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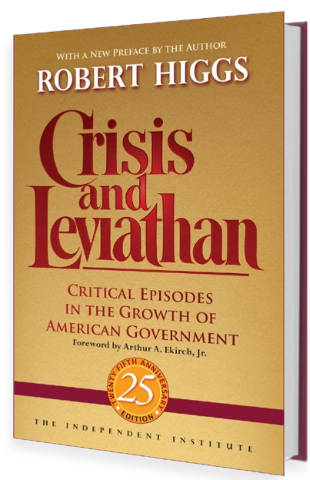

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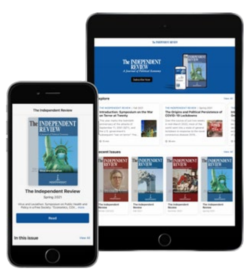

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Sustainable Energy

The Promise and Perils of the Breeder Reactor

WILLIAM BEAVER

In recent years, a great deal has been written and discussed about the need for the United States to develop sustainable sources of energy that do not pollute the air or water. Although the concept of sustainable energy is a hot-button issue today, attempts to develop such technologies are not new. In 1943, physicist Leo Szilard suggested it might be possible to construct a nuclear reactor that would create or breed fuel, producing an inexhaustible supply of energy. The concept became so compelling that the federal government would vigorously pursue it for the next forty years, with the ultimate goal of having the nation's electricity generated largely by breeder reactors. Indeed, the potential of such a device makes other sources of energy pale in comparison, knowing that even so-called renewable sources of energy are dependent on adequate amounts of sun and wind. The goal, however, has proved elusive despite decades of research and development and billions of dollars spent.

The purpose of this article is to briefly chronicle major developments in the history of the breeder reactor in the United States. It is a history of peaks and valleys, where the federal government attempted to rapidly develop a technology based on what turned out to be a set of erroneous assumptions. Perhaps something can be learned about the appropriate role of government in technological and energy development by examining the breeder's history.

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Early Years

As early as 1945, the Argonne National Laboratory began seriously to investigate the possibility of constructing a breeder reactor. Breeding is possible in nuclear fission because when the atom splits, two and sometimes three neutrons are released. One of the neutrons keeps the chain reaction going, but if the other neutrons can somehow be captured in "fertile material," a new atom can be created, which can then be fissioned, eventually creating enough fuel to keep the reactor going indefinitely. The laboratory's director Walter Zinn told the U.S. Atomic Energy Commission (AEC) that a breeder reactor was possible but would be an immensely difficult task requiring substantial research and development. Zinn also emphasized that breeders would be necessary because fissionable uranium would eventually be in short supply (Hewlett and Duncan 1969).

By 1948, Congress had authorized funds for the construction of an experimental breeder reactor (EBR-I) to be operated by the AEC in Idaho. The reactor would have a small uranium core about the size of a football, and liquid sodium would circulate around the core, acting as a coolant, with the heat absorbed then given off to a heat exchanger. Cooling in a nuclear reactor is always necessary because once the atom splits, temperatures can rise to greater than 5,000 degrees Fahrenheit—a scenario to be avoided because the reactor core can begin to melt down. A major advantage of using liquid sodium as a coolant is that temperatures can run to more than 800 degrees Fahrenheit, dramatically increasing thermal efficiency. In contrast, reactors using light or ordinary water for a coolant have temperature rises to only 523 degrees. Moreover, liquid sodium does not slow down the neutrons as water does, and the faster the neutrons move, the more the likelihood that breeding will occur. Thus, such devices using sodium were referred to as "fast reactors." Liquid sodium unfortunately had its drawbacks. One former Westinghouse official described it as "tricky" (Weaver 1988). The substance is highly corrosive and can explode when it comes into contact with water and burn when exposed to air. Hence, any leak of liquid sodium can have serious consequences. The corrosive nature of the substance only compounds the problem, considering the amount of piping in a reactor.

It should be emphasized that in these early years nuclear advocates believed that light-water reactors were just the beginning and that more advanced designs would follow. For instance, the first practical use of nuclear energy involved constructing a reactor to power the *Nautilus* submarine. Scientists at the Oak Ridge National Laboratory reported that using light water as a coolant represented the fastest route to launching such a vessel. When asked why water was selected, an official closely tied to the submarine program stated, "[W]e knew more about it than anything else" (qtd. in Weaver 1988). At that time, speed in developing the technology was essential because the Cold War had heated up, and a nuclear-powered submarine was viewed as crucial element to bolster the nation's defenses and beat the

Soviets, who had just detonated their first nuclear device (Smyth 1956). Thus, the light-water reactor was selected to meet military and political needs of official Washington but not necessarily to generate electricity—a task that would ultimately be left to more advanced designs such as breeders.

The EBR-I went critical in August 1951 and became the first reactor to produce electricity. Experiments conducted in 1953 demonstrated that the reactor could create or breed more fuel than it consumed. Perhaps the most significant event in the reactor's life occurred in 1955. During an experiment, an operator hit the wrong button and cut off the flow of liquid sodium. Temperatures in the reactor quickly rose to 2,000 degrees Fahrenheit. The fuel began to melt but was contained within the reactor. Critics charged that this accident was just a foretaste of things to come, and Walter Zinn told Congress that in the worst case such an occurrence "could disassemble the machine" (qtd. in Novack 1969, 154). That said, Zinn and the AEC put the best possible light on the incident, claiming that much had been learned about dealing with emergency situations and that "no unforeseen or catastrophic processes occurred" (Zinn 1956, 25). Following the cleanup, the reactor operated until 1963 and was then decommissioned. In the following year, President Johnson declared the EBR-I a national landmark, and the AEC declared it a success because the project showed that breeding was possible and that liquid sodium could successfully be used as a coolant.

At about the time the ERB-I was shutting down, ERB-II, a 20-megawatt sodium-cooled reactor began to operate in Idaho, albeit five years behind schedule. The stated purpose of this reactor was to show that a complete breeder reactor power plant could operate successfully and reprocess nuclear fuel. When in full operation, the reactor did supply enough electricity for the Argonne National Laboratory, where it was located, and reprocessed spent nuclear fuel. However, the reactor did not breed, but like its predecessor it did provide baseline data that could be used for a larger demonstration plant to be constructed in the 1970s and was the final step in developing the reactor that would replace first-generation light-water technology (Dawson 1976).

For the most part, the development of breeder reactors was left largely to the federal government. There was one major exception, however. In 1955, Detroit Edison proposed the construction of the world's first commercial breeder reactor. The company agreed to assume 90 percent of the costs, and, to the surprise of many, the AEC gave Detroit Edison permission to build the 200-megawatt plant about thirty miles outside of Detroit, even though the AEC's own advisory committee on reactor safeguards recommended against construction. Why was the decision made when so little was actually known about breeders? During the early 1950s, an atomic euphoria existed in which the peaceful atom was usually viewed in a positive light. Advocates predicted a golden age of cheap energy, with atomic energy being used in any number of practical applications. Some even suggested that each home would eventually have its own small nuclear reactor to supply electricity

(Pilat, Pendler, and Ebinger 1985). More important, the AEC desperately wanted private-sector involvement. The Eisenhower administration feared that if the nation's utilities did not go nuclear and assume at least part of the costs involved, Democrats in Congress would push through a much larger government-driven program. The State of Michigan tried to stop construction through various legal actions, but after some long delays Fermi I went critical in August 1963. A number of technical problems cropped up, and the reactor did not reach full power until 1966. On October 6 of that year, temperatures in the reactor began to rise, and some of the nuclear fuel melted but was contained within the reactor. Operators knew the flow of liquid sodium had been cut off, but not why that happened. After a nine-month investigation, it was discovered that a piece of metal cladding installed as a safety device—and not even on the original blueprints—had somehow come loose and blocked the flow of coolant. The reactor was eventually repaired, but in May 1970 a sodium explosion occurred, releasing two hundred pounds of radioactive gas into the environment. Repairs and a cleanup followed, and the reactor operated until 1972, when the federal government decided not to renew the plant's license. In all, Fermi I had operated for less than thirty days at full power, no breeding had occurred, and repair costs alone ran to approximately $132 million (Fuller 1975; Alexanderson 1978).

The obvious lesson of Fermi I is that technologies still in the experimental stage are not ready for commercialization. Beyond that, the entire episode raised questions about the ultimate safety of nuclear power and certainly provided fodder to the emerging environmental movement that would oppose the technology. Finally, Fermi I also raised serious questions about the integrity of government. Specifically, could it be trusted to protect public safety?

Clinch River

By the early 1960s, it was decided that the United States would develop breeders officially known as the "liquid-metal fast breeder reactors" (LMFBRs) as the major energy alternative to fossil fuels. It was a decision made within the confines of the AEC and sectors of Congress, with the tacit support of the Kennedy, Johnson, and Nixon administrations, and, in retrospect, made without much debate, at least in any democratic sense. In December 1962, AEC chairman Glenn Seaborg outlined the commission's plan to develop breeders in a report entitled *Civilian Nuclear Power: A Report to the President* (U.S. AEC 1962). The decision was certainly a bold and, as events turned out, flawed leap of faith because the AEC assumed that the development of light-water reactors was more or less complete, which would allow the government to focus on breeders. Unfortunately, as anyone knows who has followed the history of nuclear power, many problems still remained with light-water technology. Nonetheless, by 1965 the AEC's push to develop breeders had crystallized under the direction of Milton Shaw, who had been appointed director of reactor development. Shaw had served in the Naval Reactors Branch and believed strongly in the LMFBR, so much so that other promising designs were put on the back burner or ignored (Hammond 1971). In essence, the AEC's decision to move ahead with the breeder became the de facto U.S. energy policy of the 1960s and early 1970s. The stated reason for the policy was the widely held belief that Uranium-235 (the only naturally occurring fissionable isotope of uranium) would soon be in short supply, perhaps as early as the 1990s. The fact that U-235 accounts for only 0.7 percent of all uranium made the situation more urgent, along with predictions of sharp increases in the use of electricity that the AEC assumed nuclear power would supply (Cochran, Felverson, and von Hippel 2009).

With the somewhat successful operation of the government's two experimental breeders, the AEC prepared to construct a large demonstration plant—the final step toward commercialization. The commission began to lobby the Nixon White House for the necessary funding. The effort proved difficult, not just because of the considerable amount of money involved, but because various environmental groups began to express opposition to the breeder. A major concern was the fact that plutonium would be created. How so? The demonstration reactor would utilize U-238, or natural uranium, whose supply was plentiful. Although U-238 is not fissionable, in breeders it can be bombarded with neutrons, producing Plutonium-239, which is fissionable. Plutonium is considered to be one of the most toxic substances on earth. For instance, it was claimed that the release of one ton of plutonium into the atmosphere could give every person on earth lung cancer, and operating breeder reactors on a large scale would double the amount of plutonium on earth every ten years ("AEC Asks Billions for the Breeder" 1971). Despite growing opposition, the Nixon administration announced that it would support the demonstration plant. The president called it "our best hope" for the country's energy future. The White House obviously felt that the breeder was worth the risks and accepted the AEC's position that U-235 would be in short supply, putting existing light-water reactors in jeopardy. The breeder, as envisioned, would solve that problem by creating not only fuel for itself, but enough fuel for another reactor. Finally, the Nixon administration viewed the breeder as a nonpolluting source of energy that would help to improve air and water quality (Shabecoff 1971).

In 1972, Congress authorized construction of the reactor, and initial funding for the 350-megawatt demonstration plant was allocated. For the next decade, the federal government would spend between \$10 and \$15 million a month to develop and construct the plant to be located along the Clinch River in Tennessee near the Oak Ridge National Laboratory. The project was initially managed by a troika including the AEC, the Tennessee Valley Authority (TVA), and Commonwealth Edison, an Illinois-based utility. Westinghouse would supply the nuclear equipment. The inclusion of the private sector in the project's management was done to facilitate funding from industry, which ultimately would amount to approximately

$100 million. However, the troika was short-lived. By 1975, the Energy Research and Development Administration (ERDA), which had replaced the AEC, had taken over management of the project in order to speed decision making. The TVA and Commonwealth Edison would be relegated to more advisory roles. Congress agreed with the new arrangement, even though it meant that the federal government would have to fund around 85 percent of the project ("Easing Industry out of Breeders" 1975). However, any number of hurdles still had to be dealt with before construction could begin.

Opposition

The first hurdle appeared shortly after the Nixon administration announced its support for Clinch River. In May 1971, the Scientists' Institute for Public Information (SIPI), headed by Margaret Mead and Barry Commoner, filed suit in U.S. District Court to force the AEC to issue an environmental impact statement for the LMFBR technology. The group's major concern was the use of liquid sodium and the potential hazards involved. The AEC resisted, arguing that an environmental impact statement should be issued only when a particular plant was going to be constructed and not for an entire technology. The case dragged on until 1973, when the court ruled in favor of SIPI, which meant that the government would have to compile a detailed report before construction of Clinch River could begin (Lyons 1973). The seven-volume report was finally issued in 1976 (ERDA 1976) and concluded that the technology was environmentally safe. The report also stated that the ultimate safety of a breeder reactor could be proven only by operating one.

Although environmental groups would continue to oppose Clinch River, the major obstacle to its construction would be the election of Jimmy Carter. Carter's opposition to the breeder reactor was somewhat ironic because he had served as a young officer in the nuclear navy. Nevertheless, shortly after taking office, Carter called the technology a "serious risk" and said he would attempt to stop the use of plutonium as a fuel source. He suspended the licensing process for the construction of Clinch River and continued the ban initiated by President Ford on reprocessing, which would extract the plutonium from the breeding process that could then be used to fuel another reactor. The president feared that plutonium might fall into the wrong hands and be used to manufacture a nuclear weapon. Indeed, some believed that a competent nuclear scientist with twelve pounds of plutonium, the right equipment, and few hundred thousand dollars could produce a bomb ("Putting Brakes on the Fast Breeder" 1977). The president did let it be known that he would be interested in supporting an even larger breeder to take advantage of economies of scale if a fuel source other than plutonium was used. In addition, the president contended that the administration's latest calculations indicated that supplies of U-235 would be sufficient (Cochran, Felverson, and von Hippel 2009). Hence, the rush to construct Clinch River was unnecessary.

While the president was making his views known, Energy Secretary James Schlesinger assembled an eleven-member panel consisting of energy and environmental experts to investigate breeder technology. The group's report favored further development of plutonium as a fuel source and noted that the potential for making a bomb was present in other types of reactors, not just breeders. In addition, ERDA also favored breeder development and projected that the technology could lower energy costs by $50 billion over thirty years. Thus, the Carter administration was not in total agreement. Nonetheless, the president vetoed funds for Clinch River. However, the funds were later attached to a public works bill by congressional supporters of the project, which the president chose to sign. Ironically, in each year of the oppositional Carter presidency, powerful constituencies in Congress, the nuclear industry, and the federal bureaucracy were able to keep funding for Clinch River intact, motivated in part by the Arab oil embargo of 1973, which had raised fears about the nation's energy future that, it was argued, breeders could help to alleviate (Smith 1979).

Some speculated that the president's motives were not as pure as they seemed. Specifically, they believed that by killing the breeder, Carter hoped to placate environmental groups, whom he then hoped would drop their increasing opposition to light-water reactors ("Putting Brakes on the Fast Breeder" 1977). That said, the most compelling argument against Clinch River pointed to the costs involved. James Schlesinger, secretary of the newly created U.S. Department of Energy (DOE), testified before Congress that besides increasing the chances of nuclear proliferation, Clinch River would cost more than $2 billion to complete. Schlesinger also reiterated that safer and larger breeders would be investigated if Clinch River were canceled ("A Possible Reprieve" 1977). The end result was that although funding for Clinch River never stopped, the momentum for it was clearly slowed. As one congressional staffer aptly put it, "The bottom line is that if the president doesn't want it, it won't be built" (qtd. in "House to Breeder" 1978).

Ronald Reagan did want the breeder. The new president had always been a proponent of nuclear power, and in his first budget he allocated $228 million for construction of Clinch River—on top of the $1 billion that had been spent over the previous decade. Congress gave Reagan the amount requested despite a House subcommittee report that called Clinch River "a cost and technical fiasco." The report stated that the final cost to complete the plant would be at least $3.2 billion, nearly five times more than the original estimates. The subcommittee also cited loose contract language that seemingly gave contractors a blank check, leading to financial abuses. For instance, Westinghouse had agreed to construct a steam generator for $5 million in 1975, but the final cost to the government was $71 million (U.S. Congress 1981, 3-23). Nevertheless, after some wrangling, the Nuclear Regulatory Commission gave approval for site work to begin. To placate the opposition, the administration urged that the project be accelerated in order to reduce costs. Yet even within the Reagan White House there was disagreement about Clinch

River. Budget Director David Stockman argued against funding the project but was overruled. As a Michigan Congressman, Stockman had opposed Clinch River, calling it “totally incompatible with our free-market approach to energy policy” (qtd. in Lee and Salter 1981, 20).

Despite the Reagan administration’s support, the fate of Clinch River was sealed when Congress became aware that the total cost to complete the plant would run as high as $4 billion. To offset these increases, Congress called for more private-sector funding. The administration then worked out a deal, which on the surface appeared to have the nuclear industry sharing more of the costs. However, a Government Accounting Office analysis revealed that the agreement was largely smoke and mirrors and that in reality the government would actually end up spending more on Clinch River, not less. The finding outraged many in Congress to the point that funding for Clinch River was cut off in 1983. Congress did leave the door open, however, by letting it be known that if the nuclear industry made a more generous proposal, funding could be restored, but no such proposal was forthcoming. The only thing left to do was to clean up the site in Tennessee, which did not prove to be overly difficult because only a concrete base for the plant had been poured (Marshall 1983).

The Shippingport Breeder

With the demise of Clinch River, the forty-year dreams and hopes of the nuclear community were temporarily laid to rest. Although the federal government constructed numerous other test reactors to facilitate the development of breeders, one breeder technology developed in the United States was made workable during the period covered so far and for that reason alone deserves some discussion. The breeder was located at Shippingport, Pennsylvania, just north of Pittsburgh. Shippingport was the nation’s first commercial light-water atomic power plant, operated by Duquesne Light under the direction of the U.S. Naval Reactors Branch, headed by Admiral Hyman Rickover. The plant went online in 1957 and generated power until 1973, when it closed down for the installation of a light-water breeder reactor. From the beginning, the scientific community had largely dismissed the idea of using a water-cooled reactor for breeding because water slowed down the neutrons, making breeding less likely. Nonetheless, beginning in the 1960s, Naval Reactors in conjunction with Westinghouse and the national laboratories, began to investigate the possibilities of breeding in a light-water reactor. Initial research was encouraging, and serious development of the light-water breeder began after 1965 and would continue for the next ten years. The DOE offered several rationales for developing the technology. First, there was the widely held belief that supplies of U-235 would eventually become scarce. Second, light-water technology was better understood and inherently safer than the sodium-cooled reactors that produced plutonium. Hence, development would be faster and less controversial. Finally, a light-water breeder could be backfitted into any existing commercial reactor, making the technology less expensive than sodium-cooled breeders (U.S. DOE 1979).

Rationales aside, the light-water breeder would not have been possible without Hyman Rickover's ability to procure funding for the project. As one former Westinghouse official put it, "Rickover got more money than any single individual and got money when no one else could" (qtd. in Rengel 1985). In all, Congress would allocate approximately $712 million for the Shippingport breeder—a considerable sum, considering that both the scientific community and the AEC gave the technology short shrift. As one scientist commented, "[W]e just don't take it very seriously" (qtd. in Rose 1974, 351). Rickover got the money because over the years he had become a Washington icon with a reputation as a man who would produce. Just as important, for more the three decades he carefully cultivated his relationship with Congress, which extended his tenure at Naval Reactors until 1982 despite objections from the navy on different occasions. Several times each year Rickover made his way to Capitol Hill to testify and maintain his support for nuclear energy technology. To ensure its effectiveness, his testimony would be reviewed beforehand by as many as thirty different individuals. All his congressional appearances were carefully rehearsed—more like theater than testimony. Rickover would lecture and answer questions, seldom mentioning money but usually getting it. The admiral would also invite members of Congress to ship launchings, give them personal tours of new vessels, and provide them with mementos such as capsules of polar sea water from the *Nautilus* (Polmar and Allen 1982).

Another factor favored the development of the light-water breeder: Rickover's relationship with Jimmy Carter. As mentioned, Carter, an Annapolis graduate, had served in the nuclear navy under Rickover. Carter viewed Rickover as "almost a father figure," although Rickover admitted that he didn't remember the future president, who gave his autobiography the title *Why Not the Best?* (Carter 1976) after a question Rickover had posed to him during an interview. Carter supported Rickover's efforts not only out of a sense of admiration, but also because a light-water breeder would fulfill Carter's promise to support breeder technologies that did not produce plutonium. After a difficult installation of the breeder core, the reactor reached full power in August 1977. Indeed, Rickover called the entire project "one of the most difficult engineering problems ever undertaken" (U.S. Congress 1979, 1608). To show his support, Carter took part in the formal dedication from the Oval Office, where the president and Rickover gave a signal to start the reactor. The Shippingport breeder operated until 1982 with no mishaps or surprises. Rickover wanted the plant to operate until 1985, but, as mentioned, the admiral was finally retired in 1982, and with the end of his tenure at Naval Reactors came an end to the funding for the breeder. The reactor was subsequently shut down, and the fuel modules were eventually removed and shipped to Idaho. In 1987, after a lengthy analysis, Westinghouse revealed that breeding had taken place, producing enough fuel for a replacement core. The company also announced that the light-water breeder was ready for commercial use, but no utility has ever expressed much interest in purchasing one. Besides adequate supplies of U-235, the technology does have a significant downside. The breeder uses thorium U-233, a fissionable isotope of uranium. U-233 was chosen because it had a higher potential for breeding. Unfortunately, it does not exist in nature and must be manufactured in "prebreeders." Thus, any utility that wanted to have an existing reactor backfitted with a light-water breeder would have to pay the government to do so, and the process would take at least ten years (Atherton 1987).

For the most part, government interest in breeder reactors severely waned in the 1980s and officially came to an end in 1994, when the ERB-II reactor in Idaho was finally shut down and funding for research stopped. There was one exception, however. In 2006, the Bush administration proposed that fast reactors, with some adjustments to the reactor's core, could become "burner reactors." Specifically, sodium-cooled reactors could be used to make the nuclear waste problem more manageable by breeding less fissile materials than they burned. However, neither the Obama administration nor Congress has shown any interest in pursuing the technology (Von Hippel 2010).

Other Countries

Realizing the technology's enormous potential, other countries—including India, Russia, the United Kingdom, Japan, and France—have also attempted to develop breeder reactors, but the experience of Japan and France is most instructive and provides some perspective on the U.S. experience. Both countries have had a long-standing interest in breeders due largely to inadequate supplies of domestic fossil fuels. As early as 1956, the Japanese AEC expressed interest in sodium-cooled breeders, and by 1967 the Japanese decided to emphasize breeder development. An experimental plant opened in 1977 and served largely as a test reactor for materials and fuels to be used in the future. The major Japanese effort to develop breeders centered around the construction of the 280-megawatt Monju reactor. After a number of delays, the reactor went critical in 1994. Less than a year later, however, a sodium leak occurred, resulting in a major fire. No injuries or radiation releases took place, but there was major damage to the steel structure that housed the reactor. To make matters worse, the operators of the plant attempted to cover up the incident, which spawned a great deal of political turmoil. The reactor was finally set to reopen in 2002, but various legal challenges ensued, arguing that the reactor was unsafe. The Japanese Supreme Court eventually ruled that the reactor could be restarted, which it was in 2010. Shortly thereafter, a 3.3-ton piece of machinery crashed into the reactor, causing major damage, which meant the plant would be shut down for several more years (Tabuchi 2011). Despite all the problems with Monju, the Japanese government maintained that it was still committed to developing the breeder. A new demonstration plant was planned to be in operation by 2015, and the goal of commercialization was to be achieved by 2050 (Suzuki 2009). However, the recent announcement that Japan plans to phase out nuclear power by 2030, largely as a result of the Fukushima disaster following the earthquake and tsunami in 2011, has obviously put the breeder's future in jeopardy.

The French have been the most aggressive in pursing the breeder. An experimental breeder was constructed in the 1960s, followed by the Phenix, a 250-megawatt sodium-cooled reactor that went online in 1973 and became part of the French power grid. Phenix also produced plutonium for the French weapons program, creating about 12 percent more plutonium than it consumed. The reactor performed reasonably well, operating until the late 1980s, when a series of problems occurred that aroused safety concerns. In addition, a number of sodium leaks also occurred over the years. Although none was catastrophic, fires caused damage and shutdowns on different occasions. Beginning in the 1990s, the reactor operated largely as a test reactor before closing in 2009.

The most ambitious initiative of the French was the construction of the 1,200-megawatt Superphenix sodium-cooled reactor spurred by the Arab oil embargo of 1973. Construction began in 1977 with the prediction that breeders would produce 25 percent of France's electricity by the turn of the century. Yet even before construction started, large demonstrations took place as the antinuclear movement focused its attention on the breeder. In 1982, an antinuclear terrorist group launched several rocket-propelled grenades at the construction site, but the damage was minimal. Despite the protests and attack, the French government was not deterred. As one French minster stated, Superphenix was a matter of "life and comfort for the French people" (qtd. in Schneider 2009, 40). The reactor, operated by four European utilities, reached criticality in 1985 but was shut down in 1987 following a leak in the liquid-sodium cooling system. After extensive redesign and repairs, the reactor was restarted in 1989, but shortly thereafter an air leak affecting the oxidation of sodium took place, followed by the collapse of a roof after a heavy snowfall ("Superphenix Set to Rise Again" 1993). After a series of legal challenges, the reactor was finally restarted in 1995, but it never operated again after a shutdown for scheduled maintenance in 1996. The French did consider using the Superphenix as a "burner reactor" to help reduce the amount of spent nuclear fuel. However, by that time, the Green Party had joined the French government, and its influence as well as growing opposition to breeders within the European Union helped seal Superphenix's fate. The reactor is currently being decommissioned (Schneider 2009).

Conclusion

The major premise for the federal government's rapid development of the breeder reactor was that supplies of U-235 would be greatly diminished, a concern made more urgent by the belief that the bulk of the nation's electrical needs should and could be supplied by nuclear power. These assumptions were widely held, and there is nothing to suggest that they were disingenuous. The breeder experience does demonstrate the fragile nature of predictions, even when made by those who possess the best available information. Perhaps the major lesson of the breeder's checkered history is to be skeptical of predictions even when made by experts with good intentions. Such assumptions unfortunately led to a great deal of wasted money and effort. The Shippingport Breeder, ultimately made possible by Hyman Rickover's unique ability to procure funding from Congress, was a challenging and expensive project that in the end turned out to be fruitless. To be fair, the technology does appear to be safe, and had the predicted shortages of U-235 occurred, the light-water breeder could have been used as a last resort, allowing existing nuclear plants to continue operating.

The predictions about shortages of U-235 also produced a rush to develop a technology that was not ready for commercialization, as the U.S., French, and Japanese experience indicates. In retrospect, it seems obvious that the U.S. government needed to construct a larger experimental reactor and not Clinch River. An experimental plant would have provided a better setting for learning more about the technology and resolving problems, particularly with those involving liquid sodium. Public safety needed to be ensured and environmental concerns lessened, for when it comes to nuclear power, modern societies have little tolerance for mistakes or accidents. Consider that even though conventional light-water reactors have proven to be extremely safe in the United States, opposition to them still exists. One can only wonder if the breeder reactor, with its more inherent dangers, would ever have gained acceptance or if a typical American utility would ever have wanted to operate one. At the very least, had the issues with liquid sodium been resolved, utilities would have had more confidence about the LMFBR when the time came to commercialize the technology. Of course, the financial issues would have presented a major stumbling block. It is estimated that an LMFBR would cost at least twice as much to construct as a conventional light water plant.

The possibility of nuclear proliferation that Jimmy Carter and others feared did not manifest itself in part because breeders never became commonplace. In addition, many experts believe that manufacturing a nuclear weapon from reprocessed plutonium would be extremely difficult, and there are far easier ways to make a bomb (Rossin 2006). Others also argue that potential exposure to plutonium is so dangerous that even terrorists would shy away from it. Proliferation issues aside, there are those who still feel the LMFBR can provide a nonpolluting and sustainable source of energy. In addition, by reprocessing the fuel that breeders produce, the nuclear waste problem would become more manageable. However, at this point, the chances of that happening seem remote.

References

AEC Asks Billions for the Breeder. 1971. *Business Week* (May 29): 82–84.

Alexanderson, Pauline E. 1978. *Fermi-I: A New Age of Nuclear Power.* Lagrange Park, Ill.: American Nuclear Society.

A Possible Reprieve for the Fast Breeder Reactor. 1977. *Business Week* (June 20): 31–32.

Atherton, Robert. 1987. *Water-Cooled Breeder Program: A Summary Report.* WAPD-TM-1600, U.S. Department of Energy. Washington, D.C.: U.S. Government Printing Office.

Carter, Jimmy. 1976. *Why Not the Best?* Little Rock: University of Arkansas Press.

Charles H. Weaver, (Westinghouse Vice President), interview with the author, March 3, 1988.

Cochran, Thomas B., Harold A. Felverson, and Frank von Hippel. 2009. Fast Reactor Development in the United States. *Science and Global Security* 17, no. 1: 109–31.

Dawson, Frank G. 1976. *Nuclear Power: The Development and Management of a Technology.* Seattle: University of Washington Press.

Easing Industry out of Breeders. 1975. *Business Week* (March 31): 24.

Energy Research and Development Administration (ERDA). 1976. *Final Environmental Impact Statement for the Liquid Metal Fast Breeder Reactor.* 7 vols. Washington, D.C.: U.S. Government Printing Office.

Fuller, John. 1975. *We Almost Lost Detroit.* New York: Reader's Digest Press.

Hammond, Allen L. 1971. Management of the U.S. Breeder Program Draws Criticism. *Science* 174 (November 17): 8–9.

Hewlett, Richard C., and Francis Duncan. 1969. *Atomic Shield, 1947–1952.* Vol. 2 of *The History of the United States Atomic Energy Commission*. University Park: Pennsylvania State University Press.

House to Breeder: We Want You. 1978. *Science News* 144 (July 22): 54–57.

J.C. Rengel, (Westinghouse Project Manager, 1955–1959), interview with the author, April 23, 1985.

Lee, Gary, and Peter Staler. 1981. Clinch River: A Breeder for a Baker. *Time* 118 (August 3): 18–20.

Lyons, Richard D. 1973. Nuclear Reactor Delayed by Court. *New York Times*, June 13.

Marshall, Eliot. 1983. Clinch River Dies. *Science* 222 (November 11): 590–92.

Novack, Sheldon. 1969. *The Careless Atom*. Boston: Houghton Mifflin.

Pilat, John F., Robert Pendler, and Charles K. Ebinger. 1985. *Atoms for Peace: An Analysis after Thirty Years.* Boulder, Colo.: Westview Press.

Polmar, Nathan, and Thomas B. Allen. 1982. *Rickover: Controversy and Genius.* New York: Simon and Schuster.

Putting Brakes on the Fast Breeder. 1977. *Time* 109 (April 18): 59.

Rose, D. J. 1974. Nuclear Electric Power. *Science* 184 (April 19): 351–59.

Rossin, A. David. 2006. *U.S. Policy on Spent Fuel Reprocessing: The Issues.* Available at http://www.pbs.org/wgbh/pages/frontline/shows/reaction.

Schneider, Mycle. 2009. Fast Breeder Reactors in France. *Science and Global Security* 17, no. 1: 17–36.

Shabecoff, Philip. 1971. Nixon Offers Broad Plan for More Clean Energy. *New York Times,* June 5.

Smith, R. Jeffery. 1979. Carter Loses on Breeder Reactor Again. *Science* 205 (August 24): 773.

Smyth, Henry D. 1956. Nuclear Power and Foreign Policy. *Foreign Affairs* 35 (October): 1–16.

Superphenix Set to Rise Again. 1993. *Science* 262 (October 15): 327.

Suzuki, Tatsujiro. 2009. The Fast Breeder and Its Fuel Cycle Developments in Japan: Can Japan Unlock Its Development Path? *Science and Global Security* 17, no. 1: 68–76.

Tabuchi, Hiroko. 2011. Japan Strains to Fix a Reactor. *New York Times,* June 11.

U.S. Atomic Energy Commission (AEC). 1962. *Civilian Nuclear Power: A Report to the President*. Washington, D.C.: U.S. Government Printing Office.

U.S. Congress. 1979. *House Subcommittee on Public Works for Water, Power Development, and Energy Research Hearings Appropriations Bill 1979.* Part 7, 95th Cong., 2nd sess. Washington, D.C.: U.S. Government Printing Office.

———. 1981. *Hearings before the Subcommittee on Oversight and Investigation of the Committee on Energy and Commerce, House of Representatives.* 97th Cong., 1st sess. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Energy (DOE). 1979. *Light Water Breeder Reactor.* Washington, D.C.: U.S. Government Printing Office.

Von Hippel, Frank. 2010. Overview: The Rise and Fall of the Breeder Reactor. In *Fast Breeder Program: History and Status: Research Report 8.* Princeton: International Panel on Fissile Materials. Available at http://fissilematerials.org.

Zinn, Walter. 1956. A Letter on the ERB-I Fuel Meltdown. *Nucleonics* 14 (June): 25.