Fast Reactors

Unsafe, Uneconomical, and Unable to Resolve the Problems of Nuclear Power

In the push for nuclear power, proponents of fast neutron reactors have portrayed this design as a new, promising technology that could resolve the question of managing long-lived radioactive waste. But the idea of fast neutron reactors is not a new one. Ever since the first experimental fast neutron reactor generated electricity in 1951,[1] governments around the world have made huge investments into their development, but the return has been minimal. After decades of research and experimentation, fast neutron reactors remain unsafe, uneconomical, and unable to address the problems of nuclear power.

Fast neutron reactors are typically high temperature reactors fueled by a plutonium/uranium blend and cooled using an inert gas or liquid metal. They were first promoted as a way to extend uranium supplies, because as they operate, unusable uranium can be converted to fissile plutonium that can be used as fuel. It has since become clear that uranium is more abundant than originally thought. Now, fast reactors are being advocated as a waste solution that would reduce the radioactivity of spent fuel by converting long-lived plutonium and other radioactive heavy metals in the waste into shorter-lived radionuclides.

Fast neutron reactors, however, have a terrible track record in safety and economics, and are not capable of solving the waste problem.

There are four general types of fast-neutron reactors: sodium-cooled, lead-cooled, gas-cooled, and molten salt. Up to now, only liquid sodium cooled fast neutron reactors have been built on any large scale.

HISTORY OF FAILURE

The history of fast neutron reactors throughout the world has been marked by both safety and economic failure. There have been over twenty of these reactors built since 1951 in seven countries, all of which have been funded through government programs. Eleven of the reactors were large-scale designs (over 100 megawatt-thermal, MWt), eight of which have been shut down as of 2006. Only three reactors still operate: the French Phènix reactor, the Russian BN-600 reactor, and the small experimental Joyo reactor in Japan.

United States

In the United States, a 94 megawatt-electric (MWe) sodium-cooled reactor called Fermi 1 operated from 1963 to 1972, but suffered from serious problems, including a partial nuclear meltdown in October 1966,[2] and a sodium explosion in 1970. The reactor was denied a new license and closed in 1972. A second reactor, the Fast Flux Test Facility (FFTF), a 400 MWt liquid sodium cooled reactor, was operated in the United States from 1982 through 1992. FFTF was a built as a companion to the proposed Clinch River breeder reactor, which was partially built, but canceled by Congress in 1983 because of its exorbitant cost. FFTF was put on standby in 1992, and after years of public opposition to its restart, the U.S. Department of Energy (DOE) finally shut it down in December 2001.

Waste storage drums from reprocessing at Savannah River Site. Photo by the U.S. Department of Energy.

United Kingdom

In the UK, a 250 MWe liquid sodium cooled Prototype Fast Reactor (PFR) operated at Dounreay, Scotland from

1974 through 1994. PFR suffered cracking of primary system components as a result of cyclic thermal stresses.[3] In 1977, there was an explosion in a waste shaft on the site.[4] Radioactive material has been found on the shore near Dounreay since that time. In 1998, it was revealed that 170 kilograms of enriched uranium – enough to build a dozen nuclear bombs – was missing from Dounreay. Soon after, the entire facility was closed.[5]

France
In France, there have been two larger-scale fast neutron reactors built. The first was the Phènix (233 MWe), which came online in 1973 and still operates. The Phènix had problems with unexplained reactivity fluctuations while the reactor was operating at full power. These sudden drops in reactivity raised safety concerns and the reactor was shut down for several years starting in 1990.[6] The reactor was eventually restarted, but it is slated to be permanently shut-down in 2009.[7] The second large-scale French fast-neutron reactor was the Superphénix (1,200 MWe), which began operating in 1986, but was closed in 1997 as a result of continuing sodium leaks and cracks in the reactor vessel. Because of its ongoing problems, the Superphénix only operated for the equivalent of 278 days of full power, possibly consuming more energy by the time it was dismantled than it produced throughout its years in operation.[8]

Japan
In Japan, the 280 MWe Monju reactor began generating electricity in 1994. The reactor was shut down following a massive sodium leak and fire in December 1995, only eight months after startup. The accident was particularly controversial, because the video of the event was edited and concealed from the press and government agency investigating the accident. Reporting of the accident to the local government was also slow, and a deputy director of the government power corporation operating Monju committed suicide a month later. The reactor has not reopened following the incident. In September 1999, two workers were killed, 63 people were injured, and another 300,000 were forced to stay indoors after an accident in the fuel fabrication facility for a much smaller test fast reactor, the experimental Joyo reactor, near Tokaimura, Japan.[9] The small 130 MWt reactor has operated for research since 1978.

Russia
In the former Soviet Union, BN-350, a 130 MWe reactor generated electricity and desalinated water from 1972 until 1999. In October 1973, the BN-350 experienced a major sodium-water reaction in a steam generator.[10] Its successor, the BN-600, a sodium-cooled reactor generating 600 MWe, began operation in 1980 near Beloyarsk, Russia, and is still operating, though there have been problems with sodium leaks and the failure of the steam generator. Over 27 significant sodium leaks have been documented at the BN-600 reactor since its opening.[11]

Germany
In Germany, the small KNK II fast neutron test reactor (17 MWe) was operated from 1978 to 1991. Construction of a 300 MWe sodium-cooled fast reactor at Kalkar (SNR-300) was completed in 1985, but widespread public opposition and disagreement between the central government and the state government led to the project being formally terminated in March 1991. The plant was decommissioned without ever having operated.

SAFETY CONCERNS

Because fast neutron reactors use higher speed neutrons than conventional reactors, they are more difficult to control, and more prone to complete loss of control and "prompt criticality" accidents.[12] They also typically operate at a higher temperature than light water reactors, which raises concerns about the thermal properties of the reactor materials and the reactivity of various coolants, such as sodium.[13] These factors have led to complexities in their design and operation, including the need for new alloy materials and stringent requirements to keep air and moisture out of the coolant loops. Even while promoting fast-neutron reactors, the DOE admits that there are significant remaining technological problems and unknowns involved in their design and operation.[14]

FAST REACTORS LEAVE LEGACY OF WASTE

Although possible in theory, the selective conversion of long-lived waste into shorter-lived material – a process also known as transmutation – is in practice plagued by difficulties. For example, plutonium-actinide fuel causes problems in operating reactors. Other important technical issues have also not been resolved, such as low rates of conversion,[15] conflicting conversions, unproven fuel fabrication systems, and dangers to workers making the fuel.[16] The proposed systems would also leave fission products in the waste, including the long-lived and highly dangerous radionuclides technicium-99 and iodine-129, and the shorter-lived but high heat generating strontium-90 and cesium-137.

Even if these problems were addressed, however, and the technology fully developed and operated optimally and economically, fast-neutron reactors would not eliminate the need for a repository. The fundamental danger of the waste would remain, and it would still be hazardous for a very long time—1,000 to 10,000 years.

SECURITY AND PROLIFERATION RISKS

Fast neutron reactors would also require reprocessing, which would contribute to the waste problem and bring increased risks of proliferation. The only proven reprocessing technology (PUREX) is an aqueous technology, which increases the volume of radioactive material and makes it more difficult to manage. This process also results in separated plutonium and in environmental contamination. The two large-scale reprocessing plants in Britain and France both have met with serious opposition from other western European countries because of this pollution.[17] Neither of the reprocessing technologies that DOE is researching (UREX+ and pyroprocessing) is truly "proliferation resistant," as DOE claims, because plutonium can be still be separated out of the mixtures. Pyroprocessing (a non-aqueous technology) for separating waste from fast neutron reactors has never been used beyond a laboratory scale demonstration, and would still produce high-level salt waste, contributing further to the waste problem.[18]

FAST REACTORS ARE EXPENSIVE

The DOE concedes that fast-neutron reactors are not a cost-competitive energy source. The estimated research and development (R&D) costs alone for fast-neutron reactors range from $610 million for the sodium-cooled design to $1 billion for the molten salt reactor system.[19]

In addition to R&D, the National Academy of Sciences estimates that the capital costs of fast neutron reactors would be significantly higher than those for comparable light water reactors.[20] Fuel fabrication costs are also estimated to be greater for fast reactors, ranging from six to twelve times that of conventional light water reactors.[21] A commercial scale reprocessing facility of the size needed in the United States could cost as much as $30 billion to build.[22] Fast reactors would also not eliminate the cost of a repository for the waste, so there would be that expense as well.

Over $100 billion has been spent worldwide in the last four decades on fast neutron reactor construction, reprocessing, and other efforts to make plutonium a viable reactor fuel. More than $25 billion of that has been spent in construction expenditures for the large completed plants alone.[23] The Superphénix reactor in France, for instance, cost $9.1 billion (1996 dollars) to construct and the smaller Monju reactor in Japan cost $5.9 billion.[24]

Despite such excessive funding, these reactors have operated below capacity, failed to demonstrate an ability to deal with the waste, and shown little promise of becoming economical in the near future.[25]

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[1] *The History of Nuclear Energy*, DOE-NE-088, U.S. Department of Energy Office of Nuclear Energy, Science, and Technology, http://www.ne.doe.gov/pubs/history.pdf.
[2] The partial meltdown was caused by a piece of fuel cladding that came loose and blocked the flow of sodium coolant in part of the reactor.
[3] *Nuclear Wastes: Technologies for Separations and Transmutation* (1996), Commission on Geosciences, Environment and Resources, National Academies of Science, p 214, http://www.nap.edu/catalog/4912.html
[4] "Dounreay: Waste Dump for the World," BBC News, April 22, 1998, http://news.bbc.co.uk/2/hi/special_report/1998/04/98/nuclear_waste/81798.stm.
[5] "Lost Uranium Due to 'Accounting Uncertainty'," BBC News, June 3, 1998, http://news.bbc.co.uk/2/hi/uk_news/105564.stm. The material went missing between 1965 and 1968.
[6] H. Takahashi, The Safe and Economical Operations Of a Reactor Driven By a Small Proton Accelerator, 8th Journees de SATURNE (Saclay, France, 1995)
[7] Sauvage, Jean-François, *Phènix - 30 years of history: the heart of a reactor*, "Resuming Operations", Chapter VII, http://www.iaea.or.at/inis/aws/fnss/phenix/book/index.html
[8] Makhijani, Arjun, "Wind Versus Plutonium: A Comparison", 1999. Based on the 1999 IEER Report by Marc Fioravanti, *Wind Power Versus Plutonium*, http://www.ieer.org/sdafiles/vol_8/8-1/windvpu.html
[9] *Chronology and Press Reports of Tokaimura Criticality*, Institute for Science and International Security, http://www.isis-online.org/publications/tokai.html#toc
[10] Sauvage, Jean-François, Chapter IV, p. 89, http://www.iaea.or.at/inis/aws/fnss/phenix/book/index.html
[11] International Atomic Energy Agency (IAEA), "Fast Reactor Operating Experience Gained in Russia: Analysis of Anomalies and Abnormal Operation Cases", Y.M Ashurko et al., http://www.iaea.org/inis/aws/fnss/abstracts/abst_1180_5.html
[12] Arjun Makhijani, "Plutonium as an Energy Source", *Energy and Security*, Institute for Energy and Environmental Research, February 1997, No. 1, http://www.ieer.org/ensec/no-1/puuse.html
[13] Sodium explodes on contact with water, and catches fire when mixed with air. In the fast neutron sodium cooled reactor designs, the sodium has to be run through a heat exchanger, a cluster of thin-walled metal tubes. If there is a leak and the sodium and water come into contact, the sodium will burn.
[14] *A Technology Roadmap for Generation IV Nuclear Energy Systems: Ten Nations Today Preparing for Tomorrow's Energy Needs.* U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum. December 2002, pp. 3 and 83, http://gif.inel.gov/roadmap/pdfs/gen_iv_roadmap.pdf
[15] Low rates of conversion means that only a small percentage of the material is converted to the desired radionuclide when passed once through the reactor. In practice, waste materials must be put through reactors many times, which raises costs for reprocessing and fuel fabrication, and increases the time it takes to convert material.
[16] Zerriffi, Hisham and Annie Makhijani, *The Nuclear Alchemy Gamble: An Assessment of Transmutation as a Nuclear Waste Management Strategy*, IEER, August 25, 2000, Chapter III, p 51. http://www.ieer.org/reports/transm/report.pdf
[17] Arjun Makhijani, "Scrap Plans for fast breeder reactor," Institute for Energy and Environmental Research, April 25, 2001, http://www.ieer.org/op-eds/breeder.html.
[18] Hisham and Makhijani, Chapter II, p 44.
[19] *A Technology Roadmap for Generation IV Nuclear Energy Systems*, p. 3 and 83.
[20] *Management and Disposition of Excess Weapons Plutonium: Reactor Options*, National Academies, National Research Council, 1995, http://www.nap.edu/catalog/4754.html.
[21] Zerriffi and Makhijani, Chapter II, p 109.
[22] Edwin Lyman, "Extracting Plutonium from Nuclear Reactor Spent Fuel," http://www.ucsusa.org/global_security/nuclear_terrorism/extracting-plutonium-from-nuclear-reactor-spent-fuel.html.
[23] Arjun Makhijani, "Chapter 2: A Brief History of Commercial Plutonium," *Plutonium End Game*, Institute for Energy and Environmental Research, January 2001, http://www.ieer.org/reports/pu/ch2.html.
[24] Zerriffi Hisham and Makhijani, Chapter II, p 112.
[25] Makhijani, "Plutonium End Game," *Science for Democratic Action*, February, 2001, Vol. 9 No. 2, http://www.ieer.org/sdafiles/vol_9/9-2/puend.html.