituted as the reactor is refueled over a 3-year period, could upgrade breeder performance—such flexibility is one of the inherent attractions of the breeder concept—but the resulting delays in attaining economic operation might significantly increase the amount spent on electric power in the 1990's. Shaw has stopped essentially all work on advanced fuels.

To ensure the scientific quality of its programs, the AEC in the past has depended heavily on the general advisory committee, composed of nine presidential appointees from the scientific community, industry, and other backgrounds. Those present and former members of the advisory committee contacted by *Science* declined to give their opinions of the breeder program for publication, although some did express doubts privately. But a former chairman of the committee told *Science* that he had been aware of the conflicting points of view concerning the breeder program, and he stressed that the committee's role was merely advisory. In practice what seems to have happened is that Shaw's views have prevailed, largely because of the firm backing given Shaw by AEC Commissioner James T. Ramey, who reportedly has been the most influential and active of the commissioners on nuclear power matters during recent years.

Perhaps the most crucial objection, in the opinion of some observers, to Shaw's autocratic style of management is that his technical judgment and decisions are not subject to any effective review. As one critic put it, "Shaw may be doing the best job in the world, for all we know, but one man shouldn't make those decisions; the country can't afford the consequences if he's wrong."

—A.L.H.

and, although firm estimates are not yet available, may raise the costs of operating breeders and hence increase the desirability of more economic designs.

A second possible design that has so far received a lower priority is the gas cooled fast breeder reactor (GCFBR). In this concept, an inert gas such as helium is circulated to transfer the reactor's heat to the steam generator. Because the helium does not become radioactive, no intermediate heat exchanger is needed. But because the heat capacity of a gas is smaller than that of a liquid metal, the gas must be compressed to pressures between 70 and 100 atmospheres, and the entire reactor must be enclosed in a pressure vessel.

Early designs for gas cooled breeders were based on the assumption that extremely high temperatures and advanced fuels would be required and that elaborate safety precautions would have to be taken because of the high pressures involved. The development of prestressed concrete vessels, which do not undergo sudden failures and which, in the event of leaks, have a tendency to self-seal because they are always under compression, has alleviated some of the safety concerns. And recent studies have indicated that a GCFBR could be designed to run on essentially the same fuel and at the same temperature as that planned for the liquid metal cooled breeder. Gas cooled thermal reactors are already in commercial operation, so that substantial experience with this coolant technology is already available.

The potential advantages of the gas cooled design are several. Most importantly, these breeders are expected to have a shorter doubling time than the LMBFR because, compared to sodium, the helium absorbs fewer neutrons and is less of a moderator. Some estimates indicate a doubling time of less than 10 years, whereas many scientists do not expect the initial sodium cooled plants to be this efficient. Helium as a coolant is not itself radioactive, nor, unlike sodium, can it react with air and water should a leak occur. Because helium is transparent, maintenance of gas cooled reactors is expected to be easier. The bubbles that can form in sodium and that could cause overheating problems cannot occur in a gas cooled system.

The major disadvantages of the gas cooled breeder appear to be necessity to operate at high pressure and to maintain forced circulation at all times. In the event of a reactor accident involving the coolant circulating system, for example, the gas cooled reactor is dependent on mechanical equipment such as blowers to circulate the gas, so that extremely reliable back-up equipment is required. Because current gas cooled reactor designs include a vented fuel element to allow the equilization of internal and external pressures, the radioactive fission gases produced in the fuel must be passed through a purification system enclosed within the reactor vessel. Problems caused by swelling of the fuel elements, just as in the LMFBR, also exist.

Thermal Breeders

Hopes for a commercially viable breeder in the immediate future appear to depend on fast breeder reactors, either the LMFBR or the GCFBR; but on a slightly longer time scale thermal breeders may also be very attractive concepts. The AEC and Admiral Rickover are investigating a thermal breeder that would be moderated with water. Other research is continuing at the AEC's Oak Ridge, Tennessee, laboratory on a thermal breeder fueled with molten uranium salts. A molten salt breeder would be required to operate at very high temperatures, so that special materials will be necessary; but its compact size and the small amount of fuel required is expected to result in relatively low capital costs and an extremely short doubling time. Because of the molten fuel, continuous, on-line reprocessing of the fuel would be possible. Although all of the details of this novel concept have not been proved out, the coupling of power generation and fuel reprocessing in one location might have both environmental and economic advantages.

There appears to be general agreement that the liquid metal cooled breeder, for which designs are now the furthest advanced, should be built. Indeed, President Nixon's announced support for the LMFBR raises its status very nearly to that of a national goal. But some scientists and engineers believe that it is unwise to commit all U.S. resources—and the future of the country's supply of electric power—to what is still an economically unproven system, and they believe that alternative and potentially more attractive concepts should be vigorously pursued.

Supporters of the gas cooled breeder, for example, believe that demonstration plants based on this design could be built with very little additional research. The major manufacturer involved—Gulf-General Atomic—has already submitted a preliminary safety document for its design to the AEC, a step similar to that involved in applying for a construction permit. The gas cooled breeder has received only token support at AEC headquarters, however, and present AEC plans include the GCFBR only as a possible long range follow-on to the LMFBR.

The molten salt concept also has vigorous supporters. Limited funds have been provided by the AEC for continuing research on this alternative, but the experimental reactor that constituted the core of that program has been shut down.

There are some indications that the utility industry would prefer a broader program. A report of the reactor assessment panel of the Edison Electric Institute, published last year, concluded that, although development of the liquid metal cooled breeder should continue, the gas cooled breeder seemed to offer the greatest potential for achieving low cost electric power before the end of the century. This panel recommended that the development of the gas cooled breeder receive greater support. Current work on this concept is being supported primarily by a group of some 50 utilities. Another utility group is supporting work on the molten salt breeder.

Generating electricity with nuclear energy is no longer a novelty in this country, with some 22 reactors now operational and 55 more under construction, in commercial power plants alone. And despite opposition to nuclear power because of concern over reactor safety and environmental effects, the use of this energy source seems likely to expand further—more than half of the generating stations ordered by the utility industry in recent months are of the nuclear type. Breeder reactors will allow the most efficient use of nuclear fuels, and, presumably, lower costs.

Potentially, then, the breeder reactor will be a significant addition to the means for supplying electric power. Scientists who first dreamed of the benefits of nuclear energy had the breeder reactor in mind, and in fact the first electric power generated with nuclear energy, in 1951, came from an experimental breeder reactor at the National Reactor Testing Station in Idaho. But between that dream and its fulfillment still lie substantial steps in the development of this new technology—steps that ought to be carefully considered as part of a national energy policy.—ALLEN L. HAMMOND