Advanced Nuclear Power and Fuel Cycle Technologies: Outlook and Policy Options

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Summary

Current U.S. nuclear energy policy focuses on the near-term construction of improved versions of existing nuclear power plants. All of today's U.S. nuclear plants are light water reactors (LWRs), which are cooled by ordinary water. Under current policy, the highly radioactive spent nuclear fuel from LWRs is to be permanently disposed of in a deep underground repository.

The Bush Administration is also promoting an aggressive U.S. effort to move beyond LWR technology into advanced reactors and fuel cycles. Specifically, the Global Nuclear Energy Partnership (GNEP), under the Department of Energy (DOE) is developing advanced reprocessing (or recycling) technologies to extract plutonium and uranium from spent nuclear fuel, as well as an advanced reactor that could fully destroy long-lived radioactive isotopes. DOE's Generation IV Nuclear Energy Systems Initiative is developing other advanced reactor technologies that could be safer than LWRs and produce high-temperature heat to make hydrogen.

DOE's advanced nuclear technology programs date back to the early years of the Atomic Energy Commission in the 1940s and 1950s. In particular, it was widely believed that breeder reactors—designed to produce maximum amounts of plutonium from natural uranium—would be necessary for providing sufficient fuel for a large commercial nuclear power industry. Early research was also conducted on a wide variety of other power reactor concepts, some of which are still under active consideration.

Although long a goal of nuclear power proponents, the reprocessing of spent nuclear fuel is also seen as a weapons proliferation risk, because plutonium extracted for new reactor fuel can also be used for nuclear weapons. Therefore, a primary goal of U.S. advanced fuel cycle programs, including GNEP, has been to develop recycling technologies that would not produce pure plutonium that could easily be diverted for weapons use. The "proliferation resistance" of these technologies is subject to considerable debate.

Much of the current policy debate over advanced nuclear technologies is being conducted in the appropriations process. For FY2009, the House Appropriations Committee recommended no further funding for GNEP, although it increased funding for the Generation IV program. Typically, the Senate is more supportive of GNEP and reprocessing technologies.

Recent industry studies conducted for the GNEP program conclude that advanced nuclear technologies will require many decades of government-supported development before they reach the current stage of LWRs. Key questions before Congress are whether the time has come to move beyond laboratory research on advanced nuclear technologies to the next, more expensive, development stages and what role, if any, the federal government should play.

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All commercial nuclear power plants in the United States, as well as nearly all nuclear plants worldwide, use light water reactor (LWR) technology that was initially developed for naval propulsion. Cooled by ordinary water, LWRs in the early years were widely considered to be an interim technology that would pave the way for advanced nuclear concepts. After the early 1960s, the federal government focused most of its nuclear power research and development efforts on breeder reactors and high temperature reactors that could use uranium resources far more efficiently and potentially operate more safely than LWRs.

However, four decades later, LWRs continue to dominate the nuclear power industry, and are the only technology currently being considered for a new generation of U.S. commercial reactors. Federal license applications for as many as 30 new LWRs have been recently announced. The proposed new nuclear power plants would begin coming on line around 2016 and operate for 60 years or longer. Under that scenario, LWRs appear likely to dominate the nuclear power industry for decades to come.

If the next generation of nuclear power plants consists of LWRs, what is the potential role of advanced nuclear reactor and fuel cycle technologies? Do current plans for a new generation of LWRs raise potential problems that advanced nuclear technologies could or should address? Can new fuel cycle technologies reduce the risk of nuclear weapons proliferation? What is the appropriate time frame for the commercial deployment of new nuclear technology? This report provides background and analysis to help Congress address those questions.

Prominent among the policy issues currently before Congress is the direction of the existing nuclear energy programs in the U.S. Department of Energy (DOE). DOE administers programs to encourage near-term construction of new LWRs, such as the Nuclear Power 2010 program, which is paying half the cost of licensing and first-of-a-kind engineering for new U.S. LWR designs, and loan guarantees for new reactors now under consideration by U.S. utilities. DOE's Global Nuclear Energy Partnership (GNEP) is developing advanced fuel cycle technologies that are intended to allow greater worldwide use of nuclear power without increased weapons proliferation risks. Advanced nuclear reactors that could increase efficiency and safety are being developed by DOE's Generation IV program, which is looking beyond today's "Generation III" light water reactors.

The priority given to these options depends not only on the characteristics of existing and advanced nuclear technologies, but on the role that nuclear power is expected to play in addressing national energy and environmental goals. For example, if nuclear energy is seen as a key element in global climate change policy, because of its low carbon dioxide emissions, the deployment of advanced reactor and fuel cycle technologies could be considered to be more urgent than if nuclear power is expected to have a limited long-term role because of economic, non-proliferation, and safety concerns.

Nuclear Technology Overview

As their name implies, light water reactors use ordinary water for cooling the reactor core and "moderating," or slowing, the neutrons in a nuclear chain reaction. The slower neutrons, called thermal neutrons, are highly efficient in causing fission (splitting of nuclei) in certain isotopes of heavy elements, such as uranium 235 and plutonium 239 (Pu-239). Therefore, a smaller percentage of those isotopes is needed in nuclear fuel to sustain a nuclear chain reaction (in which neutrons released by fissioned nuclei then induce fission in other nuclei, and so forth). The downside is that thermal neutrons cannot efficiently induce fission in more than a few specific isotopes.

Natural uranium has too low a concentration of U-235 (0.7%) to fuel an LWR (the remainder is U-238), so the U-235 concentration must be increased ("enriched") to between 3% and 5%. In the reactor, the U-235 fissions, releasing energy, neutrons, and fission products (highly radioactive fragments of U-235 nuclei). Some neutrons are also absorbed by U-238 nuclei to create Pu-239, which itself may then fission.

After several years in an LWR, fuel assemblies will build up too many neutron-absorbing fission products and become too depleted in fissile U-235 to efficiently sustain a nuclear chain reaction. At that point, the assemblies are considered spent nuclear fuel and removed from the reactor. LWR spent fuel typically contains about 1% U-235, 1% plutonium, 4% fission products, and the remainder U-238. Under current policy, the spent fuel is to be disposed of as waste, although only a tiny fraction of the original natural uranium has been used. Long-lived plutonium and other actinides[1] in the spent fuel pose a long-term hazard that greatly increases the complexity of finding a suitable disposal site.

Reprocessing, or recycling, of spent nuclear fuel for use in "fast" reactors—in which the neutrons are not slowed—is intended to address some of the shortcomings of the LWR once-through fuel cycle. Fast neutrons are less effective in inducing fission than thermal neutrons but can induce fission in all actinides, including all plutonium isotopes. Therefore, nuclear fuel for a fast reactor must have a higher proportion of fissionable isotopes than a thermal reactor to sustain a chain reaction, but a larger number of different isotopes can constitute that fissionable proportion.

A fast reactor's ability to fission all actinides makes it theoretically possible to repeatedly separate those materials from spent fuel and feed them back into the reactor until they are entirely fissioned. Fast reactors are also ideal for "breeding" the maximum amount of Pu-239 from U-238, eventually converting virtually all of natural uranium to useable nuclear fuel.

Current reprocessing programs are generally viewed by their proponents as interim steps toward a commercial nuclear fuel cycle based on fast reactors, because the benefits of limited recycling with LWRs are modest. Commercial-scale spent fuel reprocessing is currently conducted in France, Britain, and Russia. The Pu-239 they produce is blended with uranium to make mixed-oxide (MOX) fuel, in which the Pu-239 largely substitutes for U-235. Two French reprocessing plants at La Hague can each reprocess up to 800 metric tons of spent fuel per year, while Britain's THORP facility at Sellafield has a capacity of 900 metric tons per year. Russia has a 400-ton plant at Ozersk, and Japan is building an 800-ton plant at Rokkasho to succeed a 90-ton demonstration facility at Tokai Mura. Britain and France also have older plants to reprocess gas-cooled reactor fuel, and India has a 275-ton plant.[2] About 200 metric tons of MOX fuel is used annually, about 2% of new nuclear fuel,[3] equivalent to about 2,000 metric tons of mined uranium.[4]

[1] Actinides consist of actinium and heavier elements in the periodic table.

[2] World Nuclear Association, *Processing of Used Nuclear Fuel for Recycle*, March 2007, at http://www.world-nuclear.org/info/inf69.html.

[3] World Nuclear Association, *Mixed Oxide Fuel (MOX)*, November 2006, at http://www.world-nuclear.org/info/inf29.html.

[4] World Nuclear Association, *Uranium Markets*, March 2007.

While long a goal of nuclear power proponents, the reprocessing or recycling of spent nuclear fuel is also seen as a weapons proliferation risk, because plutonium extracted for new reactor fuel can also be used for nuclear weapons. Therefore, a primary goal of U.S. advanced fuel cycle programs, including GNEP, has been to develop recycling technologies that would not produce pure plutonium that could easily be diverted for weapons use. The “proliferation resistance” of these technologies is subject to considerable debate.

Removing uranium from spent nuclear fuel through reprocessing would eliminate most of the volume of radioactive material requiring disposal in a deep geologic repository. In addition, the removal of plutonium and conversion to shorter-lived fission products would eliminate most of the long-term (post-1,000 years) radioactivity in nuclear waste. But the waste resulting from reprocessing would have nearly the same short-term radioactivity and heat as the original spent fuel, because the reprocessing waste consists primarily of fission products, which generate most of the radioactivity and heat in spent fuel. Because heat is the main limiting factor on repository capacity, conventional reprocessing would not provide major disposal benefits in the near term.

DOE is addressing that problem with a proposal to further separate the primary heat-generating fission products—cesium 137 and strontium 90—from high level waste for separate storage and decay over several hundred years. That proposal would greatly increase repository capacity, although it would require an alternative secure storage system for the cesium and strontium that has yet to be designed.

Safety and efficiency are other areas in which improvements have long been envisioned over LWR technology. The primary safety vulnerability of LWRs is a loss-of-coolant accident, in which the water level in the reactor falls below the nuclear fuel. When the water is lost, the chain reaction stops, because the neutrons are no longer moderated. But the heat of radioactive decay continues and will quickly melt the nuclear fuel, as occurred during the 1979 Three Mile Island accident. DOE’s Generation IV program is focusing on high temperature, gas-cooled reactors that would use fuel whose melting point would be higher than the maximum reactor temperature. The high operating temperature of such reactors would also result in greater fuel efficiency and the potential for cost-effective production of hydrogen, which could be used as a non-polluting transportation fuel. However, the commercial viability of Generation IV reactors remains uncertain.

DOE Advanced Nuclear Programs

DOE’s advanced nuclear technology programs date back to the early years of the Atomic Energy Commission in the 1940s and 1950s. In particular, it was widely believed that breeder reactors would be necessary for providing sufficient fuel for a commercial nuclear power industry. Early research was also conducted on a wide variety of other power reactor concepts, some of which are still under active consideration. The U.S. research effort on various advanced nuclear concepts has waxed and waned during subsequent decades, sometimes resulting from changes in Administrations. Technical and engineering advances have appeared to move some of the technologies closer to commercial viability, but significantly greater federal support would be necessary to move them beyond the indefinite research and development stage.

Global Nuclear Energy Partnership

GNEP is the Bush Administration's program for commercial deployment of reprocessing or recycling of spent nuclear fuel. The program's goal is to develop "proliferation resistant" fuel cycle technologies—not producing pure plutonium—that could be used around the world. Previous U.S. commercial reprocessing programs have been blocked at least partly over concerns that they would encourage other countries to begin separating weapons-useable plutonium.

History

The fundamental technology for spent fuel reprocessing is the PUREX process (plutonium-uranium extraction) developed to provide pure plutonium for nuclear weapons. A commercial PUREX plant operated from 1966 through 1972 in West Valley, New York, and two other commercial U.S. plants were built but never operated.

Meanwhile, DOE and its predecessor agencies worked to develop fast breeder reactors that could run on the reprocessed plutonium fuel. Major facilities included Experimental Breeder Reactors I and II, which began operating in Idaho in 1951 and 1964, and the Fast Flux Test Facility (FFTF), a larger fast reactor that began full operation in Hanford, Washington, in 1982. FFTF was designed to pave the way for the first U.S. commercial-scale breeder reactor, planned to begin construction near Clinch River, Tennessee, in 1977. However, the Clinch River Breeder Reactor (CRBR) and the federal government's support for commercial reprocessing were halted by President Carter in 1977 because of the nuclear proliferation issues noted above.

Upon taking office in 1981, President Reagan reversed the Carter policy and restarted preparations for CRBR, but Congress eliminated further funding for the project in 1983. DOE then turned to an alternative technology based on work carried out at Experimental Breeder Reactor II (EBR-II), which used metal fuel that could be recycled through pyroprocessing (melting and electrochemical separation) rather than with the aqueous (water-based) PUREX process. Supporters of this program, called the Integral Faster Reactor (IFR) and the Advanced Liquid Metal Reactor (ALMR), contended that pyroprocessing would not produce a pure plutonium product and could be carried out at a small scale at reactor sites, reducing weapons proliferation risks.

The Clinton Administration, however, moved in 1993 to terminate DOE's advanced reactor programs, including shutdown of EBR-II. Congress agreed to the proposed phaseout but continued funding for pyroprocessing technology as a way to treat EBR-II spent fuel for eventual disposal.

Current Program

The George W. Bush Administration made energy policy a high priority and placed particular emphasis on nuclear energy. The National Energy Policy Development (NEPD) Group, headed by Vice President Cheney, recommended in May 2001 that nuclear power be expanded in the United States and that reprocessing once again become integral to the U.S. nuclear program:

- The NEPD Group recommends that, in the context of developing advanced nuclear fuel cycles and next generation technologies for nuclear energy, the United States should reexamine its policies to allow for research, development and deployment of fuel conditioning methods (such as pyroprocessing) that reduce waste streams and enhance proliferation resistance. In doing so, the United States will continue to discourage the accumulation of separated plutonium, worldwide.

- The United States should also consider technologies (in collaboration with international partners with highly developed fuel cycles and a record of close cooperation) to develop reprocessing and fuel treatment technologies that are cleaner, more efficient, less waste-intensive, and more proliferation-resistant.[5]

The Bush Administration's first major step toward implementing those recommendations was to announce the Advanced Fuel Cycle Initiative in 2003 (AFCI), a DOE program to develop proliferation-resistant reprocessing technologies. The program built on the ongoing pyroprocessing technology development effort and reprocessing research conducted under other DOE nuclear programs. Much of the program's research has focused on an aqueous separations technology called UREX+, in which uranium and other elements are chemically removed from dissolved spent fuel, leaving a mixture of plutonium and other highly radioactive elements.

Congress provided $5 million above the Administration's $63 million initial request in FY2004 for AFCI, and the program received statutory authorization in the Energy Policy Act of 2005 (P.L. 109-58, Sec. 953), including support for international cooperation.

The announcement of the GNEP initiative in February 2006 (as part of the Administration's FY2007 budget request) appeared to further address the 2001 reprocessing goals of the National Energy Policy Development Group. Using reprocessing technologies to be developed by AFCI, GNEP envisioned a consortium of nations with advanced nuclear technology that would guarantee to provide fuel services and reactors to countries that would agree not to conduct fuel cycle activities, such as enrichment and reprocessing.

GNEP has attracted significant international attention, but no country has yet indicated interest in becoming solely a fuel recipient rather than a supplier. The Nuclear Nonproliferation Treaty guarantees the right of all participants to develop fuel cycle facilities, and a GNEP Statement of Principles signed by the United States and 15 other countries on September 16, 2007, preserves that right, while encouraging the establishment of a "viable alternative to acquisition of sensitive fuel cycle technologies."[6] According to DOE, GNEP currently has 21 member countries and 17 candidates and observers.[7]

Although GNEP is largely conceptual at this point, DOE issued a Spent Nuclear Fuel Recycling Program Plan in May 2006 that provided a general schedule for a GNEP Technology Demonstration Program (TDP),[8] which would develop the necessary technologies to achieve GNEP's goals. According to the Program Plan, the first phase of the TDP, running through FY2006, consisted of "program definition and development" and acceleration of AFCI. Phase 2,

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[5] National Energy Policy Development Group, *National Energy Policy*, May 16, 2001, p. 5-22.

[6] See GNEP website at http://www.gnep.energy.gov

[7] Members: Australia, Bulgaria, Canada, China, France, Ghana, Hungary, Italy, Japan, Jordan, Kazakhstan, Lithuania, Poland, Republic of Korea, Romania, Russia, Senegal, Slovenia, Ukraine, United Kingdom, and United States. Candidates and Observers: Argentina, Belgium, Brazil, Czech Republic, Egypt, Finland, Germany, Libya, Mexico, Morocco, Netherlands, Slovak Republic, South Africa, Spain, Sweden, Switzerland, and Turkey. http://www.gneppartnership.org

[8] DOE, *Spent Nuclear Fuel Recycling Plan*, Report to Congress, May 2006.

running through FY2008, was to focus on the design of technology demonstration facilities, which then were to begin operating during Phase 3, from FY2008 to FY2020. The National Academy of Sciences in October 2007 strongly criticized DOE's "aggressive" deployment schedule for GNEP and recommended that the program instead focus on research and development.[9] Similar criticism was raised in April 2008 by the Government Accountability Office.[10]

As part of GNEP, AFCI is conducting R&D on an Advanced Burner Reactor (ABR) that could destroy recycled plutonium and other long-lived radioactive elements. The ABR is similar to a breeder reactor, except that its core would be configured to produce less plutonium (from U-238) than it consumes, reducing potential plutonium stockpiles.

Funding

AFCI, the primary funding component of GNEP, has received steadily increased funding from Congress, but far less than requested during the past two budget cycles. For FY2007, DOE sought $243.0 million and received $166.1 million, and for FY2008 the request of $395.0 million was cut to $179.4 million. Typically, the Senate recommends more for the program than the House does, and that pattern appears to be continuing for FY2009.

The FY2009 Advanced Fuel Cycle Initiative funding request is $301.5 million, nearly 70% above the FY2008 appropriation of $179.4 million but below the FY2008 request of $395.0 million. The House Appropriations Committee recommended cutting AFCI to $90.0 million in FY2009, eliminating all funding for GNEP.[11] The remaining funds would be used for research on advanced fuel cycle technology, but none could be used for design or construction of new facilities. The Committee urged DOE to continue coordinating its fuel cycle research with other countries that already have spent fuel recycling capability, but not with "countries aspiring to have nuclear capabilities."

FY2009 funding of $10.4 million was requested for conceptual design work on an Advanced Fuel Cycle Facility (AFCF) to provide an engineering-scale demonstration of AFCI technologies, according to the budget justification. The FY2008 Consolidated Appropriations act rejected funding for development of AFCF, as did the House Appropriations Committee for FY2009. DOE requested $18.0 million for the ABR program for FY2009, up from $11.7 million in FY2008. The program is expected to focus on developing a sodium-cooled fast reactor (SFR). The House Appropriations Committee recommended no FY2009 funding for the ABR.

Generation IV

DOE describes "Generation IV" as advanced reactor technologies that could be available for commercial deployment after 2030. These technologies are intended to offer significant

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[9] National Academy of Sciences, *Review of DOE's Nuclear Energy Research and Development Program*, prepublication draft, October 2007.

[10] Government Accountability Office, *Global Nuclear Energy Partnership: DOE Should Reassess Its Approach to Designing and Building Spent Nuclear Fuel Recycling Facilitie*s, GAO-08-483, April 2008.

[11] The Committee voted on the FY2009 Energy and Water Development Appropriations Bill on June 25, 2008, but has not filed a report. The draft report was accessed on cq.com.

advantages over existing "Generation III" reactors (LWRs in the United States) in the areas of cost, safety, waste, and proliferation. DOE is conducting some Generation IV research in cooperation with other countries through the Generation IV International Forum (GIF), established in 2001.[12]

A technology roadmap issued by GIF and DOE in 2002 identified six Generation IV nuclear technologies to pursue: fast neutron gas-cooled, lead-cooled, sodium-cooled, molten salt, supercritical water-cooled, and very high temperature reactors.[13] These reactor concepts are not new, and some have been demonstrated at the commercial scale, but none has been sufficiently developed for successful commercialization.

The DOE Generation IV Nuclear Energy Systems Initiative (Gen IV) is focusing on a helium-cooled Very High Temperature Gas Reactor (VHTR) and conducting cross-cutting research on materials and other areas that could apply to all reactor technologies, including LWRs. The VHTR technology is being developed for the Next Generation Nuclear Plant (NGNP) authorized by the Energy Policy Act of 2005. Development of sodium-cooled fast reactors is being conducted by the AFCI program as part of the ABR effort described above.

DOE requested $70.0 million for Gen IV for FY2009—$44.9 million below the FY2008 funding level of $114.9 million, which was nearly triple the Administration's FY2008 budget request of $36.1 million. The House Appropriations Committee recommended an increase to $200.0 million.

Most of the FY2009 request—$59.5 million—is for the NGNP program. The VHTR technology being developed by DOE uses helium as a coolant and coated-particle fuel that can withstand temperatures up to 1,600 degrees celsius. Phase I research on the NGNP is to continue until 2011, when a decision will be made on moving to the Phase II design and construction stage, according to the FY2009 DOE budget justification. The House Appropriations Committee provided $196.0 million "to accelerate work" on NGNP—all but $4.0 million of the Committee's total funding level for the Generation IV program. The Energy Policy Act of 2005 authorizes $1.25 billion through FY2015 for NGNP development and construction (Title VI, Subtitle C). The authorization requires that NGNP be based on research conducted by the Generation IV program and be capable of producing electricity, hydrogen, or both.

Time Lines and Options

DOE's plans for commercial nuclear fuel recycling facilities are still being formulated. The Department is currently preparing a draft Programmatic Environmental Impact Statement (PEIS) for GNEP that will lead to decisions about development of an advanced fuel cycle research facility. The PEIS will not consider the next stages of the program, which would include commercial-scale reprocessing/recycling facilities and an advanced fast reactor, according to DOE.[14] A schedule for completing this process has not been announced.

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[12] GIF active members are Canada, China, Euratom, France, Japan, Republic of Korea, Russia, Switzerland, and the United States. http://www.gen-4.org

[13] DOE Nuclear Energy Research Advisory Committee and Generation IV International Forum, *A Technology Roadmap for Generation IV Nuclear Energy Systems*, GIF-002-00, December 2002.

[14] http://www.gnep.energy.gov/PEIS/gnepPEIS.html accessed July 9, 2008.

Industry Studies

To help determine the future direction of the GNEP program, DOE solicited studies from four industry consortia. The four studies, released by DOE on May 28, 2008, describe concepts for advanced fuel recycling/reprocessing facilities, along with general cost estimates and schedules. The four teams have signed cooperative agreements with DOE to continue developing "conceptual designs, technology development roadmaps, and business plans for potential deployment and commercialization of recycling and reactor technologies" at least through FY2008 and possibly through FY2009. According to DOE, these additional studies will "help inform a decision on the potential path forward for technologies and facilities associated with domestic implementation of GNEP."[15]

EnergySolutions, Shaw, and Westinghouse

EnergySolutions, a waste treatment and disposal firm, Shaw Group, an engineering and construction firm, and Westinghouse Electric Company, a reactor design firm, led an industry team that proposed that aqueous reprocessing facilities to handle 1,500 metric tons per year of LWR spent fuel begin operating by 2023. A fuel fabrication plant would be built to supply MOX fuel to existing LWRs. Recycling facilities during this initial phase would be funded and built by DOE.

The next phase of the EnergySolutions proposal would run from 2030 to 2049. A 410 megawatt (electric) fast reactor would begin operating in 2033, with four additional units starting up by 2045. Aqueous reprocessing capacity would be expanded by 3,000 metric tons per year, and non-aqueous reprocessing facilities would be added. In the final phase, 2050 through 2100, the fast reactor recycling fleet would expand to 96 gigawatts (about the capacity of today's U.S. LWR fleet), and less aqueous reprocessing capacity would be needed.

A federal corporation would be established to sign long-term contracts with industry for spent fuel recycling and fuel fabrication, build and operate a waste repository, and transport spent fuel. The federal corporation's funding would come from nearly doubling the nuclear waste fee currently imposed on nuclear power generation, from 1 mill per kilowatt-hour to 1.95 mills/kwh, assuming the previously collected balance in the Nuclear Waste Fund (the Treasury account that holds the waste fees) is not used. At the current rate of nuclear power generation, the proposed fee would produce revenues of about $1.5 billion per year.

GE-Hitachi

A team led by General Electric Hitachi Nuclear Energy prepared a proposal based on the IFR/ALMR program that was halted in 1993. The pyroprocessing facility that is proposed would use the electrometallurgical separations process developed by the IFR program, with improvements that have been made during the subsequent 15 years. The fast reactor is the Power Reactor Inherently Safe Module (PRISM) that GE developed for the ALMR program, also with subsequent refinements. According to the report, a power plant consisting of six PRISM modules

[15] DOE Office of Public Affairs, "DOE Releases Domestic Global Nuclear Energy Partnership (GNEP) Industry Reports and Presentations," May 28, 2008.

(totaling 1,866 megawatts electric, mwe), along with the necessary reprocessing capacity, would consume 5,800 metric tons of LWR spent fuel over its planned 60-year operating life.

The first phase of the GE-Hitachi proposal, taking about 20 years, would consist of construction and operation of one or two PRISM modules. The second phase, lasting about 10 years, would feature commercial deployment of at least one Advanced Recycling Center (ARC), consisting of six PRISM modules and a reprocessing and fuel fabrication facility. Multiple ARCs would be constructed in the third phase, after 30 years.

General Atomics

General Atomics, long associated with gas-cooled reactor technology, led a team that proposed a two-tier spent fuel recycling system. In the first tier, LWR spent fuel would be sent to aqueous reprocessing plants to extract nuclear fuel material to be used in high-temperature gas reactors, such as the type being developed by the DOE Gen IV program. Because of their high fuel burnup, the gas reactors would eliminate most plutonium and minor actinides. In the second tier, spent fuel from the gas reactors would be pyroprocessed so that the remaining plutonium and minor actinides could be fissioned in a fast reactor.

Under the team's preferred scenario, LWRs would continue to be constructed through 2050 (136 in all) and be phased out by 2110. The first gas-cooled reactor module (385 mwe) would start up by 2025, and the first aqueous reprocessing center would begin operation by about 2030. The aqueous reprocessing centers would have a capacity of about 1,500 tons of LWR spent fuel per year and cost about $8.3 billion to construct (in 2006 dollars). The first pyroprocessing facility would open in 2040, and the first fast reactor would open by 2075. The team recommended that initial facilities for the program be developed by a government corporation, which would be privatized by 2035.

Areva

The French nuclear firm Areva, which has long experience with commercial PUREX reprocessing plants in France, led a team that proposed continued reliance on LWRs with a gradual buildup of fast reactors. Through 2019, the team recommended that MOX fuel be tested in existing U.S. reactors, from plutonium extracted from U.S.-origin spent fuel reprocessed overseas. The first 800-ton per year aqueous recycling plant would open in 2023, with additional 800-ton modules starting up in 2045 and 2070. A 500 mwe fast reactor would begin operating in 2025, a 1,000 mwe reactor would open in 2035, and a 1,500 mwe reactor would begin operating in 2050, with additional 1,500 mwe units starting up about every two years thereafter. A government corporation would be established to run the recycling program. Costs are estimated to be 10%-70% higher than the existing 1 mill/kwh nuclear waste fee.

Policy Implications

For Congress and other federal policymakers, issues posed by current GNEP and Gen IV proposals are similar to those of the past several decades. The fundamental policy question is whether the government should encourage the expansion of nuclear power. The industry has long contended that new commercial reactors will not be constructed without increased government incentives or subsidies. After the initial federal push to commercialize nuclear power in the 1950s and 1960s, government support waned to the point where a nuclear phaseout seemed possible.

But nuclear power proponents now contend that dramatic growth will be needed (with federal support) to meet future energy demand in a carbon-constrained environment.

Such high-growth scenarios must overcome many of the same perceived challenges that faced the optimistic initial expectations for nuclear power. If dramatic growth were to finally occur, could light water reactors meet the challenge, or is a transition to advanced nuclear technologies necessary? And if new technologies will be needed, how urgently must the federal government move forward?

As in the early years of the nuclear power program, a primary concern with renewed nuclear power growth is long-term fuel supply, since LWRs can extract energy from only a fraction of natural uranium. During the past two decades of slowed U.S. and world nuclear power expansion, the only problem with uranium was oversupply and chronically low prices. Supply has since tightened, but uranium production capacity is expanding rapidly in response. Whether increased exploration activity will result in higher worldwide resource estimates will have important implications for this issue.

The long-proposed solution to the fuel problem—replacing LWRs with fast breeder reactors—raises the nuclear weapons proliferation issue. LWR spent fuel is highly resistant to proliferation at least for the first 100 years, although the technology requires uranium enrichment facilities that may pose their own risks. GNEP's goal of expanding nuclear power while limiting the proliferation of fuel cycle facilities is widely shared, but the success of the program's current approach remains uncertain.

Nuclear waste management has also been a longstanding problem in the United States and the world. The once-through LWR fuel cycle requires extremely long-term isolation of plutonium and other long-lived radionuclides. Reprocessing could potentially shorten the disposal horizon and make siting easier for waste repositories. But if long-term isolation is determined to be feasible, the waste disposal benefits of reprocessing may become less significant.

Other anticipated benefits of advanced reactor technologies over LWRs include improved safety, lower costs, and high-temperature heat production for hydrogen and other industrial purposes. LWR technology has improved steadily in safety, particularly in its vulnerability to loss-of-coolant accidents, and the projected risks of the latest designs have been reduced one to two orders of magnitude below that of existing reactors. Proposed Generation IV designs are intended to virtually eliminate the major risk factors inherent in LWRs, although they may have other safety risks that have yet to be as fully quantified.

New LWR designs are also intended to reduce costs from those incurred by existing reactors, but cost estimates have recently escalated (along with those of all competing power systems). Generation IV reactors are projected by their designers to reduce both construction and operating costs, but these projections have yet to be demonstrated.

LWRs are limited to relatively low-temperature operation, so high-temperature gas reactors could be the most practical technology for nuclear generation of hydrogen as a transportation fuel. If hydrogen were to become a major transportation fuel—which remains far from certain—nuclear power could begin to play a significant role in replacing petroleum. However, more commercial attention has recently been focused on battery-based electric vehicle systems, which could be recharged by LWRs.

Recent U.S. nuclear energy policy has focused primarily on large government incentives for private-sector construction of new LWRs, such as loan guarantees, tax credits, and regulatory risk insurance. Imposition of federal controls on carbon dioxide emissions would provide additional powerful incentives for LWR construction. As shown by the industry studies described above, the advanced nuclear technologies under development by GNEP and Gen IV will require many years of government-supported development before they reach the current stage of LWRs. The Bush Administration has renewed the federal research effort on these technologies, so now the question before Congress is whether the time has come to move to the next, more expensive, development stages.

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