South Korean Reprocessing: An Unnecessary Threat to the Nonproliferation Regime

South Korea is contemplating a decision that could have critical implications for the future of the international nonproliferation regime: whether to reprocess its spent fuel. Driven by a combination of factors—local government resistance to extended spent fuel storage at its nuclear power plants, irritation that the United States has consented to spent fuel reprocessing in Japan but not South Korea, and alarm over North Korea’s nuclear weapons program—much of South Korea’s nuclear establishment wants to do so.

Japan is the only non-nuclear-weapon state today that reprocesses or attempts to do so.\[1\] Reprocessing makes no sense economically, and contrary to the claims of its advocates, it complicates radioactive waste disposal. Japan’s utilities argue, however, that they have no choice; local governments will not allow extended on-site spent fuel storage, and no state prefecture (Japan’s equivalent of a state) is willing to host an interim storage facility for fear that interim will become permanent.\[2\]

Given the U.S. inability to site either a geological repository or a central interim spent fuel storage facility, there should be some sympathy in the United States for the plight of the nuclear utilities in South Korea and Japan. Yet, the United States has another option once the spent fuel storage pools at its power reactors become full: dry-cask storage of the older, cooler spent fuel next to the reactors. Japan’s and South Korea’s nuclear utilities claim that they do not have that option because local governments are not allowing them to build on-site dry-cask storage.

Reprocessing creates huge flows and stockpiles of separated plutonium. Japan’s reprocessing plant in full operation will separate enough plutonium to make 1,000 nuclear bombs annually. South Korea’s nuclear establishment proposes not to separate the plutonium completely from other transuranic elements.\[3\] but the final separation step would be relatively trivial.

Many Chinese and South Korean security analysts are deeply suspicious of Japan’s motives for reprocessing. Some Japanese security analysts acknowledge privately that it provides Japan with a quick nuclear-weapon option, even if Japan does not intend to use that option for the foreseeable future.\[4\] China, Japan, and North Korea similarly would be deeply suspicious of a decision by South Korea to reprocess.

The United States consented to Japan’s reprocessing program during the Carter administration only after the issue had escalated to the point where Prime Minister Takeo Fukuda was stating publicly that the right to reprocess was “a life or death issue for Japan.”\[5\] The trauma of the 1973 Arab oil embargo was still a fresh memory, and it is likely that the prime minister had been convinced by Japan’s nuclear energy establishment that a rapid transition to plutonium breeder reactors, which require reprocessing, would free Japan from a similar dependence on imported uranium. Demonstration breeder reactors proved to be costly and unreliable, however, and their commercialization has receded into the future.\[6\]

Today the rhetoric around reprocessing is escalating in South Korea. Following North Korea’s nuclear test in May 2009, the political opposition demanded that South Korea have “nuclear sovereignty,” i.e., the same rights as Japan.\[7\]
The 1974 U.S.-South Korean nuclear cooperation agreement requires U.S. consent if “any irradiated fuel elements containing fuel material received from the United States of America [are to be] altered in form or content.”[8] As a matter of policy, South Korea requests that the United States agree to such activities even if U.S.-origin material is not involved.[9] The cooperation agreement will expire in 2014, however, and South Korea wants to negotiate a new agreement that will give it the same programmatic permission that the United States has given the European Union, Japan, Switzerland, and, with certain conditions, India.[10]

South Korea’s government-supported Korea Atomic Energy Research Institute (KAERI) has launched a campaign to try to convince the Obama administration and the U.S. nongovernmental nonproliferation community to agree to this proposal. At the end of January 2010, the U.S. government responded to high-level South Korean lobbying on this issue by agreeing with South Korean Vice Foreign Minister Chun Yung-woo to what he described as “a technological and economical feasibility study by experts on pyro-processing prior to the negotiations on revising” the 1974 nuclear cooperation agreement.[11] Pyroprocessing is the variant of reprocessing that South Korea is pursuing.

If the U.S. government and nonproliferation community accept South Korea’s need to reprocess, however, it will become difficult to resist the same demand from additional countries. South Africa, for example, also has expressed an interest in reprocessing.[12] One of its nuclear officials has described reprocessing as “an element of contemporary power relations.”[13]

Implementation of pyroprocessing in South Korea would be inconsistent with its 1992 joint declaration with North Korea on the denuclearization of the Korean peninsula. Under this agreement, the two countries agreed not to “possess nuclear reprocessing and uranium enrichment facilities.”[14] Pyroprocessing advocates in South Korea point out that North Korea has repeatedly broken the 1992 agreement and argue that there is little hope that North Korea will denuclearize any time in the foreseeable future. If South Korea were to launch a pyroprocessing program, however, it would at best further complicate efforts to persuade North Korea to carry through on the commitment it made in 2005 to end its nuclear program.[15] At worst, it could lead to a nuclear arms race between South and North.

Concerns that South Korea’s interest in reprocessing could destabilize the nonproliferation regime should stimulate China, Japan, Russia, South Korea, and the United States—the countries that, along with North Korea, are the participants in the six-party talks on Pyongyang’s nuclear program—to discuss alternatives to a proliferation of national reprocessing plants. The U.S. government must also resist demands from some congressional Republicans that spent fuel reprocessing be part of any U.S. program to deal with climate change.[16] The fact that the United States has not reprocessed its own spent power-reactor fuel since 1972 has been critical to its ability to persuade non-nuclear-weapon states that they do not need to reprocess either. When Presidents Gerald Ford and Jimmy Carter reversed the position of previous administrations and decided to forgo reprocessing at home and discourage it abroad, Belgium, Germany, Italy, and Taiwan had pilot reprocessing plants.[17] Argentina was building a plant,[18] and France and Germany were contracting to sell reprocessing plants to South Korea and Brazil, respectively.[19] Many of these plans were originally launched out of interest in acquiring at least a nuclear weapons option.

The administration of George W. Bush proposed that the United States could build a reprocessing plant without encouraging the spread of such plants if the United States and other countries that currently reprocess offered reprocessing services to the non-nuclear-weapon states. France, Russia, and the United Kingdom already have tried that, however, and it failed because of the cost and the unwillingness of the reprocessing countries to keep the reprocessing waste.[20]

The proliferation problems that reprocessing creates are a powerful argument against it. That argument is strengthened by the failure of reprocessing to solve the spent fuel problem. The remainder of this article explains why KAERI’s reprocessing proposal, like Japan’s reprocessing program, simply amounts to a costly and dangerous political contrivance to get the spent fuel off the reactor sites. The political problem of ultimate radioactive waste disposal would still remain.
Spent Fuel Storage Problem

South Korea has nuclear power reactors at four sites with a combined generating capacity of about 18 gigawatts-electric (GWe) and more reactors with a total additional 10 GWe under construction.[21] There are plans to build enough generating capacity for an additional 15 GWe by 2030.[22] That would bring total South Korean nuclear generating capacity to 43 GWe, almost equal to Japan’s nuclear generating capacity today.

South Korea’s nuclear utility, Korea Hydro and Nuclear Power (KHNP), has stated that the spent fuel pools at some of its power reactors will be full in 2016.[23] In theory, the older spent fuel in the pools could be shifted to the pools of newer reactors being built on some of the same sites or to dry-cask storage, as is standard practice at U.S. nuclear power plants. In practice, local communities in South Korea are expected to resist both of these on-site storage expansion approaches.[24]

In January 2009, the South Korean Ministry of Knowledge Economy established the Korea Radioactive Waste Management Corporation and launched a public consensus process to formulate a national policy on spent fuel management.[25] Six months later, however, the Blue House (South Korea’s equivalent of the U.S. White House) halted the process and then announced that a legal framework was required and that expert opinion would have to be solicited first.[26]

The political issues facing South Korea with regard to interim storage are similar to the ones that Japan has been confronting for about 25 years. Originally, Japanese nuclear utilities embraced reprocessing because they shared the vision promoted in the 1960s by the United States that the future of nuclear power would be plutonium breeder reactors. In the 1980s, therefore, Japanese nuclear utilities began to ship their spent fuel to Europe for reprocessing to obtain separated plutonium for startup cores for breeder reactors. Today, Japan’s nuclear establishment does not expect to commercialize breeder reactors until after 2050.[27] Therefore, it is trying to dispose of almost 50 tons of separated plutonium[28] by recycling it into fuel for the light-water reactors (LWRs) that originally produced it.

Japan’s reprocessing program continues, however, and Japan has even built its own hugely costly reprocessing plant because the facility provides an interim storage destination for both Japan’s spent fuel and the reprocessing waste that is being shipped back from France and the United Kingdom.[29]

Commercial operation of the Rokkasho Reprocessing Plant, which has a design capacity to reprocess 800 tons of spent fuel annually,[30] has been delayed for more than eight years. The plant’s on-site storage capacity for about 3,000 tons of spent fuel is almost full. In any case, the plant does not have the capacity to reprocess spent fuel at the same rate it is discharged from the country’s power reactors. As a result, Japanese utilities are still confronted with the challenge of building additional storage capacity.[31]

KAERI’s Reprocessing Proposal

KAERI, with support from the South Korean Ministry of Education, Science and Technology, urges that the spent fuel from the country’s pressurized water reactors (PWRs) be reprocessed using pyroprocessing technology. That technology electrochemically separates the elements in the fuel after they have been dissolved in molten salt instead of in acid, as is done in standard PUREX reprocessing.[32] The plutonium and other transuranic elements[33] recovered from PWR fuel then would be recycled repeatedly in the fuel of liquid-sodium-cooled fast-neutron reactors until they were completely fissioned except for process losses. The liquid-sodium-cooled reactors would be basically the same plutonium breeder reactors on which the industrialized countries have spent about $100 billion in research and development (R&D) and (mostly failed) demonstration projects,[34] but with their cores reconfigured so that they would be net consumers rather than producers of plutonium.

Opinion within South Korea’s government is supportive of pyroprocessing R&D but divided on actual deployment. KHNP refuses to back KAERI’s proposed approach until it sees credible cost estimates.[35]
KAERI has had a modest R&D program on spent fuel reprocessing ever since the early 1970s, when South Korea briefly pursued nuclear weapons after President Richard Nixon proposed that U.S. allies in Asia take primary responsibility for their own defense.\[36\] Since 1997, KAERI has been doing R&D related to pyroprocessing. About 10 percent of KAERI’s 1,100 employees work on this effort.\[37\] This small group of government-funded researchers has had an outsized impact on South Korean spent fuel management policy. Like their counterparts at the Argonne and Idaho national laboratories in the United States, their primary interest is to sustain political support for reprocessing and fast-neutron-reactor R&D. Given public concerns about radioactive waste, key politicians have seized on KAERI’s claim to have a “solution” to the spent fuel problem.

KAERI has not yet carried out any processing of irradiated fuel in its pyroprocessing R&D program but has requested U.S. permission to do so. It has constructed an Advanced Spent Fuel Conditioning Process Facility capable of converting the uranium and transuranic elements in 20-kilogram batches of spent PWR fuel from oxide to metal form. No chemical separation would occur at this stage, but the high temperatures involved would drive off the volatile element cesium-137, which generates most of the gamma radiation field around spent fuel that is more than a decade since discharge.\[38\] This would make it much easier to separate the plutonium.

Although plutonium recovered from LWR fuel is not of weapons grade, it is weapons usable.\[39\] A single 1-GWe pressurized-water nuclear power plant discharges about 200 kilograms of plutonium in its spent fuel annually—enough, if separated, for 25 Nagasaki-type nuclear bombs.\[40\] Vice President Dick Cheney’s 2001 energy task force declared pyroprocessing more “proliferation resistant” than conventional reprocessing.\[41\] Pyroprocessing was one focus of the Bush administration’s Advanced Fuel Cycle Initiative,\[42\] which included collaborative research on pyroprocessing between KAERI and the Department of Energy’s nuclear energy laboratories. For some time, Bush administration officials who were sympathetic to South Korea’s interest in pyroprocessing even tried to argue that “pyroprocessing is not reprocessing.”\[43\] KAERI has made similar claims.\[44\]

The primary basis for the claim that pyroprocessing is proliferation resistant is that, unlike traditional PUREX reprocessing, it does not produce pure plutonium. However, like PUREX, pyroprocessing separates plutonium from the fission products that account for most of the gamma radiation field around spent fuel. As a result, the radiation field around the transuranic mix produced by pyroprocessing would be reduced to about 0.1 percent of that around the spent fuel and to less than 1 percent of the International Atomic Energy Agency’s self-protection standard.\[45\] Therefore, it would be possible to separate plutonium from the mix without the remote operations behind heavy shielding required for recovering plutonium from spent fuel. Given the confusion that was generated during the Bush administration, it is useful that the implications of this fact were recently stated clearly in a report by an Energy Department multilaboratory task force: “The assessment focuses on determining whether three alternative reprocessing technologies—COEX, UREX+, and pyroprocessing—provide nonproliferation advantages relative to the PUREX technology because they do not produce separated plutonium. [We] found only a modest improvement in reducing proliferation risk over existing PUREX technologies and these modest improvements apply primarily for non-state actors.”\[46\]

Pyroprocessing thus is slightly more proliferation resistant than traditional PUREX reprocessing but much less proliferation resistant than not reprocessing at all.

**Major Pyroprocessing Far Off**

KHNP currently projects that the spent fuel storage space at its Kori, Wolsong, Ulchin, and Yonggwang sites will be full in 2016, 2017, 2018, and 2021, respectively—only six to 11 years hence.\[47\] KAERI will still be early in its pyroprocessing R&D program at that time. It has proposed completion of:

1. An engineering-scale facility with the capacity to reprocess 10 tons of PWR spent fuel per year by 2016. By that time, South Korean PWRs will be discharging more than 400 tons of spent fuel per year.
2. A prototype facility with the capacity to reprocess 100 tons of spent fuel per year by 2025. By 2030, South Korean PWRs are expected to be discharging about 800 tons of spent fuel per year.[48]

KAERI does not project a date for having an operational pyroprocessing facility capable of dealing with South Korean spent PWR fuel at a rate at which it is being produced, but it proposes building only one 0.6 GWe demonstration fast-neutron reactor before 2050.[49] In order to fission the transuranics discharged annually in the spent fuel of 40 GWe of PWRs—the nuclear generation capacity South Korea is projecting it will have in 2030—it would have to deploy 16-30 GWe of fast-reactor capacity.[50] Thus, before 2050, KAERI’s program would address only a small fraction of KHNP’s spent fuel production. Whatever the long-term solution for South Korean spent fuel, it will need more interim storage.

The Problem of Excess Plutonium

In the meantime, if KAERI’s prototype pyroprocessing facility and fast-neutron reactor were built and operated at full capacity, South Korea would be accumulating about 100 bomb equivalents of excess separated plutonium annually. The demonstration fast-neutron reactor would have a generating capacity of 0.6 GWe[51] and would require an initial fuel-cycle inventory of 2-3 tons of plutonium.[52] After it started, however, even if operated at 90 percent average capacity, it would have a net consumption of only 0.2-0.4 tons of transuranics per year, while the prototype pyroprocessing facility would be separating out about a ton per year.

Even South Korea’s proposed engineering-scale pyroprocessing plant, if operated at full capacity, would separate out about 100 kilograms of plutonium annually, enough for more than 10 Nagasaki-type bombs. Therefore, South Korea’s pyroprocessing R&D program would deliver a nuclear-weapon option quite quickly, as did India’s reprocessing program.[53]

Thus, South Korea would be going down the same track as France, India, Japan, Russia, and the United Kingdom, where huge stockpiles of excess separated plutonium were produced with reprocessing plants that were originally proposed in the 1970s on the basis of expectations that, by 2000, the world would be building more than 100 GWe of fast-neutron reactor capacity each year.

Pending the construction of a geological repository, South Korea would have to store at its pyroprocessing plant the fission products, the surplus transuranics, and the uranium separated from the spent fuel. It would be far less costly and much less destabilizing both to the nonproliferation regime and the disarmament negotiations with North Korea if interim storage of these materials were in intact fuel, i.e., if South Korea did not have a stockpile of separated weapons-usable material.

In Japan, the extra cost of PUREX reprocessing has been estimated by Japan’s Atomic Energy Commission as $2,400 per kilogram.[54] A U.S. national laboratory comparison has found that the cost of pyroprocessing could be considerably higher than for PUREX reprocessing.[55] By comparison, the cost of centralized interim dry-cask storage for LWR spent fuel is very inexpensive—only about $100 per kilogram.[56]

Disposal Without Reprocessing

KAERI argues that South Korea is not large enough to accommodate the repositories that would be required to hold the quantity of unreprocessed spent fuel projected to be discharged by South Korean PWRs by 2100. Yet, KAERI's claims for reductions in repository size that could be achieved by pyroprocessing[57] are incorrect for South Korea because they are based on analyses that have been done by U.S. pyroprocessing advocates for YuccaMountain. In those analyses, the area of a spent fuel repository is determined by the requirement that the peak temperature in the rock midway between the waste-holding tunnels in a repository not exceed the boiling temperature of water, in order to allow the passage of liquid water downward between the tunnels. This temperature, about 40 meters from the spent fuel casks, would peak about 2,000 years after the emplacement of the spent fuel. During this period, the long-lived transuranics would be the dominant contributors to the accumulated radioactive heat in the rock around the tunnels.
This analysis is irrelevant to the Swedish type of geological repository being considered by KAERI, in which spent fuel would be buried in copper canisters embedded in clay in water-saturated granite. For KAERI's design, the capacity limit would be determined by the requirement that the clay around the canister not dry out and crack. Therefore, the amount of spent fuel that can be emplaced in a cask is determined by the current heat output of the spent fuel, not its output over millennia.

KAERI's analyses assume that spent PWR fuel would be emplaced in a repository 40 years after discharge from the reactor. At that time, the transuranics account for slightly less than one-half of the radioactive heat generation from spent fuel. Eliminating them would increase the capacity of a repository approximately by a factor of two. The same result could be accomplished, however, by waiting until the spent fuel is 100 years old before emplacing it in the repository. By then, the 30-year-half-life fission products that dominate the fission-product heat output at 40 years would have largely decayed away.

Conclusions

Because of political constraints imposed by local governments on the amount of spent fuel that can be stored at its reactor sites, South Korea must, by around 2020, either find a way to relax those constraints or find an off-site location to which spent fuel can be shipped. KAERI has proposed spent fuel pyroprocessing and transuranic recycle in fast-neutron reactors as a solution, but it does not propose to deploy more than a demonstration fast-neutron reactor before 2050. Therefore, if South Korea pyroprocesses on a large scale before 2050, the separated weapons usable transuranic elements and fission-product waste would simply accumulate at the pyroprocessing plant. It would be far less costly simply to store South Korean spent fuel, at least until the country can demonstrate that it can succeed in commercializing large numbers of sodium-cooled fast-neutron reactors where all other countries have failed.

More importantly from an international security perspective, pyroprocessing would make plutonium much more accessible, exacerbating the danger of nuclear weapons proliferation. If reprocessing does not facilitate radioactive waste management and is costly and proliferative, it would be far better for the number of countries that are reprocessing to continue to decline rather than to add a second non-nuclear-weapon state to their number.

South Korea requires more interim spent-fuel storage. Its government should launch public consultations and see whether there are conditions under which one or more local governments would be willing to provide additional interim storage and perhaps a geological repository for its spent fuel.

Aomori Prefecture, which hosts Japan's reprocessing plant, received 190 billion yen ($1.7 billion) in incentive payments by 2004 before the plant was completed and has been promised 24,000 yen ($216) for every kilogram of spent fuel shipped to the plant. That will total another 760 billion yen ($7 billion) for the projected 32,000 tons of spent fuel that are to be reprocessed during the lifetime of the plant. The total subsidy will be 30 times the $300 million incentive that was part of the package that helped persuade the local governments around South Korea's Wolsong site to host a 2-square-kilometer underground repository for low- and intermediate-level radioactive waste.

Given the inherently low danger from stored spent fuel that has cooled for about two decades in comparison with that from the fuel in an operating nuclear power plant or freshly discharged fuel in at-reactor spent-fuel cooling pools, it is quite possible that, if the compensation were comparable to what Aomori Prefecture is receiving for hosting the Rokkasho Reprocessing Plant, a jurisdiction already hosting a nuclear power plant might be willing to host an interim spent fuel storage site as well. The cost would still be small in comparison to the estimated 11 trillion yen ($100 billion) cost of building, operating, and decommissioning the Rokkasho Reprocessing Plant. In fact, in Sweden and Finland, local jurisdictions that already host nuclear power plants have volunteered to host deep-underground spent-fuel repositories.

In the meantime, if R&D on fast-neutron reactors is to continue, it should be done on a multinational basis. Because of the high cost, proliferation concerns, and uncertainty whether these reactors will
be cost effective, it does not make sense to develop fast-neutron reactors in national programs. The multinational alternative would be to emulate the fusion energy community where the countries with major fusion energy programs have decided to build a single experimental reactor jointly. Indeed, because of the decline in fission R&D funds, 13 countries established the Generation IV International Forum in 2001 to coordinate their R&D on advanced fission reactors. More than half expressed interest in joint work on fast-neutron reactors: China, the European Union, France, Japan, South Korea, and the United States. Russia, whose nuclear establishment also has a major commitment to fast-neutron reactor R&D, joined the Gen IV Forum in 2006.[64]

These countries could use China’s existing small experimental fast-neutron reactor and the BN-800 demonstration reactor being built by Russia for joint R&D. Given the huge surplus of already separated plutonium that some of them already possess, there would be no need to reprocess to acquire the fuel.

Far better would be to restrict the focus of collaborative R&D to reactor types that do not require reprocessing. Collaboration on nuclear energy among China, Japan, and South Korea would be especially useful for trust building and nonproliferation in East Asia.

What is needed especially is multinational cooperation in the sensitive parts of the nuclear fuel cycle that are required by current-generation reactors operating on a once-through fuel cycle, namely uranium enrichment and spent fuel repositories.

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ENDNOTES


3. Transuranic elements have atomic numbers higher than uranium. They are created in nuclear reactors by neutron capture on uranium followed by radioactive decays in which a neutron is transformed into a proton. Uranium has 92 protons, neptunium has 93, plutonium as 94, americium has 95, and curium 96.


10. Under most of its agreements, the United States considers requests for such activities one by one. Under the agreements with the European Union, India, Japan, and Switzerland, the United States has provided advance long-term consent for reprocessing. In India’s case, according to the Indian-U.S. nuclear cooperation agreement, this long-term consent does not go into effect until India has built and brought into operation “a new national reprocessing facility dedicated to reprocessing material” under International Atomic Energy Agency (IAEA) safeguards and the two countries have agreed on “arrangements and procedures under which reprocessing or other alteration in form or content will take place in this new facility.”


24. Jooho Whang, Kyung Hee University, South Korea, e-mail communication with author, October 21, 2009 (hereinafter Whang e-mail).


28. Japan’s most recent declaration to the IAEA was 47.4 metric tons as of the end of 2008. IAEA, “Communication Received From Japan Concerning Its Policies Regarding the Management of Plutonium,” INFCIRC/549/Add.1/12, November 9, 2009, www.iaea.org/Publications/Documents/Infcircs/2009/infcirc549a1-12.pdf. For some reason, the declaration of the amount stored in Europe is only of the contained Pu-239 and Pu-241. I have multiplied the quantity of these fissile isotopes by 1.5 to obtain the total amount of plutonium. Tons, as used in this article, means metric tons.


30. Spent fuel is ordinarily measured by the original tonnage (metric) of uranium that the fresh fuel contained. This weight does not include the weight of the oxygen in the uranium oxide or the fuel’s zirconium alloy cladding.


32. Sources differ slightly on the exact words that produced the acronym PUREX; a common version is “plutonium-uranium extraction.”

33. Twenty years after discharge, the transuranic mix in LWR spent fuel with a cumulative fission-energy release of 53 megawatt-days per kilogram of uranium (MWt-days/kgU) is plutonium, 82.4 percent; americium, 10.7 percent; neptunium, 6.6 percent; and curium, 0.4 percent. Jungmin Kang and Frank von Hippel, “Limited Proliferation-Resistance Benefits From Recycling Unseparated Transuranics and Lanthanides From Light-Water Reactor Spent Fuel,” Science and Global Security, Vol. 13 (2005), p. 169, table 1.

34. Fifty billion dollars reported by the OECD countries to the International Energy Agency (IEA) as spent between 1974 and 2007; tens of billions of dollars before 1974, when the spending rate was $3 billion per year; at least $12 billion for the Superphénix reactor not included in France’s report to
the IEA; an estimated $12 billion spent by Russia; and an unknown amount spent by India. IPFM, “Fast Breeder Reactor Programs: History and Status.”


38. Hansoo Lee, “The Korean Strategy in Nuclear Fuel Cycle” (presentation at KAERI, Daejeon, South Korea, May 25, 2009). Gamma rays are high-energy X-rays that are generated by nuclear radioactive decays. They dominate the penetrating radiation dose emitted by spent nuclear fuel.


44. “[I]ts proliferation resistance has been internationally recognized due to the impossibility to recover plutonium.” KAERI, “Pyroprocess Technology,” www.kaeri.re.kr/english/sub/sub04_03.jsp.


47. Park, “Status and Prospect of Spent Fuel Management in South Korea,” p. 27.


50. A PWR with a one-gigawatt electrical generating capacity (1-GWe) discharges about 0.24 tons of transuranics in its spent fuel annually. A 1-GWe fast-neutron reactor with a thermal-to-electric power conversion efficiency of 40 percent would have a thermal power of 2.5 GWT. (A gigawatt is 1 billion watts. GWe indicates that the power is electric; GWt indicates that the power is thermal.) If operated at a capacity factor of 0.9, it would generate about 800 GWT-days of fission heat annually, which would require the fissioning of about 0.8 tons of heavy metals, i.e., transuranics and uranium per year. However, if the transuranics were mixed with uranium, as proposed for safety reasons, some of
the uranium would be fissioned directly and some would be converted into transuranics. The net destruction rate of transuranics would therefore be 0.8(1-CR), where CR is the reactor conversion ratio. A National Academy of Sciences (NAS) study quotes a minimum safe conversion rate for a General Electric fast-reactor design of 0.6. NAS, “Nuclear Wastes: Technologies for Separations and Transmutation,” 1996, pp. 205-206. Fast-neutron reactor advocates at Argonne National Laboratory argue that a conversion ratio as low as 0.25 can be achieved safely with added control rods and twice-annual refueling. J. E. Cahalan et al., “Physics and Safety Studies of a Low Conversion Ratio Sodium Cooled Fast Reactor,” Proceedings of the PHYSOR 2004 Conference, April 2004. For a CR in the range of 0.25 to 0.6, the net destruction rate of transuranics would be 0.32, or 0.6 tons per year.

51. KAERI, “Fast Reactor Technology Development Group, R/D Activities.”


53. The plutonium for India’s nuclear weapons was separated using an engineering-scale reprocessing plant at India’s Bhabha Atomic Research Center.


55. D. E. Shropshire et al., “Advanced Fuel Cycle Cost Basis,” INL/EXT-07-12107, 2007, tables F1-4 and F2-3. The largest scale on which pyroprocessing has been conducted thus far is a rate of about 0.4 tons of heavy metal per year in the treatment of 0.7 tons of driver fuel and 2.5 tons of blanket uranium of the Experimental Breeder Reactor II in Idaho. In 2006 the total project cost was estimated at $363 million, or about $15,000 per kilogram. See U.S. Department of Energy, “Preferred Disposition Plan for Sodium-Bonded Spent Nuclear Fuel,” 2006, www.ne.doe.gov/pdfFiles/DisPlanForSodBondedSNFMarch2006.pdf.


62. The incentives provided to the region for accepting the low-level-waste site also included the transfer of the headquarters of KHNP to Gyeongju (population 280,000), the nearest city to Wolsong. See Ji Bum Chung et al., “Competition, Economic Benefits, Trust, and Risk Perception in Siting a Potentially Hazardous Facility,” Landscape and Urban Planning, Vol. 91 (2009), p. 8.

64. See www.gen-4.org.

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