Ending plutonium separation:
An alternative approach to managing Japan's spent nuclear fuel*

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Executive Summary

Japan finds itself trapped in a spent fuel reprocessing policy that has insignificant resource conservation and radioactive waste management benefits and is becoming increasingly dysfunctional, dangerous and costly.

The policy is to start commercial reprocessing at the Rokkasho Reprocessing Plant, designed to separate about 8 tons of plutonium annually, at a time when Japan does not have a clear path forward for disposing of 44 tons of already-separated plutonium – enough to make more than 5000 Nagasaki-type bombs.

Weapon-useable separated plutonium is a magnet for would-be nuclear terrorists and, as the only non-weapon state that reprocesses, Japan is undermining the nonproliferation regime by setting an example that other states interested in a nuclear-weapon option – or even nuclear weapons – can emulate.

Operating the Rokkasho Reprocessing Plant will cost the Japanese people ¥8 trillion more over the life of the plant than not operating it and simply storing the spent fuel.

Like other advanced countries, Japan began reprocessing spent light water reactor fuel to recover plutonium to startup the uranium-efficient, liquid-sodium-cooled plutonium breeder reactors that were to be deployed by the thousands starting in the 1980s. As Japan has learned from its experience with its prototype breeder reactor, *Monju*, however, sodium-cooled reactors are much more costly and unreliable than water-cooled reactors. No country has succeeded in commercializing them.

With the failure of the breeder-reactor commercialization program, Japan decided to recycle its accumulating separated plutonium into mixed-oxide (MOX) uranium-plutonium fuel for light water reactors. This program too has failed thus far.

The major argument for operating the Rokkasho Reprocessing Plant today is the need to have an off-site destination for the spent fuel at Japan's nuclear power plants. The United States and most of the other countries that operate nuclear power plants avoid the costs and risks of reprocessing simply by moving older spent fuel into air-cooled dry casks when their spent fuel pools fill up. But Japan can't change its reprocessing policy without the central government and nuclear utilities making a number of difficult decisions at the same time. They must:

1. Persuade the prefectural and local governments that host Japan's nuclear power plants to allow onsite dry-cask storage. The central government and utilities have been promising for decades that spent fuel will be removed from the nuclear power plants to the Rokkasho Reprocessing Plant (RRP) as soon as it is cool enough to be shipped. Shipment has been delayed, however, because operation of RRP has been delayed for more than 15 years. The utilities therefore have steadily increased the density of spent fuel storage in the nuclear power plant pools.
2. Renegotiate with Aomori Prefecture and Rokkasho Village, which are accepting spent fuel from around Japan in exchange for the jobs provided for construction and operation of the RRP and the associated mixed-oxide (MOX) uranium-plutonium fuel fabrication facility and other operations, and for the spent-fuel-related tax and grant

income that provides one half of the total revenue of the government of Rokkasho Village and one seventh of the tax income of Aomori Prefecture.

If the prefectures that host the nuclear power plants are willing to allow on-site storage as an alternative to reprocessing, then Aomori Prefecture will be forced to bargain to retain the current benefits it is receiving in exchange for providing central interim storage of spent fuel without reprocessing.

3. Change the law governing the national Reprocessing Fund to allow continued payment of the loans used to pay for the Rokkasho Reprocessing Plant even if a decision is made not to start its commercial operation. Under the current law the Fund will repay the bank and utility loans made to Japan's Nuclear Fuel Limited only if JNFL maintains its commitment to operate RRP. During the Noda Administration, a serious and honest public debate over the possibility of changing Japan's reprocessing policy was prevented by the secret concern that, if the reprocessing plan was cancelled, the banks would demand repayment of their loans and potentially cause the bankruptcy of some of the nuclear utilities that guaranteed JNFL's loans.
4. Concede that, contrary to the repeated claims of the Ministry of Economy, Trade and Industry (METI), recycling plutonium in light water reactor fuel does not make the radioactive waste significantly less dangerous or easier to dispose of.
5. Accept that the central government will be responsible for disposal of spent fuel. In both the United States and the United Kingdom, decisions by the governments to take this responsibility were key to making possible the abandonment of reprocessing by the utilities. Japan's reprocessing policy is too complicated to be changed incrementally.
6. Directly dispose of Japan's 44 tons of already separated plutonium instead of trying to force public acceptance of the use of MOX fuel in Japan's nuclear power plant.

Introduction

After the Fukushima nuclear accident of March 2011, the Noda administration's review of Japan's nuclear power policy resulted in two decisions:

1) Shut down Japan's nuclear power plants by the end of the 2030s, and

2) Continue with the plan to start operations at the Rokkasho Reprocessing Plant in 2013.

The Abe administration reversed the nuclear phase-out decision but maintained the policy of going forward with reprocessing.

It is remarkable that two administrations that disagreed totally about the future of nuclear power in Japan did not disagree on the need to continue reprocessing, an area where Japan's policy differs from almost all other countries with nuclear power plants. Japan is the only non-nuclear-weapon state that reprocesses – despite the efforts of the United States, over almost four decades to persuade Japan to join the U.S. in abandoning reprocessing for nonproliferation reasons. Japan has accumulated 44 tons of separated plutonium and now plans to separate annually an additional 8 tons.

Plutonium is a nuclear weapon material and separating it makes no sense economically. In spent fuel, it is virtually inaccessible, but separated plutonium is an attractive target for would-be nuclear terrorists. The 8 tons that Japan plans to separate annually would be sufficient to make one thousand Nagasaki-type bombs.

Countries can use "civilian" reprocessing to mask efforts to obtain nuclear-weapon options. That is what India did in the late 1960s and early 1970s. A number of other countries, including South Korea, started down that same path but political pressure from the United States and internal political change resulted in their programs being cancelled before they reached fruition. Japan, by persisting, in reprocessing, is, however, providing legitimacy for South Korea to reassert its right to reprocess at a time when nuclear threats from North Korea have stimulated a demand within South Korea for its own nuclear deterrent.

Reprocessing makes no sense economically. Despite the huge cost of separating plutonium, it has negative value as a fuel. According to calculations made by Japan's Atomic Energy Commission in 2011, the cost of reprocessing will more than double the cost of Japan's spent fuel management, including the cost of disposal of the radioactive wastes produced by reprocessing, compared to simply storing the spent LEU fuel and disposing of it directly.[1] This is why, of the thirty-one countries that have nuclear power as part of their energy mix, only France and Japan reprocess on a large scale for recycle of the plutonium in light water reactors.[2]

In France, Électricité de France (EDF) has its fuel reprocessed by AREVA only because the government insists. Rather than signing a new reprocessing contract, EDF recently extended the term of its 2009-2012 reprocessing contract only through 2013.

In 1993, when one of us (FvH) met with the nuclear fuel cycle managers of TEPCO and KEPCO, he was told that they felt "trapped" into reprocessing. When he asked whether they would choose reprocessing over spent fuel storage again, the response was "never!"

The "trap" was constructed, starting in the 1960s, with the law on Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors, which required that an application

for construction of a new nuclear power reactor specify “the method of spent fuel disposal”. It also required that the application should not lead to "hindrance of the execution of the planned development and use of nuclear power." The government’s Long-Term Plans for nuclear energy made clear that the development of nuclear power in Japan required reprocessing. [3] Thus reprocessing was made an obligation for utilities.

In June 2012, at the same time as language was inserted to establish the Nuclear Regulation Agency, the law was revised to remove the requirement for reprocessing.[4] However, the Designated Radioactive Waste Final Disposal Act still does not list spent fuel among the types of wastes to be put into a geological disposal site. It includes only vitrified high level and transuranic waste from reprocessing and MOX fuel production.

Even if that omission were fixed, the nuclear utilities would still be trapped into reprocessing by other constraints:

- In most cases, they do not have consent from prefectural and local governments to build dry cask spent fuel storage at their nuclear power plants because their plan has been to ship spent fuel to a reprocessing plant after it has cooled a few years; and
- They have guaranteed and made loans to build the Rokkasho Reprocessing Plant that will only be repaid if their commitment to the plant’s operation is maintained.

METI claims reprocessing has environmental advantages. One is that reprocessing and plutonium and uranium recycle is uranium conserving. The net savings of uranium resulting from plutonium and uranium reuse in light water reactor fuel would be up to 25 percent in a best-case scenario that has not yet been achieved anywhere. But similar savings would be possible at one tenth the cost by increasing the percentage of U-235 extracted from natural uranium when uranium is enriched.[5]

In any case, most plutonium use programs have failed. Even in France, by far the world leader in MOX use, the national stockpile of separated civilian plutonium has increased from about 1 ton in 1988 to 57.5 tons as of the end of 2011.[6]

Of the 41 tons of plutonium Japan had separated in Europe – mostly during the 1990s thirty four tons still remain unused in Europe. Only 2.5 tons have been loaded into Japan’s reactors as MOX fuel. At Rokkasho, 3.6 tons of separated plutonium from a test run of the reprocessing plant are in storage while construction on a MOX fuel production plant has only recently begun. Why then is Japan Nuclear Fuel Limited (JNFL) hurrying to launch plutonium separation operations at Rokkasho?

Independent analysts asked the same question of the UK Government 20 years ago when it gave permission to British Nuclear Fuels Limited to begin reprocessing operations at its new Thermal Oxide Reprocessing Plant (THORP). In his book, *Nuclear Entrapment*, William Walker discusses the domestic and foreign bureaucratic forces that drove the UK government to this decision. His words could be applied with only minor changes to Japan’s plan to start operating the Rokkasho Reprocessing Plant in FY2013:[7]

> One of Britain’s largest industrial facilities was being turned on to provide plutonium that was no longer needed or wanted and whose stockpiling was considered by many to endanger international security. This was a facility which would give rise to significant risks and liabilities; which was “serving” customers several of whom wished to escape their commitments; whose construction had been – and operation would be – funded through

> surcharges and taxes on electricity consumers … and whose successful operation depended upon governments and other actors sorting out problems…for which there were no assured solutions.

The UK – like Japan today – had already separated about 50 tons of civilian plutonium. As of the end of 2011, the amount of separated plutonium in storage in the UK had increased to 118 tons of which 90 tons were its own, 17 tons belonged to Japan, with the remainder belonging to an assortment of European utilities. The UK finally decided to end its reprocessing program in 2011 and is now facing the question of what is to be done with the plutonium that it separated at such great cost.

By starting the Rokkaho Reprocessing Plant without an operating MOX plutonium disposal program – or even a clear plan for restarting its shutdown reactors – Japan would be proceeding blindly down the same road.

In what follows, we examine:

1. Japan's accumulation of weapon-usable plutonium and its failure thus far to dispose of much of it in MOX fuel;
2. The spent-fuel storage problem that drives Japan's reprocessing policy;
3. The claimed radioactive waste management benefits of reprocessing;
4. The alternative, on-site dry cask storage, which has been adopted by most of the other countries with nuclear power plants;
5. The need to repay JNFL's debts from the money in Japan's Reprocessing Fund;
6. The likely need to centralize control over spent fuel management in Japan if a policy shift away from reprocessing is to be accomplished; and
7. Alternative options for disposing of Japan's already separated plutonium.

The dream of plutonium breeder reactors

Japan's reprocessing program originated in the 1960s and 1970s as part of an effort by the industrialized countries to commercialize uranium efficient plutonium breeder reactors. The plutonium in the spent fuel of water-cooled reactors was to be extracted to provide startup fuel for breeder reactors.

Later, in the 1980s and 1990s, when it was understood that low-cost uranium was more abundant than originally predicted and that liquid-sodium-cooled breeder reactors would not be able to compete in cost or reliability with existing water-cooled reactors, the United States and most European countries decided to abandon reprocessing. Three countries, however, continued with programs to reprocess virtually all their spent fuel: France, Japan and the United Kingdom. India and Russia continued to reprocess on a smaller scale to support continuing breeder reactor R&D programs and, in 2010, China launched civilian reprocessing on a pilot scale in support of a breeder reactor R&D program.

France and the U.K. each built a second reprocessing plant in the 1980s, primarily to reprocess foreign fuel from Japan and Germany. Neither the foreign or domestic customers of the UK's THORP reprocessing plant have renewed their contracts, however.

The last domestic Magnox reactor, whose fuel is reprocessed in the UK's older B-205 reprocessing plant is scheduled to shut down this year. Both the UK reprocessing plants therefore will shut down in a few years after they have dealt with their backlogs.

Of all of France's foreign reprocessing customers, only the Netherlands has renewed its contract for one small aging reactor. The future of reprocessing in France therefore is now the subject of a battle between two huge government-owned companies: Électricité de France, which wants to reduce its operating costs, and the national nuclear services company, AREVA, which operates the reprocessing plants. One consideration that is keeping reprocessing alive in France is that AREVA has been making a major effort, supported by successive presidents of France, to sell China a €20 billion reprocessing plant similar to the AREVA-designed Rokkasho Reprocessing Plant. AREVA also has not given up hope of selling the U.S. a similar reprocessing plant.

Japan's growing stock of separated plutonium

About 41 tons of Japanese plutonium were separated in French and UK reprocessing plants, mostly during the 1990s. The original plan was to ship the plutonium back to Japan for use in Japan's fast-neutron breeder reactor (FBR) program. After the FBR program stalled, however, it was decided to fabricate the plutonium into MOX fuel in Europe and ship it back to Japan to be used in 16 to 18 of Japan's light-water power reactors.

The first shipment of MOX fuel from Europe, in 1999, was a combined shipment from France and the UK. Before the fuel was loaded into reactors, however, it was discovered that workers in the UK MOX pilot fuel fabrication plant had falsified the quality control measurements of the diameters of some of the MOX fuel pellets and the fuel was sent back to the UK.

The UK's commercial Sellafield MOX Plant (SMP), which began operations in 2001, proved to be able only to operate at an average of one percent of design capacity and the small amount of fuel that it did produce was shipped to European customers. On 30 April 2010, Japan's ten nuclear utilities, by then the sole remaining customers of SMP, agreed to fund the effort to increase its throughput. After the Fukushima accident, however, the UK Nuclear Decommissioning Authority (NDA), decided to abandon the SMP in light of "the changed commercial risk profile for SMP arising from potential delays following the earthquake in Japan and subsequent events".[8]

In 2010, TEPCO finally obtain consent from Fukushima Prefecture to load its 1999 shipment of MOX fuel into Fukushima Daiichi unit #3. In 2001 France shipped MOX fuel for TEPCO's Kashiwazaki Kariwa unit #3 but the fuel was never loaded. The MOX fuel in the third and fourth shipments from France, which arrived in 2009 and 2010, fared better. Some was loaded into three of the five intended reactors (Genkai #3, Ikata #3 and Takahama #3) but the fuel intended for the other two reactors (Hamaoka #4 and Takahama #4) was not.

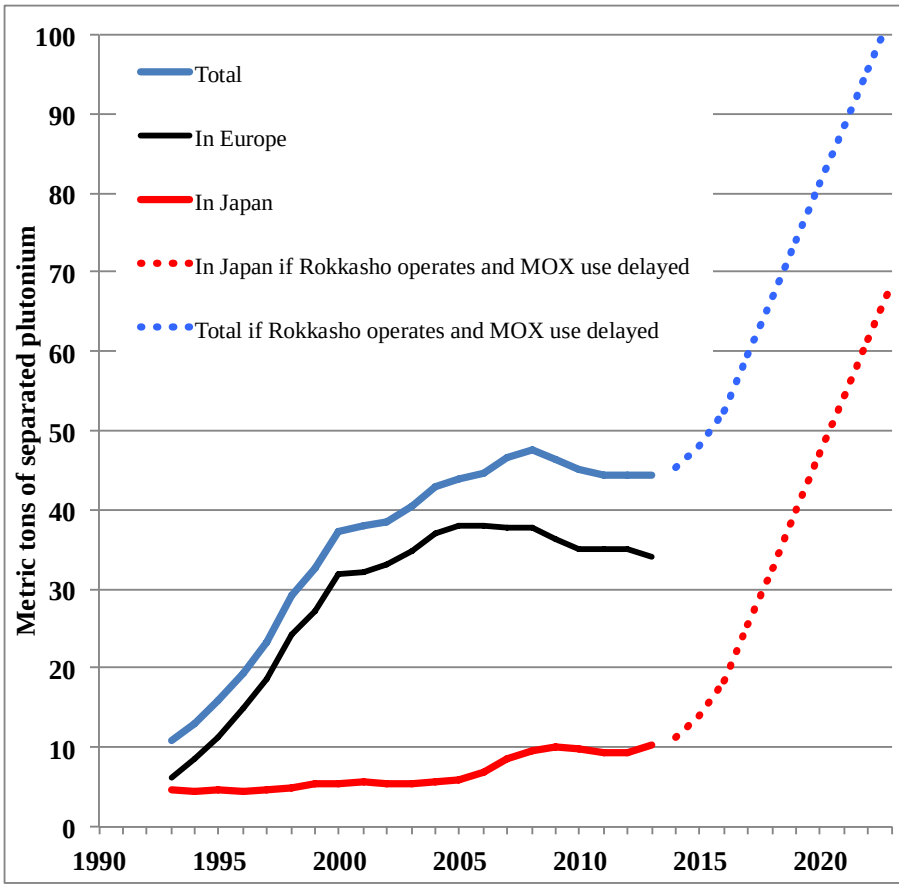

Figure 1. **Japan's stockpile of separated plutonium** grew in the 1990s and early 2000's primarily due to reprocessing of Japan's spent fuel in Europe. During 2006-8, test operations at the RRP separated 3.6 tons of plutonium but then were halted because of an inability to solidify the liquid high-level waste. In 2013, France shipped 0.9 tons of plutonium in MOX fuel to Japan. Japan Nuclear Fuel Limited's (JNFL's) most recent (31 Jan. 2013) plan is to start operations at the RRP in the latter half of fiscal year 2013.[9] We assume that plan will be delayed by nine months but that otherwise, in accordance with JNFL's plan, 1 ton of plutonium will be separated in calendar 2014, 2.9 tons in 2015, and 4.4 tons in 2016.[10] We assume that thereafter the RRP, operating at its design capacity of 800 tons of spent fuel per year, will separate 7.2 tons of plutonium annually.[11] If this plan is carried out and the MOX program continues to be stalled, Japan's total stockpile will rise to about 100 tons within ten years.

In total therefore, as of the time of the Fukushima Daiichi accident, 3.5 tons of plutonium in MOX fuel had arrived from France and 2.5 tons had been loaded into four reactors, one of which had (coincidentally) suffered a core meltdown.

After the accident, on 27 June 2013, MOX fuel estimated to contain another 0.9 tons of plutonium arrived at the Takahama plant after two-month voyage from France. Like other Japanese nuclear utilities intent on getting consent from prefectural and local governments to restart their reactors, however, the owner of the plant, KEPCO, had no immediate plans to use MOX fuel.

During 2006-2008, the stockpile of separated plutonium in Japan was increased by 3.6 tons as a result of a test run of the Rokkasho Reprocessing Plant. That test revealed a

technical problem with vitrification (solidification in glass) of the high-level radioactive waste. JNFL now believes that the problem has been solved and hopes to declare the plant operational in October 2013 and begin operations in the second half of fiscal year 2013 (Oct. 2013-March 2014). This plan most probably will be delayed, however, because Japan's new Nuclear Regulation Authority (NRA) has announced that it will not be able to review the safety of RRP until after its new safety regulation rules for nuclear fuel cycle facilities are finalized in December 2013.

Although the J-MOX plant, where plutonium separated at the RRP is to be made into MOX fuel is still scheduled to start operations in March 2016, construction work was delayed for about one year by the Fukushima accident with construction of the building only starting in Oct. 2012. Assuming a multi-year construction delay typical of such projects, any additional plutonium separated at Rokkasho during the next several years will simply go into storage.

Reactor-grade plutonium is weapon-usable.

Although some reprocessing advocates still continue to deny it, power reactor plutonium can be used to make nuclear weapons. By the IAEA's metric of 8 kg for a Nagasaki-type nuclear explosive, the 44 tons currently in Japan's stockpile is enough for more than 5,000 nuclear explosive. This is of concern for Japan's neighbors and also the United States. In a speech during his visit to South Korea for the Seoul Nuclear Summit in March 2012, President Obama urged[12]

> We simply can't go on accumulating huge amounts of the very material, like separated plutonium, that we're trying to keep away from terrorists.

More recently, in April 2013, Vice Chairman of the JAEC, Tatsujiro Suzuki, reported that, during his visit to Washington early that month, two high-level Obama Administration officials had made pointed comments to him about Japan's reprocessing plans:[13]

- Thomas Countryman, Assistant Secretary of State for Nonproliferation, stated that, for Japan to operate the Rokkasho Reprocessing Plant could undercut US nonproliferation efforts with Iran and its efforts to persuade South Korea not to reprocess.
- Deputy Energy Secretary, Daniel Poneman expressed deep concern that reprocessing without a credible plutonium use program would further increase Japan's stock of separated plutonium.

In Sept. 2012, Poneman pointed out to emissaries from the Noda Administration the inconsistency in the Noda administration's nuclear policy.[14] One cannot reject nuclear power and embrace reprocessing at the same time:

1. If nuclear power is abandoned, reprocessing must also be abandoned because use of the separated plutonium in reactor fuel would become impossible.
2. Conversely, if a policy of plutonium separation is adopted, nuclear power must continue in order to provide a use for the plutonium.

This message never was transmitted clearly to Japan, however. Instead, some have turned Poneman's support of nuclear power and fast reactor research and development into the message that "the US wants Japan to reprocess."

Japan's spent fuel storage problem as a rationale for continuing reprocessing

A major driver that keeps reprocessing alive in Japan is the limited spent fuel storage at Japan's nuclear power plants. This is a self-perpetuating situation, however. Japan's nuclear utilities have not moved to expand on-site storage because of their plans to send spent fuel off site for reprocessing.

Table 1 shows the current situation at each of Japan's nuclear power plants. According to METI's projection, if they are allowed to resume operation, three of Japan's nuclear power plants could run out of storage space after three years. Two have about 15 years of space. Eventually, however, all the pools at operating reactors would fill up.

Utility	**Plant**	**Net generating capacity** (Gwe)	**16 month fuel reload** (tonnes U)	**Spent fuel stored** (31March2013) (tonnes U)	**Total available capacity** (tonnes U)	**Years till full**
Hokkaido	Tomari 1-3	1.97	50	400	1020	16.5
Tohoku	Onagawa 1-3	2.09	60	420	790	8.2
	Higashidori 1	1.07	30	100	440	15.1
TEPCO	Kashiwazaki-Kariwa 1-7	7.97	230	2,370	2,910	3.1
Chubu	Hamaoka 3-5	3.47	100	1,140	1,740	8.0
Hokuriku	Shika 1-2	1.61	50	160	690	14.1
KEPCO	Mihama 1-3	1.57	50	390	680	7.7
	Takahama 1-4	3.22	100	1,150	1,730	7.7
	Ohi 1-4	4.49	110	1,420	2,020	7.3
Chugoku	Shimane 1-2	1.22	40	390	600	7.0
Shikoku	Ikata 1-3	1.92	50	610	940	8.8
Kyushu	Genkai 1-4	3.31	90	870	1,070	3.0
	Sendai 1-2	1.69	50	890	1,290	10.7
JAPC	Tsuruga 1-2	1.45	40	580	860	9.3
	Tokai Daini	1.06	30	370	440	3.1
Total		38.11	1,080	11,260	17,220	7.4

Table 1. Spent fuel stored and total available capacity for spent fuel at each of Japan's nuclear power plants as of the end of March 2013. The Fukushima I and II nuclear power plants are not shown – presumably because METI does not expect them to restart. The 16-month reloads shown in METI's estimates appear to be for an average burnup of 36.5 GWt-days/ton. Current burnups in Japan are typically 45-50 GWt-days/ton.[15] The rate of spent-fuel discharge used by METI is therefore high by a factor of about 1.3 and, with current burnups, the remaining years of storage capacity would be correspondingly longer

Instead of doing something about Japan's spent fuel storage situation, Japan's Atomic Energy Commission (JAEC) has been arguing for more than eight years that it would take too long to persuade prefectural and municipal governments to allow expanded on-site storage at the nuclear power plants. In 2005, in its long range plan for nuclear energy in Japan, the JAEC argued:[16]

> "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."

This argument has been reinforced by threats from the governments of Aomori Prefecture and Rokkasho Village that, if the Rokkasho Reprocessing Plant (RRP) is not operated, they will demand that the approximately 3,000 tons of spent fuel currently in the RRP intake storage pool be returned to the nuclear power plants.

Aomori Prefecture also has threatened that, if the RRP is not operated, it will block use of an interim spent fuel storage facility being completed nearby by TEPCO and JAPC. The facility is designed to store initially 3,000 tons and later 5,000 tons of spent fuel from reactors belonging to the two companies – but only on the understanding that the stored fuel eventually will be reprocessed.[17]

It is doubtful that either of these threats would be carried out if Japan indefinitely suspended reprocessing or abandoned it and began to expand spent fuel storage at the reactor sites because, in the absence of operation of the Rokkasho Reprocessing Plant, Aomori Prefecture has shifted its nuclear taxes to spent fuel storage.

In any case, reprocessing has become an extravagantly expensive alternative spent-fuel storage policy. Instead of the older cooler spent fuel being stored in dry casks as in other countries, in Japan, it is to be separated into uranium, plutonium, radioactive wastes that are to be stored in separate locations at the Rokkasho complex of JNFL. Of course, this is not the way in which reprocessing is being represented to citizens of Aomori Prefecture or of Japan as a whole. The public is being told that reprocessing creates the equivalent of a domestic energy source and makes Japan more self-sufficient by reducing its uranium imports by up to 25 percent[18] and also that MOX use reduces the long-term radioactive hazard from spent fuel.

Does reprocessing enable reductions in radioactive waste volume and toxicity?

Japan's Ministry of the Economy, Technology and Industry (METI) argues that reprocessing and the use of MOX fuel in light water reactors (LWRs) and eventually in sodium-cooled fast-neutron reactors would have important waste-management benefits:[19]

1. The volume of high-level waste would be reduced to about 1/4 and 1/7 by plutonium recycle in LWRs and fast-neutron reactors respectively.
2. The time required for the toxicity of the high-level waste to decay to the same level as the original natural uranium would be reduced from about 100,000 years to 8,000 years and 300 years respectively.

Calculations for the case of France have shown, however, that, if *all* the radioactive waste streams from reprocessing and MOX fuel fabrication that require deep burial are included,

the volume of waste is the same as that of the original spent fuel, within uncertainties.[20] Furthermore, the area of a deep geological repository is determined not by the volume of the waste but rather by its heat output. Here too, reprocessing and MOX fuel use in light water reactors have negligible benefit since spent MOX fuel, which would most likely be placed in the repository, would have about as high a long-term heat output as the low-enriched uranium spent fuel from which it had been produced.[21]

Plutonium recycle in LWRs does not greatly reduce the long-term hazard from spent fuel either. The irradiation of MOX fuel typically reduces the amount of plutonium in the MOX only by about 40 percent, including the plutonium that would have been produced in the low-enriched uranium fuel that otherwise would have been used.[22] Trying to reduce the plutonium further with multiple recycles in light water reactors would become increasingly difficult as the percentage of isotopes that are not fissionable with the slow neutrons that mediate the chain reactions in light water reactors would increase

Separation of plutonium and other transuranic elements and their repeated irradiation in sodium-cooled fast neutron reactors such as *Monju could* over hundreds of years reduce the total amount of plutonium and other transuranic elements in waste to a few percent of the amount in LWR spent fuel. The cost would be huge, however. A major U.S. National Academy of Sciences (NAS) review concluded that "none of the dose reductions seem large enough to warrant the expense and additional operational risk of transmutation".[23] In addition to the operational risk, there are of course the much more significant risks of nuclear proliferation and nuclear terrorism.

In any case, there are no firm plans yet, even in France, to separate out and use in fast reactor fuel the plutonium in spent MOX fuel. Despite about $100 billion spent promoting their commercialization, only a few pilot and prototype fast reactors exist in the world today.[24] It therefore would be foolish to separate even more plutonium now on the assumption that fast neutron reactors will be built in significant numbers some time in the future.

Dry cask storage as an alternative to reprocessing

In countries such as the United States, which have abandoned reprocessing, when their spent fuel pools fill up, the fuel that has cooled longest in the pools is moved into massive air-cooled casks – usually on the nuclear power plant sites.

The nuclear industry around the world considers dry storage a low-cost mature technology. In Germany, after an agreement between the German government and utilities in 2000 to end shipments of spent fuel to France and the UK for reprocessing by mid-2005, every single operating nuclear power plant quickly built on-site, air-cooled dry cask storage to make space in the pools for the continued discharge of spent fuel. Figure 2 shows two examples.

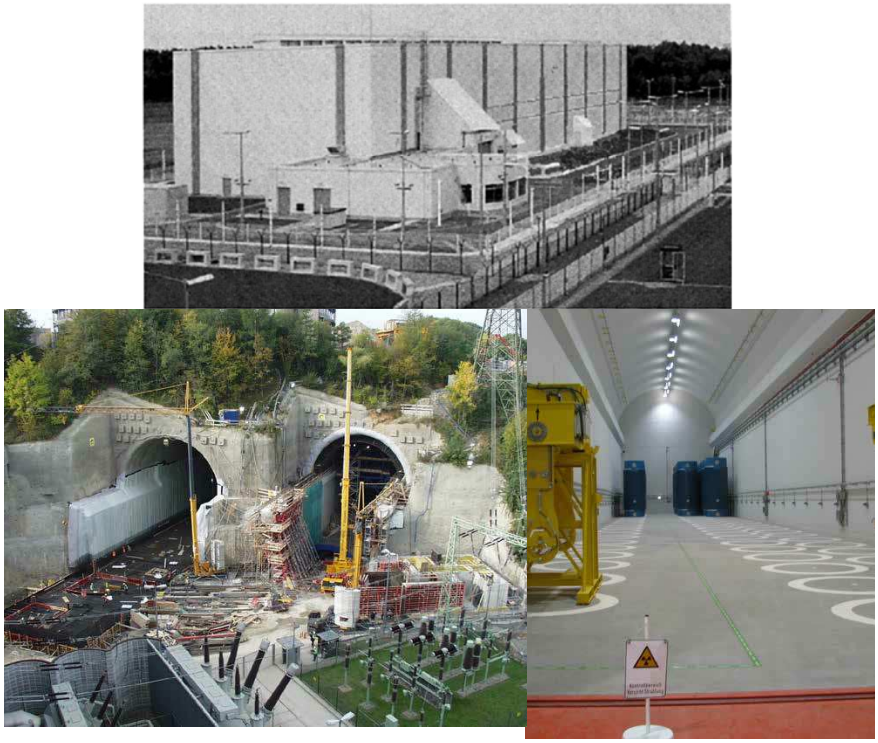

Figure 2. Above, the dry-cask storage building at the Emsland Nuclear Power Plant (NPP), Germany. Below, storage tunnels under construction (left) and with the first casks emplaced (right) at the Neckar-Westheim NPP, Germany, where there was not enough space for a new building.

Japan is different from the United States and perhaps other countries in that its nuclear utilities have "gentlemen's agreements" that require prefectural and local government consent to the restart of nuclear power plants at the beginning of each 16-month operating cycle (13 month operation and three month shutdown for inspection). As a result of the March 2011 accident at Fukushima Daiichi, as of mid-2013, all but two of Japan's nuclear power reactors have been shut down. To restart, they will first require permission from the Nuclear Regulation Authority (NRA) under its new safety regulations of July 2013. Even after the NRA approves applications for restart, however, the consent of prefectural and local governments also will be required.

The present moratorium on operation of nuclear power reactors in Japan resulted from safety concerns after the Fukushima Daiichi accident. Moving older spent fuel from pool into dry cask storage would not increase safety risks at the reactor sites. Indeed, Shunichi Tanaka, in his first press conference as chairman of the Nuclear Regulation Authority, urged that spent fuel more than five years since discharge be moved into dry casks:[25]

> "Spent fuel not requiring active cooling should be put into dry casks … for five years or so cooling by water is necessary… I would like to ask utilities to go along those lines as soon as possible."

If the central government made a firm decision to end reprocessing and the prefectures were convinced that the nuclear power plants that they host are safe, it seems unlikely that the plants would be shut down over the issue of dry cask spent fuel storage.

The real concern that the prefectures would have about expanding on-site storage would be that, with no prefecture willing to host a geological repository or interim off-site storage of spent fuel, on-site interim storage might become permanent.

Japan, like other countries, needs a credible strategy for moving forward with spent fuel and high-level-waste disposal. The search for a repository site was initiated in Japan's 2000 Radioactive Waste Final Disposal Act, which established the Nuclear Waste Management Organization (NUMO). In December 2002, NUMO started soliciting applications from local communities to host a geological repository for vitrified high-level waste that would be at least 300 meters underground. One community volunteered, but then withdrew because of local political opposition.

The lack of progress in geological repository siting does not, however, require reprocessing either technically or politically. In Germany, the United States and many other countries, with no near-term path forward for siting a geological repository or a central storage facility, on-site dry cask storage has nevertheless been chosen over of reprocessing.[26]

Currently, the Rokkasho complex is Japan's interim storage site. It now stores about 3,000 tons of spent fuel. It also stores Japan's high level waste from reprocessing in Europe. Finally, it also stores the plutonium, uranium and radioactive waste from the reprocessing of 425 tons of spent fuel during test operation of the Rokkasho Reprocessing Plant (RRP) in 2006-8. If the RRP operates, these stocks of separated materials will increase rapidly.

Aomori Prefecture probably understands today that the central government may not be able to fulfill its promise that radioactive waste will stay in Aomori Prefecture for no more than 50 years. The prefecture is willing to accept the situation, however, because of its past commitments and the economic benefits:

- Fourteen hundred Aomori residents directly employed by JNFL plus almost twice as many indirectly on construction and later operational jobs for the J-MOX fuel fabrication facility;[27]
- The taxes that JNFL pays to the prefectural government for importing and storing spent fuel in the prefecture. This accounts for most of the prefecture's "nuclear fuel taxes," which totaled ¥16 billion or 14% of the Prefecture's total tax income in Fiscal Year (FY) 2012; [28] and
- The large central government grants that Rokkasho Village receives (¥2.6 billion in FY 2011) in addition to the property taxes and contributions from JNFL that in total amount to half of its income. [29]

Would Aomori be willing to continue to provide interim storage for Japan's nuclear wastes if operations of the RRP were indefinitely suspended or a decision to shut it down were made? The reality that the Prefecture is an interim storage site would not change. In fact, because the operations at Rokkasho have been so long delayed, Aomori has already shifted its "nuclear fuel taxes" to the amount of spent fuel stored from the amount of spent fuel brought in for reprocessing each year. But it would be necessary to face the fact that, ever since 1997 at the latest, when the emphasis for plutonium use shifted to

recycling the separated plutonium back into light water reactors, reprocessing has not been a meaningful enterprise .

The central government should negotiate fairly with Aomori Prefecture and Rokkasho Village about their choices between the economic benefits of continuing to serve as Japan's interim storage site for high-level waste and spent fuel in dry casks and the loss of those benefits. Alternative economic development assistance also could be offered.

If a decision is made not to operate the Rokkasho Reprocessing Plant the prefectures and municipalities that host Japan's nuclear power plants also would be faced with a choice: either accept on-site dry-cask storage, which is safer than pool storage, or lose the tax and other economic benefits of hosting operating nuclear power plants when their spent fuel pools fill up. Whether or not the prefectures hosting nuclear power plants will agree to have the spent fuel in the RRP intake pool shipped back to their nuclear power plants is a separate matter.

Paying off the RRP loans with Reprocessing Fund money

A problem that helped prevented serious consideration of a change in Japan's reprocessing policy is the legal requirement that money in the national Reprocessing Fund can be used only for reprocessing-related purposes. If Japan's commitment to reprocessing is abandoned, the money in the Reprocessing Fund will be frozen and Japan Nuclear Fuel Ltd (JNFL) will not be able to pay back the bank loans used to help finance the construction of the RRP – currently about ¥800 billion, down from ¥1.1 trillion in 2005. The nuclear utilities have guaranteed the loans. In addition, the nuclear utilities that own JNFL will not be able to recover from the Fund their prepayments (i.e, direct loans) for reprocessing services made before the Reprocessing Fund was established. The outstanding amount of these loans is currently at ¥654 billion, down from ¥1.1 trillion in 2005. Given the currently delicate financial condition of some of the nuclear utilities, some in the nuclear industry warned that a halt in payments from the Reprocessing Fund could drive some of the utilities into bankruptcy and result in chaos in Japan's financial markets.

This problem may have been exaggerated because most of the bank loans to JNFL (84% in March 2006) were from the government-owned Development Bank of Japan, which would be unlikely to force JNFL or the nuclear utilities into bankruptcy against the wishes of the government. [30]

In any case, the government could solve the problem by changing the law controlling payments from the Reprocessing Fund and making it possible for the loans and prepayments to be repaid even if the Rokkasho Reprocessing Plant is shut down. In the long run, this would save money for the ratepayers. It therefore could be a part of a comprehensive package of policy changes to allow reprocessing in Japan to end.

A government takeover of spent fuel management

Currently, responsibility for managing spent fuel in Japan is shared between the central government (the Diet and METI), nine regional semi-monopolistic nuclear utilities, and the Japan Atomic Power Company, which is owned by the nine utilities:

- The central government provides the general policy framework.
- Japan Nuclear Fuel Limited is responsible for spent fuel reprocessing. The company owned primarily by the ten nuclear power utilities; its head is a former TEPCO director of public relations and the chair of its board is the president of KEPCO.
- The Nuclear Waste Management Organization (NUMO), a non-governmental organization established by law, is responsible for siting and building a geological repository for radioactive waste. It is led by a former TEPCO Managing Director of nuclear power and plant siting..[31]
- The Radioactive Waste Management Funding and Research Center (RWMC), a non-governmental organization set up by law, manages the funds for reprocessing and high-level waste disposal and is responsible for research on geological disposal. It is led by a former TEPCO General Manager for Nuclear Power and Plant Siting,[32]

To be able to change Japan's dysfunctional reprocessing policy, the central government may have to take more direct control. In the UK and U.S., the governments took increased responsibility for spent fuel management as part of the process of abandoning reprocessing.

United Kingdom. In the United Kingdom, from 1971 to 2005, reprocessing was managed by the government-owned British Nuclear Fuel Services Limited (BNFL). In 2005, in the absence of a renewal of the foreign reprocessing contracts and facing rising operating costs, the UK Government decided to establish the UK Nuclear Decommissioning Authority (NDA) to take over BNFL's sites and the responsibility for cleaning them up, disposing of the spent fuel from the U.K.'s first and second generation gas-cooled power reactors, and establishing a geological repository for radioactive waste and spent fuel. In 2011, the NDA decided formally on economic grounds to phase out reprocessing in favor of interim storage and direct disposal of spent fuel.[33]

United States. In the United States, before 1977, civilian reprocessing was expected to be a profitable business for private companies. Nuclear Fuel Services operated a small reprocessing plant in New York State from 1966-72. General Electric embarked on the construction of another plant in Illinois in 1967 but realized in 1972 that the design was fundamentally flawed and converted the plant into a spent-fuel storage facility. Allied General Fuel Services began construction of a third reprocessing plant in South Carolina in 1970 but, after India's 1974 "peaceful nuclear explosion", the Carter Administration suspended the licensing process in 1977 out of concern that the U.S. example could help legitimize the construction of reprocessing plants in additional countries.

In 1981, President Reagan announced that his Administration would resume the licensing of private reprocessing plants in the U.S. By that time, however, U.S. nuclear utilities had realized that plutonium and uranium recycle would not be economical and decided that they would prefer that the federal government take responsibility for disposal of their spent fuel.[34] The following year, Congress passed the Nuclear Waste Policy Act (NWPA) under which the Department of Energy took responsibility for spent fuel disposal in exchange for a fee of $0.001 (~ ¥0.1) per nuclear kilowatt hour – about one tenth the cost estimated by the JAEC of reprocessing in Japan. In the wake of the political failure of the proposed geological repository under Yucca Mountain, Nevada, Congress is considering

a proposed law that would move the responsibility for siting and constructing central spent fuel storage facilities and a geological repository from the Department of Energy to a new specialized government agency, the Nuclear Waste Administration.

If Japan's utilities are to escape from their reprocessing "trap," the Government of Japan will probably similarly have to take full responsibility for spent fuel disposal.

Alternatives to MOX for plutonium disposal

As of the end of 2011, Japan owned about 44 tons of separated plutonium stored in the UK, France and Japan (Table 2).

Japan's unirradiated plutonium (end of 2011)	**Metric tons**
In the United Kingdom	17.0
In France	18.0
Subtotal in Europe	*35.0*
In Japan	
–At Rokkasho in solution or oxide form	3.6
–At Tokai reprocessing facility in solution or oxide form	0.8
– Oxide form, in fabrication, fuel product at Tokai fuel fabrication facility or unirradiated fabricated fuel stored at the *Joyo, Monju* and *Fast Critical Assembly facilities*	4.0
–In unirradiated MOX fuel from France	1.0
Subtotal in Japan	*9.3*
Total	**44.3**

Table 2. Japan's unirradiated plutonium as of the end 2011[35]

In the United Kingdom. As of the end of 2011, seventeen tons of Japan's separated plutonium were stored at the UK's Sellafield reprocessing site. The UK had contracted to convert this plutonium into MOX fuel for use in Japan's nuclear power plants. Following the failure and abandonment of the Sellafield MOX Plant, however, the UK offered to take ownership and dispose of Japan's plutonium "subject to commercial terms that are acceptable to UK Government,."[36] The UK is currently thinking of disposing of its own 100 tons of separated plutonium in light water reactor MOX fuel but would have to build both a new MOX fuel fabrication plant and light water reactors to use the fuel before it can proceed.

Figure 3. **Proposed technology for immobilization of impure plutonium in the United Kingdom.** The container at the left is filled with powdered material. For plutonium disposal, it would be a mixture of plutonium, calcium, zirconium and titanium oxides. On the right, after 8 to 9 hours of hot isostatic pressing, the powder has been turned into 5 liters of solid ceramic. Credit. UK National Nuclear Laboratory.[37]

In the meantime, the UK is already moving to immobilize for direct disposal some 50 to 250 kg of impure separated plutonium residues.[38] Impure powdered plutonium oxide will be mixed with calcium, zirconium and titanium oxide powders. Hot isostatic pressing (HIP) for 8 to 9 hours will then turn the mix into a very durable ceramic form (figure 3).

Japan could pay to have its plutonium in the UK immobilized in this form. The immobilized plutonium then would have to be securely stored until disposal with the UK's immobilized plutonium or in Japan. One option for disposal in the UK could be with the UK's spent fuel, which, with the end of reprocessing, will be disposed of directly in a geological repository. Another option could be disposal in 3 to 5 km deep boreholes, an option that is currently being explored in the U.S. for spent fuel disposal.[39]

In France. With regard to Japan's plutonium in France, the understanding with AREVA is that it is to be used to make MOX fuel that is to be shipped to Japan as soon as it can be used. If Japan cannot use the MOX fuel in reactors, one option would be to treat it as a disposal form and dispose of it with spent fuel in casks.[40]. If this decision were made in advance of fuel fabrication, the very precise dimensional specifications to which the pellets must be ground for MOX fuel could be relaxed. This would reduce both France's production costs and the fraction of MOX pellets that are rejected because they do not meet specifications.[41]

In Japan. Finally, with regard to the plutonium in Japan, the material that is already in MOX form could be treated as a direct disposal form. One option for the plutonium in liquid and powder form could be to immobilize it for direct disposal using the UK HIP method.

Japan and the UK are not the only countries encountering problems in disposing of their plutonium. In April 2013, the Obama Administration announced that the MOX program that the U.S. had launched to dispose of 34 tons of its excess weapons plutonium in parallel with Russia "may be unaffordable…due to cost growth and fiscal pressure" and that the administration "will assess the feasibility of alternative plutonium disposition strategies."[42] Japan may therefore find a willing partner in the United States for research and development on alternative approaches to plutonium disposal.

References and Notes

[1] JAEC, "Estimation of Nuclear Fuel Cycle Cost and Accident Risk Cost (Statement)", 10 Nov. 2011.

[2] In 2011, the UK decided to abandon reprocessing when existing contracts had been fulfilled (circa. 2018). China, India and Russia reprocess in connection with continuing R&D on plutonium breeder reactor programs:. Also, the Netherlands continues to send the spent fuel from its single reactor to France to be reprocessed and the Ukraine continues to send the fuel from its two oldest and smallest reactors to Russia to be reprocessed.

[3] Masafumi Takubo, "Wake Up, Stop Dreaming: Reassessing Japan's Reprocessing Program," *Nonproliferation Review*, Vol. 15, No. 1, March 2008.

[4] http://law.e-gov.go.jp/htmldata/S32/S32HO166.html

[5] In 2012, the average price of natural uranium purchased by U.S. nuclear utilities was about $145/kg and the average cost of a separative work unit (SWU) of enrichment was about $141, US Energy Information Administration, *2012 Uranium Marketing Annual Report*. At these prices, low enriched uranium is produced at the lowest cost by producing depleted uranium containing 0.227 percent U-235 (down from the 0.72 percent U-235 in natural uranium). If the amount of U-235 in the depleted uranium were reduced to 0.07 percent, the amount of natural uranium required would be reduced by 21 percent and the cost of nuclear fuel would increase by ¥0.1/kWh, which is about one tenth the amount by which reprocessing is estimated to increase the cost of nuclear power in Japan, JAEC, "Estimation of Nuclear Fuel Cycle Cost and Accident Risk Cost (Statement)", 10 Nov. 2011.

[6] Mycle Schneider and Yves Marignac, *Spent Fuel Reprocessing in France* (IPFM, 2008) Figure 9; and IAEA, "Communication Received from France Concerning its Policies regarding the Management of Plutonium", INFCIRC/549/Add.5/16, 2012

[7] William Walker, *Nuclear Entrapment: THORP and the politics of commitment* (Institute for Public Policy Research, 1999), pp. 113-114.

[8] http://www.nda.gov.uk/news/smp-future.cfm, 3 August 2011.

[9] Japan Nuclear Fuel Limited, reprocessing plan for FY2013 through FY2015, 31 Jan. 2013, http://www.jnfl.co.jp/press/pressj2012/20130131tenpu.pdf

[10] These numbers in JNFL's plan are the amount of plutonium in the MOX product (50% of which is plutonium oxide, the other 50% uranium oxide) produced in each period and not the amount of plutonium separated but should be close enough for this calculation.

[11] Based on the 3.612 tons of plutonium recovered from 425 tons of spent fuel reprocessed during the test operation of Rokkasho during 2006-8.

[12] President Obama, Speech at Hankuk University of Foreign Studies in Seoul, 26 March 2012.

[13] Vice Chairman of JAEC Tatujiro Suzuki's written report on his trip to the United States (April 7-12) presented at a JAEC meeting on April 22, 2013, rough translation from the Japanese, http://www.aec.go.jp/jicst/NC/iinkai/teirei/siryo2013/siryo14/siryo2.pdf

[14] Masakatsu Ota, "Excessive Plutonium Problem; No. I Priority for Japan after 3/11," Gaiko (Diplomacy), Vol 18 13 March 2013.

[15] Available capacity is the storage capacity minus 1 full core and 1 reload as of the end of March 2013. Data from METI's Agency for Natural Resources and Energy. The figures for Tokai Daini include the dry-cask storage there. Average burnup calculated using the energy availability factor of 0.669 of 2010 from the IAEA's database, http://www.iaea.org/PRIS/WorldStatistics/ThreeYrsEnergyAvailabilityFactor.aspx, and an average ratio of heat to net electricity of 3.1 for the reactors in Table 1, also from the IAEA's data base, http://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=JP. So (38.11 GWe)x(3.1 Gwt/GWe)x0.669x(365 days)/(0.75x1080 tons/yr) = 35.6 GWt-days/ton.

[16] JAEC, *Framework for Nuclear Energy Policy* (translation by JAEC) 11 Oct. 2005, p. 33, http://www.aec.go.jp/jicst/NC/tyoki/taikou/kettei/eng_ver.pdf

[17] Although the Mayor of Mutsu, in solidarity with the neighboring communities, officially has been maintaining the same stance as the governor of Aomori Prefecture. In an interview with one of us (Takubo) and Tadahiro Katsuta on 23 Dec. 2011, he stated that the fate of the spent fuel to the stored at the Mutsu Storage Facility should be decided by future generations.

[18] http://www.nsr.go.jp/archive/nisa/koho/symposium/files/shimane/program01.pdf
This METI document in response to questions from Shimane Prefecture, states that reprocessing of 1,000 kg of spent fuel could result in 130 kg MOX fuel containing about 10 kg of plutonium and 130 kg of fuel made from recovered uranium. In France, which has been reprocessing and recycling plutonium since 1987, the estimated savings from plutonium and uranium recycle in 2010 were 8 percent and projected to rise to 16% in 2020, *Managing Spent Fuel from Nuclear Power Reactors: Experience and Lessons from Around the World* (International Panel on Fissile Materials, 2011) Table 3.2

[19] http://www.enecho.meti.go.jp/info/committee/kihonmondai/33th/33-4.pdf

[20] Mycle Schneider and Yves Marignac, *Spent fuel reprocessing in France* (International Panel on Fissile Materials, 2008).

[21] Roald A. Wigeland *et al*, Argonne National Laboratory, "Repository Impact of Limited Actinide Recycle," *Proceedings of Global 2005, Tsukuba, Japan, Oct 9-13, 2005*, Paper No. 496.

[22] *Plutonium Fuel* (OECD Nuclear Energy Agency, 1989).

[23] In the case of plutonium and the other transuranics, "transmutation" means fission. In the case of long-lived fission products, it means conversion into a shorter-lived or stable isotope, *Nuclear Wastes: Technologies for Separations and Transmutation* (National Academy Press, 1996), p. 3.
[24] *Fast breeder reactor programs: History and Status* (International Panel on Fissile Materials, 2010).
[25] http://www.nsr.go.jp/kaiken/data/20120919sokkiroku.pdf
[26] In the United States over 170 groups from all 50 states endorsed a set of principles including low-density, open-framework spent fuel pools, hardened on-site storage, and prohibitions against reprocessing, http://www.psr.org/nuclear-bailout/resources/principles-for-safeguarding.html
[27] Out of 608,000 worker-days (2400 worker years, assuming 250 days worked per year) spent on construction work at the complex in FY 2011, 85% were for local Aomori Prefecture workers. Out of 66,000 worker years from FY 1985 through 2011 (2500 per year on average), 62% were for local workers. Out of the total of ¥3.55 trillion construction related orders in the same period, 18% were for local companies.
http://www.pref.aomori.lg.jp/soshiki/energy/g-richi/files/2013_yutaka.pdf
[28] http://cgi.daily-tohoku.co.jp/cgi-bin/tiiki_tokuho/kakunen/kikaku/tenki/money_02.htm. Aomori followed the example Fukui Prefecture, which was the first to introduce the fuel tax system in 1976. For the taxes in each of the 13 prefectures see: http://www.zengenkyo.org/katudou/kaku.pdf
[29] The large central government grants that Rokkasho Village receives (¥2.6 billion in FY 2011) in addition to property taxes from JNFL and contributions from the nuclear industry that in total amount to half of its income.

National Citizen Ombudsman Association, http://www.ombudsman.jp/nuclear/yugami.pdf

[30] A document accompanying the notice of the 27th regular shareholders meeting of JNLF dated 14 June 2006 shows that, as of the end of March 2006, ¥924 billion or 84% of the outstanding long term loans, were from the government owned Development Bank of Japan Inc. Such detailed information about the loans has not been disclosed more recently.
[31] http://www.numo.or.jp/en/jigyou/new_eng_tab02.html,
http://www.numo.or.jp/en/jigyou/new_eng_tab01.html, http://icgr2012.org/bio-toru-yamaji.php
[32] http://www.rwmc.or.jp/english/councilors_and_officials/
[33] UK Nuclear Decommissioning Authority, *Oxide Fuels: Preferred Option* (2012).
[34] Anthony Andrews, *Nuclear Fuel Reprocessing: U.S. Policy Development* (U.S. Congressional Research Service, 2008), http://www.fas.org/sgp/crs/nuke/RS22542.pdf
[35] "The Current Situation of Plutonium Management in Japan," 11 Sept. 2012, http://www.aec.go.jp/jicst/NC/iinkai/teirei/siryo2012/siryo39/120911e.pdf
[36]UK Department of Energy and Climate Change, *Management of the UK's Plutonium Stocks: A consultation response on the long-term management of UK-owned separated civil plutonium*, 2011, http://www.decc.gov.uk/assets/decc/Consultations/plutonium-stocks/3694-govt-resp-mgmt-of-uk-plutonium-stocks.pdf, para. 1.8.
[37] J.W. Hobbs et al, "A Programme to Immobilise Plutonium Residues at Sellafield," *Annual Meeting of the Institute for Nuclear Materials Management*, Orlando, FL, 15-19 July 2013.
[38] UK Nuclear Decommissioning Authority, *Conditioning of Plutonium Residues by Hot Isostatic Pressing and Options for Packaging and Disposal (Pre-Conceptual stage) Summary of Assessment Report*, 2009, www.nda.gov.uk/documents/upload/Executive-Summary-Letter-of-Compliance-Assessment-Report-Conditioning-of-Plutonium-Residues-July-2009.pdf
[39] U.S. Department of Energy, "FY 2014 Congressional Budget Request," DOE/CF-0086, April 2013, p. NE-45.
[40] J. Kang, F. N. von Hippel, A. MacFarlane, R. Nelson, "Storage MOX: A Third Way for Plutonium Disposal?" *Science and Global Security*, Vol. 10 (2002) p. 85.
[41] In its annual report to the IAEA on its holdings of civilian plutonium, France's report of "plutonium contained in unirradiated MOX fuel or other fabricated products at reactor sites or elsewhere" has risen from 3.6 tons at the end of 1995 to 29.1 tons at the end of 2011, IAEA, "Communication(s) Received from France Concerning its Policies regarding the Management of Plutonium," INFCIRC/549/Add.5.
[42] U.S. Department of Energy, fact sheet on fiscal year 2014 budget, http://www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/energy.pdf. See also Tom

Clements, Edwin Lyman and Frank von Hippel, "The Future of Plutonium Disposition," *Arms Control Today*, July 2013.