CHAPTER 4

PLUTONIUM, PROLIFERATION, AND RADIOACTIVE-WASTE POLITICS IN EAST ASIA

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Depending upon how negotiations between the United States and South Korea, France and China, and the United States and Vietnam turn out, chemical reprocessing of spent nuclear fuel and recycling of recovered plutonium, which has been in decline in Europe, may make a resurgence in East Asia. Unfortunately, East Asia has not created a security architecture such as has been created in Europe, where a major conflict is now unthinkable. In fact, East Asia today is characterized by rising tensions, as North Korea threatens its neighbors and continues to expand its nuclear weapon capabilities, and China becomes increasingly assertive about its sovereignty over the resources under the seas whose shores it shares with Japan, South Korea, the Philippines, Indonesia, Brunei, Malaysia, and Vietnam. There is also the unresolved issue of the future of Taiwan. The spread of reprocessing in East Asia could therefore create the basis for a proliferation chain reaction that could make the region much more dangerous. Today, Japan is the only non-nuclear weapon state in the world that reprocesses. It has built up a domestic stockpile of about 10 tons of separated plutonium. This is a modest amount when measured in terms of fuel value but sufficient for more than 1,000 nuclear warheads. That amount will become much larger if and when the Rokkasho Reprocessing Plant goes into operation. The idea of producing nuclear weapons has come up a number of times in Japan's security debate but has never been pursued seriously. Nevertheless, Japan's nearest neighbors regard it as a "virtual" nuclear weapon state, a country that could quickly acquire nuclear weapons if it felt threatened.

South Korea's nuclear-energy establishment feels that it has reached maturity, as demonstrated by the smooth operation of its 20 nuclear-power reactors and its 2009 success in beating out French and U.S.-Japanese consortia for a contract to sell the United Arab Emirates (UAE) four nuclear power reactors. Its nuclear-energy establishment chafes at the United States refusing to grant South Korea the same rights to reprocess and enrich as Japan. This became a popular issue, following North Korea's nuclear test of May 9, 2010, when some South Korean politicians began calling for "nuclear sovereignty" for South Korea.[1] The timing suggests that they see some deterrence value in South Korea becoming a virtual nuclear weapon state like Japan. South Korea's nuclear-energy establishment denies such an interest, but argues that reprocessing is the only way for South Korea to manage its spent fuel problem. This issue has arisen at a time when South Korea and the United States have begun to renegotiate their current agreement for nuclear cooperation, which expires in 2014.

In the 1970s and again in the 1980s, Taiwan launched clandestine reprocessing programs aimed at providing it with its own nuclear deterrent against Mainland China. Both times, the United States forced Taiwan to abandon these programs. Today, Taiwan's interest in nuclear weapons appears quiescent, but its agreement for nuclear cooperation with the United States also is due for renegotiation in 2014.

Meanwhile, China has built a pilot civilian reprocessing plant next to one of its military reprocessing plants and is considering acquiring a large facility like Japan's Rokkasho Reprocessing Plant from France. But France's Foreign Ministry is worried about the fact that China has not, like the other four permanent members of the United Nations Security Council, committed itself to end production of plutonium for weapons.

Finally, the United States is negotiating an agreement of nuclear cooperation with Vietnam, and a debate has broken out within the U.S. Government over whether or not to try to persuade Vietnam to join the UAE in renouncing its rights to acquire national enrichment or reprocessing facilities.

The most bizarre aspect of all of these developments is that reprocessing is uneconomical and unnecessary for current generation nuclear-power reactors. Countries are justifying their pursuit of reprocessing for reasons that appear to be discredited or subjective, and therefore suspect: either the dream of commercializing plutonium breeder reactors, which failed in the United States, Western Europe, and Japan, or the claim that reprocessing will ameliorate domestic political problems with regard to the disposition of spent fuel.

THE DREAM OF A 'PLUTONIUM ECONOMY'

The U.S. World War II Manhattan project spawned nuclear weapons. It also spawned the dream that fission could power human civilization for millennia. Enrico Fermi, the scientific leader of the U.S. wartime plutonium-production program, and his co-workers thought that uranium was scarce and that therefore chain-reacting U-235, which makes up only 0.7 percent of natural uranium, would not be abundant enough to fuel fission power on a large scale. They therefore invented the plutonium-breeder reactor, whose ultimate fuel would be uranium-238, which comprises 99.3 percent of natural uranium.[2]

U-238 is not chain-reacting, but can be converted into chain-reacting plutonium-239 by the absorption of neutrons. A fast-neutron reactor fueled by plutonium could breed more plutonium out of U-238 than it consumed. With the resulting hundred-fold increase in the amount of energy extractable from natural uranium, even the three grams of U-238 in a ton of average crustal rock would, if converted into plutonium and fissioned, release the energy equivalent of several tons of coal.

According to his junior colleague, Alvin Weinberg, Fermi worried, however, that "It is not clear that the public will accept an energy source that produces this much radioactivity and that can be subject to diversion of material for bombs."[3]

Glenn Seaborg, a co-discoverer of plutonium, had no such doubts and, while Chairman of the U.S. Atomic Energy Commission (AEC) from 1961 till 1971, relentlessly promoted the idea of a "plutonium economy." In a visionary speech on "The Plutonium Economy of the Future" at the end of his tenure as AEC chairman, Seaborg predicted that, by the year 2000, plutonium "can be expected to be a predominant energy source in our lives." The AEC staff projected that U.S. nuclear power-generating capacity that year would be 1,100 billion Watts (gigawatts [GWe]). It is actually about 100 GWe today. Seaborg also projected that the United States would be increasing its stock of separated plutonium by more than 100,000 kilograms (kg) each year.[4]

Seaborg did not mention the implications of the fact that the predominant use of plutonium at the time was for nuclear weapons. The United States had already produced about 80,000 kg, enough to make the fission triggers for 30,000 nuclear weapons. Obviously, the diversion to weapons of only a miniscule rivulet from the plutonium river that Seaborg was looking forward to would transform the global security situation.

CONCERNS ABOUT REPROCESSING AND PROLIFERATION

Under Seaborg's leadership, the AEC promoted the vision of a plutonium economy worldwide through the U.S. Atoms for Peace program. In 1974, 3 years after Seaborg stepped down as AEC chairman, however, India used the first plutonium separated from the fuel of its first research reactor for a "peaceful nuclear explosion" that turned out to be its first step toward becoming a nuclear-armed state.[5]

India's nuclear test drew the attention of the White House and the State Department to the security implications of the AEC's promotion of plutonium as the commercial fuel of the future. President Gerald Ford and then President Jimmy Carter launched reviews that concluded that breeder reactors would not be economical for the foreseeable future. After some delay, the U.S. Congress, faced with the skyrocketing costs of the U.S. Clinch River demonstration breeder reactor, agreed with this reversal of policy and cancelled the project in 1983.[6]

In the meantime, the United States had succeeded in winning the cancellation of France's contracts to sell reprocessing plants for separating plutonium from irradiated uranium fuel to South Korea, Pakistan, and

Taiwan. Ultimately, with the assistance of the democratic opposition to Brazil's then military government, Germany's contract to provide a reprocessing plant to that country was cancelled as well. The United States did not try to stop the entrenched reprocessing programs in the three states whose nuclear-weapon programs had spawned civilian reprocessing programs—France, the Soviet Union, and the United Kingdom (UK).

The judgments by the Ford and Carter Administrations of the poor economic prospects of the breeder reactors that were being used to justify plutonium separation have been vindicated by the abandonment of breeder-commercialization programs in Germany and the UK, and the postponement of those programs for 80 years by France and Japan.[7] India and Russia are both building liquid-sodium-cooled "demonstration" breeder reactors, but it is extremely unlikely that they will demonstrate economic competitiveness with today's water-cooled reactors. As Admiral Hyman Rickover concluded after trying a sodium-cooled propulsion reactor in a submarine, such reactors are "expensive to build, complex to operate, susceptible to prolonged shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair."[8]

Reprocessing in Japan.

Japan started the construction of a pilot-reprocessing plant at Tokai-mura village in 1971.[9] This plant, although small on the scale that Seaborg had envisioned, was designed to separate 2,000 kg of plutonium per year, enough for more than 250 Nagasaki bombs.[10] The Carter administration tried to persuade Japan not to start up the Tokai Reprocessing Plant. The United States was Japan's main supplier of reactor technology and fuel at the time, and their 1968 Agreement of Cooperation Concerning Civil Uses of Atomic Energy gave the United States veto power over reprocessing in Japan. The debate quickly escalated, however, to the tops of the two governments, and Prime Minister Takeo Fukuda declared Japan's right to reprocess a matter of "life or death" for Japan.[11]

It is interesting to speculate about the reasons Japan's government felt so strongly about this issue. The primary reason probably was related to the fact that the 1973 Arab oil embargo had dramatized Japan's vulnerability to a cutoff of its imported oil. This caused Japan, like many other major industrialized countries, to invest heavily in nuclear power. But, for Japan, which, unlike the United States, had no domestic uranium resources, the nuclear power plants brought a new potential vulnerability: a cutoff of imported uranium fuel. Indeed, the rise of demand for uranium after 1973 outpaced the rise in supply, and the price of natural uranium on the spot market increased six-fold by 1975.[12] This would have made breeder reactors appear more attractive. By the 1980s, however, the price of uranium in constant dollars had fallen back to its 1973 level.

There was also a second reason Japan's security establishment embraced reprocessing. Even though Japan relied primarily on the U.S. "nuclear umbrella" against nuclear and other threats from the Soviet Union and China, reprocessing would provide Japan with its own nuclear-weapon option, "just in case."[13] In any case, the Carter administration backed down and agreed to the operation of the Tokai Pilot Reprocessing Plant and, in 1988, the Reagan administration signed a new Agreement of Cooperation that gave Japan blanket "prior consent" for the reprocessing of its spent fuel.[14]

By that time, however, breeder reactors were fading rapidly into the more distant future. Originally, Japan's nuclear-energy establishment, like the AEC, had planned to commercialize breeder reactors in the 1970s. But, in 1987, the commercialization target was pushed back to after 2020 and, in 2006, until after 2050.[15] Nevertheless, Japan shipped some of its spent fuel to France to be reprocessed and built a full-scale reprocessing plant in Rokkasho-mura, with a design capacity of 800 tons of spent light-water reactor fuel per year. Reprocessing at that rate would result in the annual separation of about eight tons of plutonium—enough for about 1,000 Nagasaki-type nuclear weapons.[16]

In the absence of breeder reactors, Japan decided to recycle the separated plutonium back into the fuel of the light-water reactors from which it had been separated. Japan's Atomic Energy Commission estimated in 2004 that this would increase the cost of nuclear power in Japan by about 0.6 yen (0.7 cents) per kilowatt-hour, relative to the direct underground disposal of the unreprocessed spent fuel.[17] Although the reprocessing plant was completed in 2001,[18] it has not yet gone into regular operation because of a seemingly unending series of technical problems.

Recycling plutonium and uranium recovered from spent fuel in light-water reactors would reduce Japan's uranium imports by 25 percent, at most. In any case, however, Japan's concern about its uranium import dependence, unlike its concern about its dependence on imported oil, appears to have dissipated. Japan has a strategic reserve of 6 months of oil imports but no strategic uranium reserve, although it would be 30 times less costly on an energy-equivalent basis.[19]

Nevertheless, Japan's commitment to reprocessing remains undiminished. A new rationale was given in the Japan Atomic Energy Commission's 2004 cost-benefit analysis. It argued that, if Japan gave up its reprocessing program, the reactors would have to shut down as their on-site storage facilities filled up:

> If we make a policy change from reprocessing to direct disposal, it is indispensable for the continuation of nuclear power generation to have communities that up until now have accepted selection as a site for nuclear facility, based on the assumption that spent fuel would be reprocessed, understand the new policy of direct disposal and accept the temporary storage of spent fuel at the site. It is clear, however, that it takes time to do so, as it is necessary to rebuild relationships of trust with the community after informing them of the policy change. It is likely that the nuclear power plants that are currently in operation will be forced to suspend operations, one after another, during this period due to the delay of the removal of spent fuel.[20]

The cost of replacing the power from Japan's nuclear power plants was estimated as being up to twice as great as the cost of reprocessing.[21]

Reprocessing is therefore kept alive in Japan in good part by concerns about the disposition of spent fuel. Local governments that host nuclear power plants want assurance that their spent fuel will not accumulate indefinitely on-site. At the same time, other local governments are reluctant to host interim central storage sites for spent fuel, for fear that they will become permanent. These governments are reluctant to host even 500-meter-deep geological repositories for radioactive waste for fear that natural processes or human intrusion could pollute the surface millennia hence.

Reprocessing plants are, in effect, interim central storage sites, but they bring enough economic benefits to the isolated poor communities that host them that those communities are willing to accept government guarantees that the radioactive waste will stay there only temporarily. In Japan, the government has guaranteed Aomori Prefecture, which hosts the Rokkasho Reprocessing Plant, that no radioactive waste will stay on its soil for more than 50 years. This sets a deadline for Japan to begin moving the high-level waste from reprocessing to an underground repository by 2045.

The estimated cost of reprocessing and associated activities, excluding transport and radioactive waste disposal, over the 40-year life of the Rokkasho Reprocessing Plant was estimated in 2003 as about 9 trillion yen ($100 billion).[22] That is obviously significant for a prefecture that in 2004 had an annual gross domestic product (GDP) of about 4.3 trillion yen ($50 billion) and was the second to the poorest of Japan's 47 prefectures measured in terms of GDP per capita.[23] The prefecture's government will receive about $200 million per year directly when the reprocessing plant is operating at full capacity.[24]

The Rokkasho Reprocessing Plant is not operating, however, and its 3,000-ton storage pool is virtually full. This means that Japan's nuclear utilities have to devise other forms of interim storage, and they are doing so. An interim storage facility is being built by Tokyo Electric Power and the Japan Atomic Power in Aomori Prefecture near the reprocessing plant, with an ultimate capacity of 5,000 tons. The first module, with a capacity of 3,000 tons, is scheduled to begin operation in 2012.[25] Chubu Electric Power, which operates the Hamaoka Nuclear Power plant, has proposed—as part of a plan to replace the two oldest nuclear units on the site—to build dry storage to accommodate the spent fuel that has accumulated in the storage pools that are to be decommissioned.[26] Kyushu Electric Power, which has 5 GWe of nuclear capacity, is looking for a site for an interim dry-cask storage facility.[27] If such efforts succeed, they could provide a relief valve for the pressures that have sustained Japan's reprocessing.

Changing Japan's reprocessing policy will be very difficult, however, because so many legal and political commitments have been attached to it. Aomori Prefecture accepted the Mutsu spent-fuel storage facility, for example, only after the governor had been ensured that there would be a second reprocessing plant to which the spent fuel would be shipped. And, as local governments are being canvassed about their willingness to accept a geological radioactive waste repository, they are being ensured that only high-level reprocessing waste from which the plutonium has been separated will be buried there. The implication is that plutonium dominates the long-term hazard of spent fuel. In fact, that is not necessarily true. In the U.S. Department of Energy's Yucca Mountain Feasibility Study, the calculated doses to people who used aquifer water downstream from the mountain are dominated for the initial 50,000 years by technicium-99, a 210,000-year half-life fission product, and thereafter by neptunium-237, a 21-million-year half-life transuranic element.[28]

Thus, due to a combination of Japan's commitment to breeder reactors in the 1960s, problems of public acceptance with regard to interim storage of spent fuel, and a growing web of legal and political commitments, the country has trapped itself in a reprocessing program that generates huge stocks and flows of weapon-usable plutonium and sets a dangerous example for its neighbors.

South Korea's Push for the Right to Reprocess.

South Korea's nuclear power program is about 25 years behind Japan's, but the storage pools for its heavy water reactors (HWRs) have long since filled up, and the storage pools at its three pressurized water reactor (PWRs) sites—Kori, Ulchin, and Yonggwang—are projected to be full by 2016, 2018, and 2021, respectively.[29] Dry-cask storage is being built for the heavy water reactor (HWR) fuel, but the Korea Atomic Energy Research Institute (KAERI) argues that such storage is politically unfeasible at the PWR sites and proposes instead to build a reprocessing plant using pyroprocessing technology[30] and fast-neutron reactors to fission the plutonium and other transuranic elements separated from the PWR fuel.[31] The design of KAERI's proposed fast-neutron transuranic burner reactors would be basically the same as those of the breeder reactors that several countries have tried unsuccessfully to commercialize.[32]

South Korea has a long history of interest in reprocessing. During the 1970s, the interest was briefly in a nuclear-weapon program, triggered by President Richard Nixon's decision that U.S. allies in Asia should take more responsibility for their own defense. The United States decided to keep its military forces in South Korea and succeeded in persuading South Korea to cancel its order for a pilot reprocessing plant from France.[33] In 2004, however, South Korea's government informed the International Atomic Energy Agency (IAEA) that, from 1979 through 2000, KAERI had continued to conduct secret laboratory-scale enrichment and reprocessing experiments.[34]

In 1992, South and North Korea agreed not to enrich uranium or reprocess spent fuel. After North Korea conducted its second nuclear test in May 2009, however, that agreement lost its remaining credibility. South Korea's 1974 Agreement of Cooperation with the United States expires in 2014, and South Korea's government is pressing the United States for a new agreement that would give it the same blanket prior consent for reprocessing as Japan.

KAERI's pyroprocessing "solution" to South Korea's spent-fuel storage problem has its own credibility problems, however. First, it would come to fruition decades after the crisis it is proposed to solve. KAERI proposes to put into operation in 2025 a prototype facility capable of reprocessing 100 tons of spent fuel a year and, in 2028, a prototype 0.6 GWe fast-neutron reactor able to fission annually the transuranics from 50 tons of spent fuel.[35] By 2030, however, South Korea's light-water reactors are projected to be discharging about 800 tons of spent fuel annually.[36] Obviously, for the foreseeable future, South Korea will have to depend upon interim storage.

With regard to this mismatch of timing and capacity, KAERI argues that:

> To win public acceptance [South Korea's authorities] need to show that pyroprocessing or other long-term storage options are viable. Otherwise, local communities will not be convinced that any interim storage facilities will in fact be temporary.[37]

Even if full-scale pyroprocessing took place and South Korea succeeded in deploying tens of full-scale fast reactors, however, an underground repository would be required for the reprocessing waste and for the spent fuel being discharged by the heavy water reactors. KAERI argues, however, that, without fast-neutron reactors, the footprint of the underground repositories would be too large for South Korea:

> By the end of the century (assuming the new planned reactors come online), the cumulative amount of spent fuel produced by South Korean reactors is expected to exceed 110,000 tons. To dispose of such a large amount of spent fuel at a single site, an underground repository (and an exclusion zone surrounding the site) would need to cover as much as 80 square kilometers, an area considerably larger than Manhattan. Finding that much free space in South Korea would be enormously difficult. The country is approximately the size of Virginia [110,000 km^2] and is home to about six times as many people.[38]

A technical KAERI study finds, however, that the area underlain by tunnels would be about 20 square kilometers.[39] This area could be reduced by a factor of two if the spent fuel were cooled on the surface for 100 instead of 40 years. Use of fast reactors to fission the transuranics would not accomplish more at 40 years than aging the spent fuel for 100 years.[40] In any case, there is not much competition for real estate at a depth of 500 meters, and the area required for the surface facilities associated with an underground repository would be small in comparison with the area of, for example, a nuclear power plant.

It is the proliferation implications, however, that make this an issue of international concern. Although it would take a long time to deploy the pyroprocessing and fast reactor capacity required to keep up with the rate of discharge of transuranics in South Korea's PWR spent fuel, even the engineering prototype pyroprocessing plant that KAERI hopes to bring online in 2016 would be of proliferation concern. It would be able to separate 100 kg of plutonium, or enough for more than 10 nuclear bombs per year. KAERI argues pyroprocessing's "proliferation resistance has been internationally recognized due to the impossibility to recover plutonium."[41] The U.S. Department of Energy did, in fact, promote the "proliferation-resistance" of pyroprocessing during the George Bush Administration. A 2009 interlaboratory review reported, however, the results of an:

> assessment [that] 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.[42]

KAERI therefore would be creating a nuclear-weapon option for South Korea in 2016, while its proposed costly approach *might* begin reducing the transuranics in South Korea's spent nuclear fuel after 2050. India followed this path and implemented its nuclear-weapon option in 1974. Only now, more than 35 years later, is India building its first demonstration breeder reactor, which may or may not work. South Korea may not today have any more intention than Japan to actually exploit a nuclear-weapon option, but, if a future government wished, it could do so quickly and secretly within weeks before domestic or international opposition could stop it.

On October 25, 2010, U.S. and South Korean officials met for the first session of their negotiations on a new Agreement of Cooperation. The South Korean negotiators accepted the U.S. proposal to do a joint study on the "feasibility" of pyroprocessing. The study is expected to take up to several years. Most likely, this means that negotiations on pyroprocessing in South Korea will be taken up after the new Agreement of Cooperation is negotiated.

It appears that KAERI will not be able to do experiments with spent fuel during the negotiation period. The Bush administration did not approve such experiments in South Korea, but allowed joint experiments with spent fuel at the Idaho National Laboratory. That could only be accomplished within the strictures of the 1978 Nonproliferation Act, however, with the legal subterfuge of defining pyroprocessing as "not reprocessing" and therefore not a "sensitive nuclear technology" subject to export controls. Late in the Bush administration, a rebellion by nonproliferation experts in the Departments of Energy and State forced a reversal of this position, which has resulted in a cutoff of U.S. cooperation with KAERI on pyroprocessing.

Taiwan: Dry-cask Interim Storage for Now.

Taiwan, like Japan and South Korea, is trying to find its way forward with regard to spent-fuel management. Like South Korea, Taiwan has security concerns that led it twice to launch secret reprocessing programs. The first, launched in the 1960s, was shut down under U.S. pressure in 1976; the second, launched in 1987, was shut down in 1988—again at U.S. insistence.[43]

Taiwan built three 2-unit nuclear-power plants (Chinsan, Kuosheng, and Maan Shan) during 1978-1985 and has one under construction (Lungmen). As of 2006, the spent-fuel pools of the three operating power plants had all been re-racked once or twice to increase their storage density, but the oldest plant, Chinsan, was expected to run out of storage capacity in 2011, and the second oldest, Kuosheng, in 2016.[44] After looking into reprocessing in Europe, Taiwan opted for on-site dry-cask storage for the mid-term while an attempt is made to site a geological repository.[45]

Taiwan has an Agreement of Cooperation with the United States that gives the United States prior consent rights with regard to the reprocessing of Taiwan's spent fuel. This agreement will expire in 2014, and therefore, like South Korea's Agreement of Cooperation, must be renegotiated.

China: Committed to Reprocessing?

China's initial source for nuclear-energy technology was France. France reprocesses, and China announced that it would do so too, in 1987, 7 years before its first nuclear power plant went into operation. As of 2010, China had built a pilot reprocessing plant in Gansu Province, with a capacity of 50 tons of spent fuel per year, expandable to 100. China was also discussing with France the acquisition of an 800-ton-per-year plant, which, like Japan's Rokkasho Reprocessing Plant, would be based on the design of France's UP-3 plant. The new plant would have a spent-fuel storage capacity of 3,000-6,000 tons and would begin receiving spent fuel in 2018. Reprocessing would begin in 2025.[46]

China does not appear to have done a cost-benefit analysis on reprocessing vs. storage. Also, unlike Japan and South Korea, which are having trouble getting agreements from local governments to allow the siteing of central spent-fuel interim storage or a geological repository, there is no indication that China will encounter resistance to its proposal to site a repository in a remote area of Gansu Province next to the Gobi Desert. China's plans for reprocessing appear to be driven more by a concern that it may become difficult to obtain enough domestic and imported uranium to fuel the immense nuclear capacity it plans to build. This is the classic argument for plutonium breeder reactors, and China is indeed in discussions with Russia over the possibility of buying one or two copies of the BN-800 demonstration breeder reactor that Russia is currently completing.

Both the China National Nuclear Corporation (CNNC) and France's Foreign Ministry have reservations about the proposed sale of a French reprocessing plant to China, however. CNNC is concerned about the price that AREVA reportedly wants to charge for the plant: 20 billion Euros, according to a CNNC expert. For its part, France reportedly is concerned that China has not renounced the production of further plutonium for weapons and that China wishes to locate the reprocessing plant next to one of its military reprocessing plants.[47]

In the late 1970s, after India's 1974 nuclear test, the United States argued in effect, when pressing Japan, South Korea, and Taiwan to abandon their reprocessing programs: "We don't reprocess; you don't need to either." When asked about the example China's decision to reprocess might have on its neighbors such as South Korea, Vietnam, and Indonesia, Chinese officials respond that Japan has already set the reprocessing precedent and that, in any case, it is the United States, not China, that is currently negotiating Agreements of Cooperation on nuclear energy and therefore has influence on the nuclear policies of countries such as Vietnam.

Is there an Alternative to the Spread of Plutonium Separation in East Asia?

South Korea and China are both at critical junctures in their spent-fuel policies. If South Korea succeeds in persuading the United States to acquiesce to its right to reprocess, it will be the second nonweapon state to do so, and it will become correspondingly more difficult to persuade other countries not to acquire national reprocessing plants. If China continues forward to actually implement its reprocessing plan, the increasing weight of its example may help legitimize reprocessing as a standard part of the nuclear power fuel cycle. Japan is continuing with its reprocessing program even though its costs continue to mount and it continues to encounter technical problems. Is there an alternative scenario in which the building momentum toward plutonium economies and latent proliferation in East Asia might be reversed? This last section of the chapter considers the possibilities.

South Korea.

The justification being put forward for South Korea's interest in reprocessing has been developed by the KAERI. KAERI, by virtue of its technical expertise, has been able to largely monopolize the debate in South Korea—and, to a considerable extent, in Washington, DC, through the employees that it has stationed at nongovernmental organizations, think tanks, and universities there.

KAERI's primary interest is in research and development (R&D). It has been interested in reprocessing since the 1960s and has pursued it to the extent allowed by the United States. During the Bush administration, KAERI focused on pyroprocessing after Vice President Dick Cheney's Energy Commission embraced pyroprocessing as proliferation resistant and not reprocessing, which opened the door for the Department of Energy's national laboratories to pursue pyroprocessing R&D in cooperation with KAERI.

To justify the funding of its pyroprocessing R&D to the South Korean government, however, KAERI has had to argue that the interim storage and geological disposal of spent fuel, although probably less costly, are unfeasible in South Korea. This is not implausible, since South Korea, like other countries—including the United States—has encountered political problems siting central spent-fuel interim storage and underground radioactive-waste disposal facilities.

The United States has gone to extended interim storage at its nuclear power plants while it works out the politics of its siting policy. South Korea should try seriously to do the same. In fact, it has no alternative. South Korea nuclear power plants will have used up their current on-site storage capacity by 2021, and the "solution" that KAERI is offering would be deployed only after 2050.

KAERI argues that, by embracing pyroprocessing and fast-neutron reactors, South Korea would make expanded on-site storage more feasible politically, because the local governments will see that there is a plan beyond interim storage. But the fast-neutron reactors that are the linchpin of KAERI's strategy could fail economically and technologically in South Korea, as they have elsewhere. It is at least as credible that South Korea could site a geological repository by 2050.

The joint South Korean-U.S. "feasibility study" on pyroprocessing could provide a broader set of policy options for both countries to consider. It will only do so, however, if KAERI's grip on South Korea's spent-fuel policy can be broken. This would require involving officials from South Korea's responsible Ministries in the feasibility study so that they can be educated about the alternatives and empowered to develop their own views.

China.

China's government similarly needs to question the precipitous pace at which the China National Nuclear Corporation proposes to move toward reprocessing and breeder reactors. That strategy is 50 years old, and has not worked well for the other countries that have pursued it. As did France, India, Japan, Russia, and the UK in the past, China has premised its reprocessing plans on the expectation of rapid commercialization of breeder reactors. Not having a design of its own, the CNNC plans to start building BN-800 reactors at a rate of one per year starting in 2013.[48] China is building light-water reactors at this rate, but their basic designs have been proven in other countries over decades. There is no such experience base for sodium-cooled reactors. Indeed, after failed attempts, plans to commercialize them on a large scale were abandoned in Germany, the UK, and the United States and postponed until after 2050 by France and Japan.

Construction of the Soviet Russian prototype of the BN-800 was begun in 1986, suspended in 1990, resumed in 2002, and currently is to be completed in 2014.[49] The BN-800 is an 800-megawatt-electric (MWe) sodium-cooled design that builds on the BN-600 reactor, which has operated in Russia since 1980—with a cumulative capacity factor as of the end of 2009 of 74 percent.[50] The BN-600 is the only sodium-cooled prototype reactor that has not been a total failure, but most countries would not judge it a full success either. As of 1997, it had experienced 14 sodium fires—some of them quite substantial.[51] Also, Russia has not yet established a plutonium fuel cycle for breeder reactors. Thus far, the BN-600 has been fueled with highly enriched uranium.

Given the historic problems of sodium-cooled reactors, China should treat the BN-800 as an experiment and not a prototype ready for mass production. If China committed only to a single BN-800 for now, there would be no need to build a large-scale reprocessing plant. Russia could provide the startup fuel and first few fuel reloads out of its stockpile of 46 tons of separated reactor-grade plutonium.[52] The core of the BN-800 requires 2.1 tons of plutonium and, assuming a 75-percent capacity factor—about 1.4 tons of plutonium annually thereafter until recycling of plutonium from its spent fuel can commence.[53] Russia has no current need for this plutonium because, under an agreement with the United States, it has committed to fuel its BN-600 and BN-800 reactors with 34 tons of excess weapon-grade plutonium.[54]

Japan.

Japan is already deeply committed to reprocessing, but this has been costly both economically and to the public credibility of Japan's nuclear establishment. At least as far back as 1993, the fuel-cycle managers of Japan's three largest nuclear utilities told the author that, knowing what they did at that point, they wished that Japan had pursued a once-through fuel cycle with interim storage of spent fuel like the United States. But they described their companies as "trapped" into reprocessing by the commitments that had been made to the local governments that host their nuclear power plants.[55] Japan's Atomic Energy Commission made the same argument publicly in 2005 (see above). Japan should not trap itself more deeply.

Japan has already postponed for decades the construction of a second reprocessing plant, which was originally to have been put into operation in 2010. The current plan is to bring it into operation around 2050,[56] but that would be after the proposed opening of the geological repository, currently planned for around 2035.[57] Japan should reserve for itself the option of not building the reprocessing plant but simply emplacing in the repository spent fuel not reprocessed by the first plant.

ENDNOTES - CHAPTER 4

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2. Thomas Cochran *et al*., "Fast Reactor Development in the United States," *Fast Breeder Reactor Programs: History and Status,* Princeton, NJ: Princeton University, International Panel on Fissile Materials, 2010, p. 89.

3. Alvin Weinberg, *The First Nuclear Era: The Life and Times of a Technological Fixer,* New York: Springer, 1994, p. 41.

4. Glenn Seaborg, "The Plutonium Economy of the Future," paper presented at the Fourth International Conference, "Plutonium and Other Actinides," Santa Fe, NM, October 5, 1970, U.S. Atomic Energy Commission press release S-33-70.

5. George Perkovich, *India's Nuclear Bomb,* Berkeley, CA: University of California Press, 1999, pp. 27-31.

6. Anthony Andrews, *Nuclear Fuel Reprocessing: U.S. Policy Development,* Washington, DC: Congressional Research Service, March 27, 2008, available from *www.fas.org/sgp/crs/nuke/RS22542.pdf*.

7. Cochran *et al*.

8. Richard G. Hewlett and Francis Duncan, *Nuclear Navy: 1946–1962,* Chicago, IL: University of Chicago Press, 1974, p. 274.

9. *History of Japan Nuclear Cycle Development Institute,* Ibaraki, Japan: Japan Nuclear Fuel Cycle Development Institute, 2005, p. 19, available from *www.jaea.go.jp/jnc/siryou/skikoushi/pdf/e_jnc.pdf.*

10. The IAEA assumes that 8 kilograms (kgs) of reactor-grade plutonium is sufficient to make a nuclear weapon, including production losses. The Nagasaki bomb contained 6 kg of weapon-grade plutonium.

11. Charles S. Costello III, "Nuclear Nonproliferation: A Hidden but Contentious Issue in US-Japan Relations During the Carter Administration (1977-1981)" *Asia-Pacific Perspectives,* May 2003, p. 1. I have been informed by Dr. Fumihiko Yoshida that, although the translation "a matter of life and death" is literally correct, the sense in Japanese is less dramatic, i.e., "a critical matter."

12. Cochran *et al*., Figure 1.2.

13. See, for example, "Declassified Documents Show Japan Balked at Signing Nuclear Weapons Treaty in 1970," November 30, 2010, available from *mdn.mainichi.jp/mdnnews/news/20101130p2a00m0na012000c.html*. The documents include draft "diplomatic policy guidelines in September 1969 [that] pointed to the need for Japan to have the capability to convert its nuclear technology into nuclear weapons while promoting the peaceful use of nuclear energy."

14. Agreement for Cooperation Between the Government of the United States of America and the Government of Japan Concerning Peaceful Uses of Nuclear Energy, available from *nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/Japan_123.pdf.*

15. Tatsujiro Suzuki, "Japan's Plutonium Breeder Reactor and Its Fuel Cycle," *Fast Breeder Reactor Programs: History and Status, International Panel on Fissile Materials, 2010*, p. 56.

16. Used in the Nagasaki design, reactor-grade plutonium would most likely produce a yield of 1,000 tons of chemical explosive equivalent, vs. the 20,000-ton yield of the Nagasaki bomb. More advanced designs are insensitive to the grade of plutonium.

17. Citizen's Nuclear Information Center, "Long-Term Nuclear Program Planning Committee Publishes Costs of Nuclear Fuel Cycle," *Nuke Info Tokyo,* No. 103, November-December 2004, available from *www.cnic.jp/english/newsletter/nit103/.*

18. "History of Japan's Reprocessing Policy," Tokyo, Japan: Citizens Nuclear Information Center, available from *cnic.jp/english/newsletter/nit111/nit111articles/nit111rokkasho.html*.

19. At $130 per kilogram, the average price during 2009-2010, uranium contributed about $0.003 to the cost of a kilowatt hour. At $70/barrel, the cost of oil would contribute $0.085 to the cost of a kilowatt hour generated by an oil-fired power plant operating with 50-percent heat to electricity conversion efficiency.

20.*Framework for Nuclear Energy Policy*, Tokyo, Japan: Japan Atomic Energy Commission, 2005, p. 33, available from *www.aec.go.jp/jicst/NC/tyoki/taikou/kettei/eng_ver.pdf*.

21. "Long-Term Nuclear Program Planning Committee Publishes Costs of Nuclear Fuel Cycle."

22. "Report of Cost Estimate by the Federation of Electric Power Companies," *Nuke Info Tokyo,* No. 98, November 2003- February 2004, p. 10, available from *cnic.jp/english/newsletter/pdffiles/nit98.pdf*.

23. "Investing in Japan: Regional Information, Aomori Prefecture," Tokyo, Japan: Japan External Trade Organization (JETRO), available from *www.jetro.go.jp/en/invest/region/aomori/.*

24. The payments to Aomori Prefecture include 23,800 yen ($270) per kg of spent fuel imported into the prefecture. At 800 tons/year, that comes to about $200 million/year. Masafumi Takubo, "Wake Up, Stop Dreaming: Reassessing Japan's Reprocessing Program," *Nonproliferation Review,* Vol. 15, No. 1, 2008, p. 71.

25. *Japan's Spent Fuel and Plutonium Management Challenges,* Princeton, NJ: Princeton University, International Panel on Fissile Materials, 2006; Hisanori Nei, "Back End of Fuel Cycle Regulation in Japan," session 2A; and M. Kato, *et al*., "Activities Related to Safety Regulations of Spent Fuel Interim Storage at Japan,"Session 5A, "International Conference on Management of Spent Fuel from Nuclear Power Reactors," Vienna, Austria: IAEA, May 31–June 4, 2010, available from *www-ns.iaea.org/meetings/rw-summaries/vienna-2010-mngement-spent-fuel.htm.*

26. "Hamaoka Nuclear Power Station Replacement Plan," Chuden, Japan: Chubu Electric Power Co, 2008.

27. "Activities Related to Safety Regulations of Spent Fuel Interim Storage at Japan."

28. "Viability Assessment of a Repository at Yucca Mountain," *Total System Performance Assessment,* DOE/RW-0508/V3, Washington, DC: U.S. Department of Energy, 1998, pp. 4-23.

29. Ki-Chul Park, "Status and Prospect of Spent Fuel Management in South Korea," *Nuclear Industry*, August 2008 (in Korean).

30. Conventional PUREX reprocessing dissolves spent fuel in acid. Pyroprocessing dissolves it in molten salt.

31. Park Seong-won, Miles Pomper, and Lawrence Scheinman, "The Domestic and International Politics of Spent Nuclear Fuel in South Korea: Are We Approaching Meltdown?" Academic Paper Series, Washington, DC: Korea Economic Institute, March 2010. Dr. Park is a former vice president of KAERI. Pomper

and Scheinman are with the James Martin Center for Nonproliferation Studies.

32. The cores would be more pancake-shaped than cylindrical and would not be surrounded by uranium blankets to minimize the breeding of plutonium.

33. Jungmin Kang and H. A. Feiveson, "South Korea's Shifting and Controversial Interest in Spent Fuel Reprocessing," *Nonproliferation Review,* Spring 2001, p. 70.

34. Jungmin Kang *et al.*, "South Korea's Nuclear Surprise," *Bulletin of the Atomic Scientists*, January/February 2005, p. 40.

35. For the proposed dates of the pyroprocessing facilities, see Korea Atomic Energy Research Institute, Nuclear Fuel Cycle Process Development Division, available from *www.kaeri.re.kr/english/sub/sub01_04_02_02_01.jsp*. For the proposed date of the fast reactor demonstration plant, see Fast Reactor Technology Development Division, available from *www.kaeri.re.kr/english/sub/sub01_04_02_01_01.jsp*. For the capacity of the demonstration plant, I assume 0.6 GWe as proposed by KAERI in its KALIMER-600 design and a very low "conversion ratio" of 0.25, i.e., of production of new transuranic atoms per transuranic atoms fissioned.

36. Based on 40 GWe of light-water-reactor capacity projected for 2030, National Energy Committee, *The 1st National Energy Basic Plan* (2008-2030), 2008 (Korean). South Korea currently has 15 GWe of LWR capacity and 10 GWe under construction.

37. "The Domestic and International Politics of Spent Nuclear Fuel in South Korea: Are We Approaching Meltdown?"

38. *Ibid*.

39. Won Il Ko *et al.*, "Implications of the New National Energy Basic Plan for Nuclear Waste Management in Korea," *Energy Policy,* Vol. 37, 2009, p. 3484.

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which has copper canisters surrounded by bentonite clay emplaced in granite along tunnels spaced equal distances apart. Preserving the radioisotope retardation properties of the bentonite requires that it be wet, i.e., kept below a temperature of 100 oC. Both SKB and KAERI analyses show that the temperature peaks about 20 years after emplacement. Jan Sundberg *et al*., "Modeling of Thermal Rock Mass Properties at the Potential Sites of a Swedish Nuclear Waste Repository," *International Journal of Rock Mechanics and Mining Sciences*, Vol. 46, 2009, p. 1042; and S. K. Kim, "A Comparison of the HLW Underground Repository Cost for the Vertical and Horizontal Emplacement Options in Korea," *Progress in Nuclear Energy,* Vol. 49, 2007, p. 79. The thermal power output of spent fuel drops by a factor of more than 2 between 40 and 100 years after discharge. Roald A. Wigeland, "Separations and Transmutation Criteria to Improve Utilization of a Geologic Repository," *Nuclear Technology,* Vol. 154, April 2006, p. 95.

41. "Pyroprocess Technology," Daejeon, South Korea: KAERI, available from *www.kaeri.re.kr/english/sub/sub04_03.jsp*.

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48. "Nuclear Power in China," London, UK: World Nuclear Association, available from *www.world-nuclear.org/info/inf63.html*.

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