2 Japan's Spent Fuel and Plutonium Management Challenges

Tadahiro Katsuta and Tatsujiro Suzuki

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The mission of IPFM is to analyze the technical basis for practical and achievable policy initiatives to secure, consolidate, and reduce stockpiles of highly enriched uranium and plutonium. These fissile materials are the key ingredients in nuclear weapons, and their control is critical to nuclear weapons disarmament, to halting the proliferation of nuclear weapons, and to ensuring that terrorists do not acquire nuclear weapons. IPFM research and reports are shared with international organizations, national governments and nongovernmental groups.

The Panel is co-chaired by Professor José Goldemberg of the University of São Paulo, Brazil and Professor Frank von Hippel of Princeton University. Its founding members include nuclear experts from fifteen countries: Brazil, China, Germany, India, Japan, the Netherlands, Mexico, Norway, Pakistan, South Korea, Russia, South Africa, Sweden, the United Kingdom and the United States.

Princeton University's Program on Science and Global Security provides administrative and research support for IPFM.

For further information about the panel, please contact the International Panel on Fissile Materials, Program on Science and Global Security, Princeton University, 221 Nassau Street, 2nd floor, Princeton, NJ 08542, or by email at ipfm@fissilematerials.org.

Foreword

Plutonium can be used to make nuclear weapons, whether it is "weapon-grade" or "reactor-grade," the isotopic mix produced by standard light water power reactors. Making sure that plutonium is secure is therefore critical to preventing nuclear-weapon proliferation and terrorism.

Plutonium in spent reactor fuel is relatively secure. It is diluted with one hundred times as much uranium and mixed with highly-radioactive fission products that create a lethal gamma radiation field around a spent-fuel assembly for a century after it is discharged. Plutonium itself emits very little penetrating radiation. It is mainly dangerous if inhaled. It can therefore be safely transported in a tightly sealed, lightweight container.

Enough civilian plutonium to make 30,000 Nagasaki warheads has been separated out and is in storage today – mostly at spent-fuel reprocessing plants in the United Kingdom, France and Russia. In 1998, a Royal Society report stated that the risk that the United Kingdom's very large stockpile of separated civilian plutonium, "might, at some stage, be accessed for illicit weapons production is of extreme concern."

It is in this context that Japan's decision to put into operation the Rokkasho reprocessing plant must be viewed. If that plant operates at design capacity, it will add 8,000 kilograms a year to Japan's stockpile of separated plutonium – enough to make about 1000 nuclear weapons. As of the end of 2004, Japan owned a stockpile of 42,000 kilograms - mostly stored at the reprocessing plants in France and the United Kingdom where it was separated from Japanese spent fuel.

The argument Japan's utilities make for startup of the Rokkasho plant is that it is practically impossible to find additional storage capacity for spent fuel without continuing reprocessing. By contrast, the prefecture of Aomori is willing to store spent fuel, the high-level waste and separated plutonium that result from reprocessing in exchange for the jobs and tax payments that come with a $20 billion reprocessing plant. The utilities also say that it is the government policy to recycle the separated plutonium into reactor fuel, although their plans for doing so with their existing stockpile have been delayed for more than a decade.

The authors of this report show that there is enough spent fuel storage in Japan so that further reprocessing could be postponed for one or two decades. This would give Japan this time to re-consider its plutonium and spent-fuel management policies.

We hope that this analysis will be useful to the government, utilities and people of Japan as they debate Japan's reprocessing policy.

José Goldemberg and Frank von Hippel
Co-chairs, International Panel on Fissile Materials

Summary

Japan’s spent fuel management and fuel cycle programs are now at a critical stage. Its first commercial-scale reprocessing plant, at Rokkasho Village, will soon start full-scale operation.

Japan's commitment to plutonium recycling has been maintained since the introduction of nuclear power to Japan and has been explicitly stated in its Long Term Program since 1956. Under Japan's nuclear regulatory requirements, utilities must submit evidence that their spent fuel will be reprocessed before they load the fuel. They also commit to their local communities to ship spent fuel from the reactor site to reprocessing plants "soon" (without any time period being specified, however). Therefore, there has been no choice for utility companies but to make reprocessing contracts.

Despite the clear cost disadvantage of reprocessing compared with direct disposal or storage of spent fuel, the latest *Framework for Nuclear Energy Policy* published in November 2005 by Japan's Atomic Energy Commission (JAEC) did not change the policy that spent fuel must be reprocessed. The Rokkasho reprocessing plant therefore started active testing on March 31, 2006.

The financial risk to Japan’s nuclear utilities from operating the Rokkasho plant has been significantly reduced by the establishment of a “reprocessing fund” that is, in effect, a tax on all Japan's electric-power consumers – not just consumers of nuclear-power – to pay the costs. The risk has not been eliminated entirely, however. Losses due to accidents or operational problems will probably not be covered by the fund.

Since 1977, Japan has separated a total of 7 tons of plutonium in Japan. In addition, during the 1970s, Japan's utilities made reprocessing contracts with BNFL (in the United Kingdom) and COGEMA (in France) which have resulted in the separation of a total of 41 tons of plutonium out of which only 2 tons have been returned to Japan. Japan's stockpile of separated plutonium held at home and abroad totaled 43 tons at the end of 2004.[1] Japan's cumulative consumption of plutonium has been only 5 tons to date and its future consumption rate is still uncertain. But once the Rokkasho reprocessing plant starts its operation, Japan will separate about 8 tons of plutonium *annually*. There is every reason to postpone this reprocessing until Japan has dealt with its backlog of separated plutonium.

Japan's utilities, however, are under pressure to deal with their accumulating spent fuel. According to Government and industry estimates, some nuclear power plant (NPP) storage pools will be filled up by the end of 2006. This is the main reason given for starting operation of the Rokkasho reprocessing plant. In addition, because the Rokkasho plant, even operating at full capacity, will not be able to keep up with the projected discharges of spent fuel, Japan's utilities have decided to build an interim away-from-reactor (AFR) spent-fuel storage facility (which has been allowed since 1998). This facility will be built in Mutsu city at Aomori prefecture and is projected to start operation in 2010.

Our analysis shows that, with optimum use of available at-reactor and away-from-reactor storage capacity, there would be no need for reprocessing until the mid 2020s. There would be sufficient spent fuel storage capacity up to 2025 (low spent-fuel burn-up case) or 2028 (high burn-up case). With an additional 30,000 tons of AFR spent fuel storage capacity (the equivalent of six more Mutsu type facilities but potentially at a smaller number of sites or even all at Mutsu) reprocessing could be avoided until 2050.

But, the political obstacles to such a no-reprocessing strategy would be severe. Transfers of spent fuel among NPP sites and the siting of additional AFR storage facilities would be opposed by local authorities. Also, because Japan Atomic Power Company (JAPC) has the exclusive rights to the PWR spent fuel storage capacity at Mutsu, storage pools owned by some other utilities could be filled up by 2014, while the Mutsu storage capacity for PWR remained unfilled.

Similarly, some BWR sites at-reactor pools would fill up by 2019, since the Mutsu storage capacity of 4,000 tHM owned by Tokyo Electric Power Company (TEPCO) is not scheduled to be completed by then. And, if the Rokkasho plant does not operate as planned, its spent fuel storage capacity will likely be filled by 2020.

Japan's recovered plutonium is to be recycled in Light Water Reactor (LWR) mixed-oxide (MOX) fuel and in Japan's Fast Breeder Reactor (FBR) R&D program. Due to delays in the MOX and FBR programs, however, Japan has accumulated a large stockpile of separated plutonium. If the Rokkasho plant goes into full scale operation in 2007, Japan’s plutonium stockpile will likely grow to more than 70 tons by 2020 from 43 tons in 2005. Deferring operation of the Rokkasho plant with optimal spent-fuel storage, at least until the plutonium stockpile had been worked down to the minimum required level, would minimize international concern about Japan's plutonium stockpile. We recommend postponing the full scale operation of Rokkasho for about a decade, and we found this feasible even under the current spent fuel storage management planning. This would give Japan sufficient time to re-consider plutonium and spent fuel management.

I. Introduction

Japan's commitment to plutonium recycling with eventual commercialization of Fast Breeder Reactors (FBRs) has been steady since the introduction of nuclear power to Japan and has been specified in its Long Term Program since 1956. Today, Japan has 55 Nuclear Power Plants (NPPs) in operation (50.5 GWe), 2 NPPs under construction and 11 NPPs planned as of March 2006 (see Appendix I). Figure 1.1 shows the nuclear fuel cycle including fast breeder reactor.

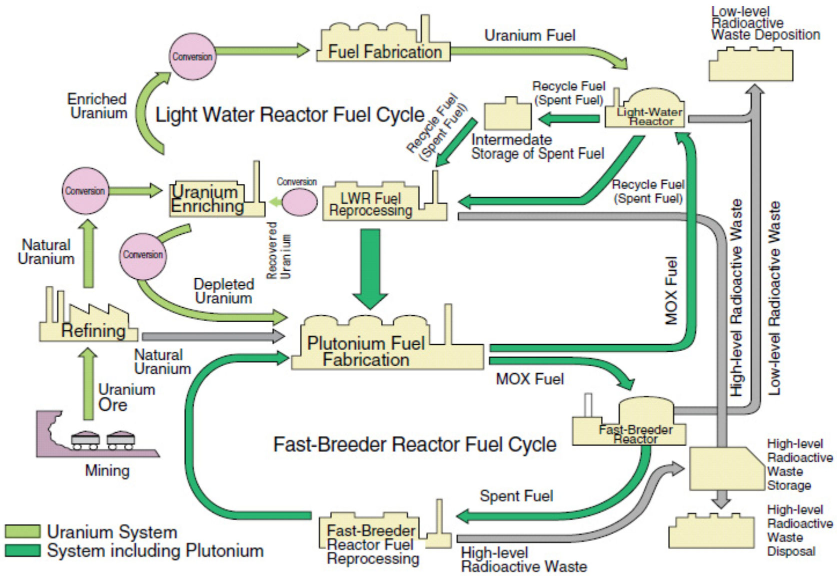

Figure 1.1. Nuclear fuel cycle[2]

Under Japan's nuclear regulatory requirements, utilities must submit evidence that their spent fuel will be reprocessed before they load the fresh fuel. They also commit to the local community to ship spent fuel from the reactor site to reprocessing plants "soon" (without any time period being specified). Therefore, there has been no choice for utility companies but to make reprocessing contracts.

Since Japan's reprocessing capacity was not large enough to accommodate its increasing spent fuel arisings, during the 1970s, Japan's utilities made long-term contracts with European reprocessing companies (COGEMA of France and BNFL of the UK).

In 1980, Japan's nuclear utilities established a commercial fuel cycle company, Japan Nuclear Fuel Limited[3](JNFL), and decided to build a large reprocessing plant in Rokkasho village with a design capacity of 800 tons heavy-metal per year (tHM/yr). Figure 1.2 shows a picture of the Rokkasho reprocessing plant. The Tokai reprocessing pilot plant[4] has operated since 1977 with a nominal capacity of 90 tHM/yr but has processed on average less than 40 tons per year. [5] On March 31, 2006, after many delays and much policy debate, the Rokkasho reprocessing plant started active testing. Japan's recovered plutonium is to be recycled in mixed-oxide (MOX) fuel and in Japan's Fast Breeder Reactor (FBR) R&D program. Due to delays of the MOX and FBR programs, however, Japan has accumulated a large stockpile of separated plutonium.

Figure 1.2. Rokkasho reprocessing plant 2005[6]

As of the end of 2004, Japan had 37.4 tons of separated plutonium in Europe recovered under long-term contracts with BNFL and COGEMA and about 5.7 tons from its domestic Tokai reprocessing pilot plant. International shipments of plutonium from France and the United Kingdom and Japan's increasing stockpile of plutonium have caused international concern.

In order to reduce this concern, Japan's Atomic Energy Commission[7] (JAEC) introduced in 1991 a "no plutonium surplus" policy in Japan.[8] In addition, in order to increase transparency, the Japanese government decided to disclose annually its plutonium stockpile by location. The evolution of and major events affecting Japan's plutonium programs from 1980 to 2006 are summarized in Appendix II.

On March 31, 2006, the Rokkasho reprocessing plant started active testing. It is to start commercial operation in 2007. If it operates at nominal capacity of 800 tHM/yr, about 8 tons of plutonium will be recovered annually.[9] Japan's utilities plan to recycle all their plutonium, including the 37.4 tons stored in Europe, into existing LWRs. As of July 2006, however, not a single reactor had been loaded with MOX fuel. Therefore, it is likely that Japan's stockpile of separated plutonium will increase once the Rokkasho plant starts operating.

In this paper, we analyze Japan's future requirements of spent fuel storage under different assumptions concerning the rate of reprocessing and examine possible options to minimize Japan's future stockpile of separated plutonium without compromising its energy security.

II. Current Status and Policy Issues Concerning Japan's Nuclear Fuel Cycle Program

Japan's nuclear fuel cycle today

Rokkasho spent-fuel recycling complex. JNFL will have five facilities in Rokkasho Village in the Aomori prefecture:

- A reprocessing plant,
- A MOX fuel fabrication facility (planned),
- An uranium enrichment facility,
- A high-level radioactive waste storage and management center, and
- A low-level radioactive waste disposal center.

Table 2.1 and Figure 2.3 describe the facilities (note that ¥100 is roughly equivalent to $1).

Table 2.1. Nuclear fuel cycle facilities at JNFL Rokkasho Site[10]
(as of the end of October 2005)

	Reprocessing Plant	MOX Fuel Fabrication Plant	Uranium Enrichment Facility	High Level Radioactive Waste Storage Center	Low Level Radioactive Waste Disposal Center
Technology	Aqueous (Purex) process	-	Gas centrifuge	-	-
Design Capacity	800 tHM/yr plus storage for 3,000 t spent fuel; 4,000t UO_2 and 30 tPu in 50-50 Pu-U mix.	130tHM/year	1,500 tSWU/year (Final goal)	1,440 canisters (2,880 in the future)	1 million 200-liter drums (3 million drums in the future)
Current Status	Testing	Planned	Operating (1,050tSWU/year)	1,016 canisters	181,715 drums
Construction Cost	¥2.14 trillion	¥120 billion	¥250 billion	¥80 billion	¥160 billion
Operation Year	2007 (plan)	2012 (plan)	1992	1995	1992

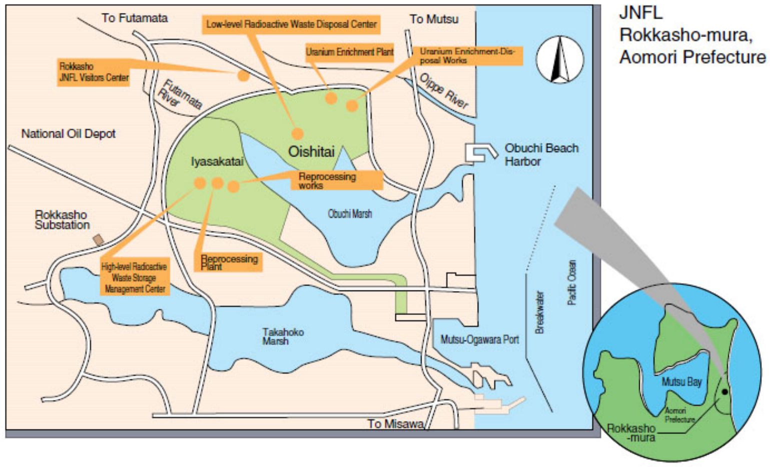

Figure 2.1. Location of nuclear fuel cycle facilities in Rokkasho[11]

Spent fuel management. Japan's utilities are under pressure to deal with their accumulating spent fuel. Table 2.2 shows the current status of fuel storage at each site including our estimate of the year when the storage capacity would be filled up were there no off-site shipments.[12] According to these estimates, the storage pools at Fukushima II, Takahama and Hamaoka, will be filled up by the end of 2006. However, since some of the spent fuel has been sent to the Rokkasho reprocessing plant starting in 1999, these sites will not encounter spent-fuel-storage shortage problem this soon. As of April 2006, the Rokkasho reprocessing plant had received 1,776 tHM[13] of spent fuel. Figure 2.1 shows the spent fuel storage pool at a nuclear power reactor and Figure 2.2 shows the pool at the Rokkasho reprocessing plant.

Table 2.2. Amount of Spent Fuel at Each Power-Reactor Site
(as of the end of March 2004)

Owning Power Companies	Plant Name	No. of Reactors	1 Full Core Each [tHM]	Annual Discharge [tHM]	Amount of Spent Fuel [tHM]	Effective Storage Capacity [tHM] [a]	Year when Storage Capacity will be Filled up[b]
Hokkaido	Tomari	2	100	30	290	420	2008
Tohoku	Onagawa	3	260	60	280	790	2012
Tokyo	Fukushima I	6	580	150	1,360	2,100	2009
	Fukushima II	4	520	140	1,250	1,360	2005
	Kashiwazaki -Kariwa	7	960	250	1,840	2,630	2007
Chubu	Hamaoka	4	420	110	820	1,090	2006
Hokuriku	Sika	1	60	20	70	160	2008
Kansai	Mihama	3	160	50	360	620	2009
	Takahama	4	290	100	940	1,100	2005
	Ohi	4	360	120	1,030	1,900	2011
Chugoku	Shimane	2	170	40	330	600	2011
Shikoku	Ikata	3	170	60	450	930	2012
Kyusyu	Genkai	4	270	100	660	1,060	2008
	Sendai	2	140	50	630	900	2009
JAPC	Tsuruga	2	140	40	520	870	2013
	Tokai-II	1	130	30	300	420	2008
Total		**52**	**4,730**	**1,350**	**11,110**	**16,940**	**2008**

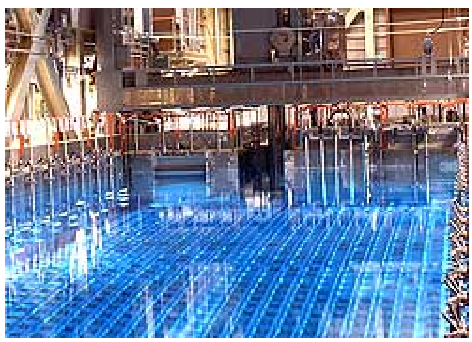

Figure 2.2. Spent-fuel storage pool at nuclear power plant[14]

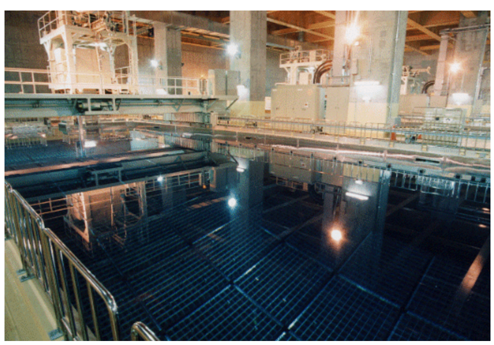

Figure 2.3. Spent fuel storage pool at Rokkasho reprocessing plant[15]

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[a] Effective storage capacity ESC=SC-(1 Full core + AD), SC: Storage Capacity, AD: Annual discharge.
[b] Year when storage capacity is filled up for NPP site $Y_f = Y_{2004} + (ESC-SF)/AD$, Y_{2004}: amount of spent fuel in pool as of March 2004, SF: Amount of spent fuel. The estimate assumes no spent fuel is shipped off-site.

In order to solve their future spent fuel storage shortage problem, Japan's utilities decided to build in addition to the reprocessing plant an interim dry-cask away-from-reactor storage facility. Such storage has been allowed since 1998.[16] The first such facility will be built in Mutsu city, Aomori prefecture, and is projected to start operation in 2010. The Recyclable-Fuel Storage Company[17] was established in November 2005 for managing this interim storage facility. Table 2.3 and Figure 2.4 describe the facility.[18]

Table 2.3. Mutsu interim storage

Technology	Dry storage
Capacity	5,000 tHM
Status	Planned
Construction cost	¥100 billion (including dry casks)
Year of Operation	2010 (plan)

Figure 2.4. Mutsu interim storage facility (Image)

The policy debate over Japan's nuclear fuel cycle options

Comparison of fuel cycle options by JAEC. In November 2005, Japan's Atomic Energy Commission (JAEC) finished its deliberation process on its latest *Long Term Program for the Peaceful Use of Nuclear Energy* (it has since been re-named the *Framework for Nuclear Energy Policy).*[19] One of the most urgent and controversial issues it dealt with was whether Japan should maintain its commitment to nuclear fuel recycling. The focus in particular was on an economic comparison of reprocessing and a once-through fuel cycle.

In the JAEC study, four scenarios of spent fuel management were compared from various perspectives, including economics. Table 2.4 shows the four scenarios and Table 2.5 shows the results of the cost comparison.

Table 2.4. Spent-fuel management options considered by JAEC

Scenarios	Assumptions
1. Full reprocessing	All spent fuel reprocessed. Spent fuel quantities that are beyond the capacity of the Rokkasho plant would be reprocessed in the future, following interim storage. Recycle in fast breeder reactors assumed for the future.
2. Partial reprocessing	Spent fuel that cannot be reprocessed due to a lack of capacity at the Rokkasho plant would be directly disposed after interim storage for cooling.
3. Direct disposal	All spent fuel would be directly disposed after interim storage for cooling.
4. Temporary storage	All spent fuel would be sent to interim storage and the decision on reprocessing would be delayed.

The results of the economic comparison shown in Table 2.5, clearly show that direct disposal is less expensive than recycling. However, the JAEC assumed that there would be additional costs if Japan abandoned reprocessing. It was estimated that cancellation of the Rokkasho reprocessing plant would cost 0.2 ¥/kWh and a fossil fuel cost of 0.7 to 1.3 ¥/kWh was added based on the assumption that, without the Rokkasho plant, all nuclear plants would be shut down eventually due to shortage of spent fuel storage capacity and that new fossil-fueled plants would be built to compensate for the loss of nuclear power plants. With these added costs, the costs of scenario 3 and 4 were estimated at 5.4-6.2 ¥/kWh and 5.6-6.3 ¥/kWh respectively, which would make them more expensive than scenarios 1 and 2. The assumption that nuclear power plants would have to be shut down rather than the utilities adopting alternative storage arrangements may be considered extreme, and perhaps unrealistic.

Table 2.5. Cost [¥/kWh] comparison for four scenarios[20]

			1. Full Reprocessing	2. Partial Reprocessing	3. Direct Disposal	4. Temporary Storage
Nuclear fuel cycle cost	Front -end	Uranium fuel	0.57	0.57	0.61	0.61
		MOX fuel	0.07	0.05	-	0.00
	Back -end	Reprocessing	0.63	0.42	-	0.16
		HLW storage, transport and disposal	0.16	0.10	-	0.06
		TRU storage, transport and disposal	0.11	0.07	-	0.03
		Interim storage	0.04	0.06	0.14	0.13
		Spent fuel direct disposal[a]	-	0.12-0.21 (0.09-0.21)	0.19-0.32 (0.14-0.32)	0.09-0.16 (0.07-0.16)
	Total		1.6 (1.5) [b]	1.4-1.5	0.9-1.1	1.1-1.2
Generation Cost[c]			**5.2 (5.1)**	**5.0-5.1**	**4.5-4.7**	**4.7-4.8**
Cost for Policy Change[d]			-	-	**0.9-1.5**	
Total Cost			**5.2 (5.1)**	**5.0-5.1**	**5.4-6.2**	**5.6-6.3**

[a] Figures in parentheses assume horizontal placement of the casks.
[b] Cost of the second reprocessing plant is assumed to be half that of the Rokkasho reprocessing plant.
[c] Cost excluding fuel cycle (i.e. capital, operation and management cost) is assumed as 3.6 Yen/kWh in all scenarios.
[d] Assuming 1) Construction cost of Rokkasho reprocessing plant: ¥0.2/kWh; and 2) Thermal power generation cost to replace nuclear power plants which would be shut down early due to shortage of spent fuel storage capacity: ¥0.7-1.3/kWh.

Evaluations with regard to energy security and non-proliferation also were carried out.[21] In comparison with the economic analysis, these other evaluations were superficial.[22] In the end the JAEC concluded that reprocessing all Japan's spent fuel would be superior to the other three options.

In November 2005, the JAEC therefore decided to maintain its recycling policy. Operational testing using uranium fuel ("cold testing") was carried out at the Rokkasho reprocessing plant the following month. At the same time, JAEC also allowed the start of research on direct disposal for the first time in its official program, in order to meet future uncertainties.[23]

Establishment of a "Reprocessing Fund." The Electrical Industry Subcommittee of the Advisory Committee on Energy for the Agency for Natural Resources and Energy in the Ministry of Economy, Trade and Industry (METI) concluded that nuclear power generation costs would be competitive (¥5.3/kWh) with electricity generated by fossil power plants (¥6-10/kWh), and that the back-end fuel-cycle cost would be around ¥0.8/kWh.

At the same time, the committee found that total costs of the back-end fuel cycle would reach 18.8 trillion yen for 40 years operation of the Rokkasho reprocessing and MOX fuel fabrication plants (see Appendix III). It concluded that, in a liberalized electricity market, the utilities could not afford such high economic risks and that a new cost recovery system would be needed.

The government committee decided to exclude 6.1 trillion yen for MOX fuel fabrication, spent fuel interim storage, and high level waste disposal from the 18.8 trillion yen back-end costs, because they are already covered by an existing fund. Therefore, a total of 12.7 trillion yen is to be recovered under the new scheme. This cost covers principally the estimated lifetime cost of the Rokkasho reprocessing plant (construction, operation and decommissioning) and of TRU waste disposal.[24]

The fund will be collected through special cost charges on both electricity transmission and retail electricity – non-nuclear as well as nuclear. The law establishing the new "reprocessing fund" was passed by the Diet in May 2005 (see Figure 2.3).

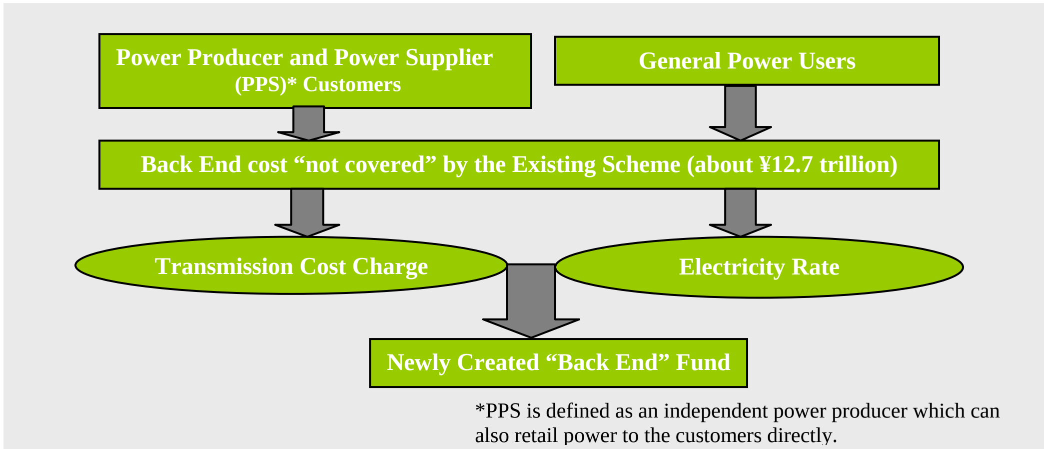

Figure 2.3. Scheme for new reprocessing fund

This does not eliminate the financial risks of the reprocessing option entirely, however. The fund only covers the costs of reprocessing 32,000 t of spent fuel (i.e. 40 years of operation of Rokkasho reprocessing plant) and does not cover storage costs of all spent fuel during that period and future reprocessing costs.[25] In addition, use of the fund is subject to METI approval and losses due to accidents and other adverse developments caused by the operators will not be covered by the fund. Therefore, even with this scheme, utilities may face future financial risk associated with the reprocessing option.

The 'no surplus plutonium' policy and its implementation

Management of plutonium separation. Table 2.6 shows the locations of the stockpile of 5.7 tons of separated plutonium in Japan as of the end of December 2004. In addition, Japan also had 37.4 tons in the United Kingdom and France.

Table 2.6. Japan's stockpile of separated plutonium
as of the end of December 2004 (2003)[26]
[kilograms]

1. Separated Plutonium in Japan			
Reprocessing Plant	JNC Tokai pilot reprocessing plant	Plutonium nitrate, etc[a]	562 (478)
		Plutonium oxide[b]	275 (218)
	Subtotal		*837 (695)*
		Pu fissile in total	569 (474)
Fuel Fabrication Plant	JNC Plutonium Fabrication Plant	Plutonium oxide[c]	2,422 (2,465)
		Plutonium in the stage of test or fabrication	686 (739)
		In new fuel	433 (331)
	Subtotal		*3,562 (3,536)*
		Pu fissile in total	2,499 (2,488)
Power Plants, etc.	Joyo	In unirradiated fuel at the plants	85 (18)
	Monju		367 (367)
	Fugen		0 (0)
	Commercial		415 (415)
	R&D[d]		445 (445)
	Subtotal		*1,311 (1,244)*
		Pu fissile in total	976 (928)
Total			**5,710 (5,475)**
	Plutonium fissile in total		4,045 (3,889)
2. Separated Plutonium in Foreign Storage[e]			
At U. K. reprocessing plant			15,897 (13,614)
At France's reprocessing plant			21,503 (21,554)
Total			**37,400 (35,168)**
	Plutonium fissile in total		25,285 (23,838)
3. Separation, Import and Use of Plutonium in Japan During 2004			
Supply	Plutonium oxide recovered from the JNC Reprocessing plant		171 (167)
	Plutonium oxide transferred from overseas		0 (0)
Usage[f]	Monju, Joyo , Fugen etc.		130 (270)

New policy guidelines. In August 2003, the JAEC announced new guidelines for plutonium management. Under the new arrangement, utilities are expected to submit annually a plan covering their use of plutonium to be separated in the following year. The plan is supposed to include the following information:

- Planned amount of reprocessing and of recovered plutonium during the year;
- Estimated amount of plutonium in inventory at the end of previous year;
- Planned sites of the nuclear reactors that will recycle the recovered plutonium;
- Estimated amount of plutonium use during the year; and

[a] After separation but before mixture and conversion.
[b] Stored as mixed oxide powder in containers.
[c] Stored as mixed oxide powder in containers.
[d] Fast Critical Assemblies, etc.
[e] The plan is to fabricate this plutonium into MOX fuel in Europe and use it in LWRs in Japan.
[f] Defined as the amount of plutonium removed from storage process to the fabrication process zone in the fuel fabrication facilities. Numbers rounded.

- Estimated timing and duration of plutonium use.

The following information can be added later:

- Planned amount of MOX fabrication and number of fuel assemblies during the year; and

- Planned timing of MOX loading and the name of the power plant.

On January 6, 2006, all electric companies that plan to recycle plutonium published their utilization plans for the plutonium that will be recovered at the Rokkasho reprocessing plant during its period of active testing (FY2005, 2006). According to this plan, 238 tons of spent fuel will be reprocessed and 1.4 tons of fissile plutonium (tPuf) will be separated by the end of March 2007. An annual consumption rate of 5.5-6.5 tPuf is expected after 2012 (see Appendix IV).

It should be noted that this plan does not include information on the MOX program for plutonium recovered in Europe.

Status of MOX program. Officially, the Federation of Electric Power Companies (FEPCO) of Japan has a plan to use MOX fuel in 16 to 18 nuclear power plants by 2010 – primarily for plutonium recovered in Europe. In order to facilitate this MOX program, METI decided to increase its subsidy (kofu-kin) to local governments that accept a MOX program.[27] The plan has been delayed, however by a series of non-nuclear and nuclear incidents, notably TEPCO's damage cover-up and data falsification in 2003 and the Kansai Electric Power Company's (KEPCO) steam pipe rupture accident at the Mihama nuclear power plant in August 2004. As a result, these companies' MOX plans are stopped at present.

Some smaller utilities (Kyusyu, Shikoku and Chugoku electric power company) may therefore start MOX program sooner than these two larger utilities. Kyusyu Electric Power Company, for example, announced that it will load MOX fuel at the Genkai power station as early as 2010.[28] At present, there is no specific plan to reprocess spent MOX fuel, although the long-range policy is to recycle plutonium from MOX spent fuel also. It is likely that spent MOX fuel will be stored for a foreseeable future.

Japan Atomic Energy Agency (JAEA), owner and operator of the “Monju” fast breeder prototype reactor (280MWe), is now preparing for restart after almost 10 years of negotiations with the local government. The legal efforts by opposition groups to prevent restart were lost in 2005 when the Supreme Court made a final decision to endorse the safety licensing of Monju. JAEA plans to restart Monju around 2010.[29] But its future operational schedule has not yet been finalized. JAEA also owns other smaller reactors which use plutonium as their primary fuel (see Table 2.7).[30]

Table 2.7. Status of JAEA's plutonium-fueled reactors (as of the end of May 2006)

	Fugen	Joyo	Monju
Type	**Advanced Thermal Reactor (ATR) Prototype**	**Experimental Fast Reactor**	**Prototype Fast Breeder Reactor (FBR)**
Output (MWt/MWe)	557/165	140/-	710/280
Criticality Year	1978	1977	1994
Cumulative Plutonium Use (kg)	1845	85[a]	367[b]
Current Status	Closed Down(2005)	Operating	Stopped since 1995

[a] As of the end of March 2004.
[b] As of the end of March 2004.

III. Future Spent Fuel and Plutonium Management

Spent fuel management

Future discharges. In order to clarify the needs and timing of away–from-reactor (AFR) spent fuel storage, we have estimated the future generation of spent fuel and storage capacity at reactor sites, at the Mutsu interim storage facility, and at the Rokkasho reprocessing plant.

We calculate Japan's cumulative future discharge of spent fuel up to 2050[31] and compare it with Japan's planned storage capacity[32] (see Figure 3.1). The cumulative amount of spent fuel stored at Japan’s NPP sites as of the end of 2004 was 11,100 tHM (see Table 2.2). Cumulative spent fuel discharges are expected to increase to 30,000 tHM by 2020 and 38,000 tHM by 2030. Total spent fuel storage capacity (including capacity at the NPP sites, the Rokkasho storage pool and the Mutsu interim storage facility) will reach 33,000 tHM in 2026 and is assumed to stay constant after that.

The figure shows that, even if Rokkasho does not operate, Japan has sufficient spent fuel storage capacity until 2025 (low spent-fuel burn-up) or 2028 (high burn-up). Therefore, there is no urgent need for reprocessing until the mid-2020s. Beyond that time, without reprocessing, 30,000 t of additional AFR spent fuel storage capacity (equivalent to six more Mutsu facilities) would be required by 2050.[33] For higher fuel burn-up, the generation of spent fuel would be reduced by 10%, which would eliminate the need for one Mutsu-size storage facility.

Under the existing High Level Waste (HLW) disposal law, spent fuel is not considered HLW.[34] Therefore, utilities must prepare spent fuel storage capacity assuming that the final disposal site, which is now planned to start operation during the 2030s, will not accept spent fuel. If the law were amended to include spent fuel as HLW, the need for interim spent fuel storage capacity could be reduced by opening the final disposal site.

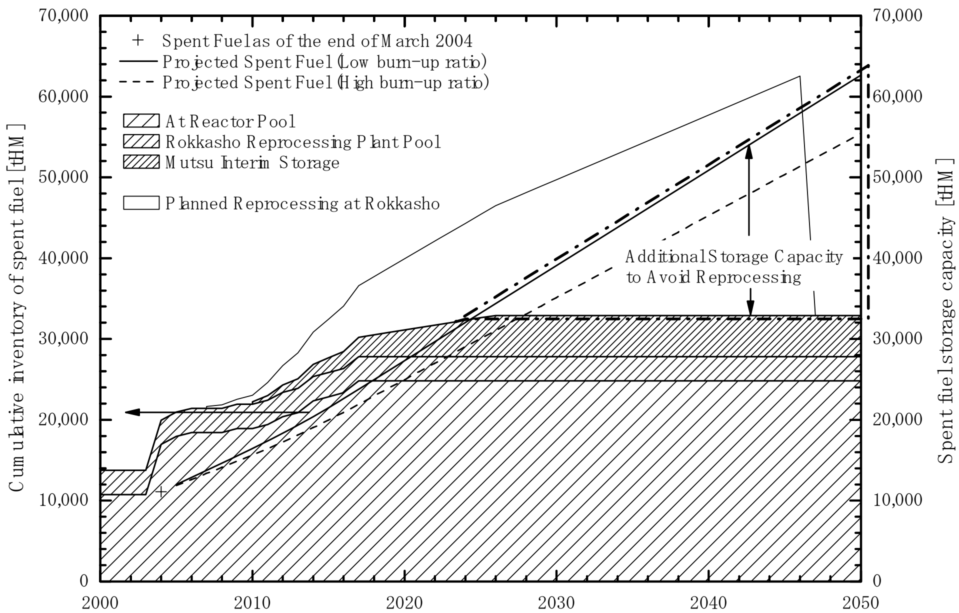

Figure 3.1. Cumulative inventory and management of spent fuel in the future

Barriers to interim spent fuel storage. The above analysis does not consider, however, the political difficulties of spent fuel transfer among NPP sites and of siting AFR storage facilities. For example, although TEPCO did succeed once in establishing an on-site spent fuel storage pool and dry cask storage facility at Fukushima-1 NPP site in the early 1990s,[35] Fukushima prefecture is no longer willing to accept the construction of additional storage facilities.[36]

Figure 3.2. The dry cask storage facility at Fukushima-1 NPP site[37]

If transfer of spent fuel is not allowed, some utilities will face a shortage of spent fuel storage earlier. Assuming low burn-up fuel, by 2020 ten NPPs would run out storage space. The plants and the year their pools would be full (in parenthesis) are; BWRs: Fukushima II (2006), Kashiwazakikariwa (2010), Tokai (2010), Hamaoka (2013), Fukushima I (2020), and PWRs: Takahama (2007), Genkai (2011), Mihama (2013), Sendai (2013), Ohi (2015).

After those storage pools are filled up, we have assumed that spent fuel will be shipped to the Rokkasho storage pool. This storage pool has a capacity of 3,000 tHM, but is divided into three sections; 1,000 tHM for PWR spent fuel, 1,000 tHM for BWR spent fuel and 1,000 tHM for either type of spent fuel. In the case of the Mutsu interim storage facility, it has 5,000 tHM spent-fuel storage capacity but availability of this capacity can be limited because of its ownership. TEPCO is entitled to store 4,000 tHM and JAPC is entitled to 1,000 tHM. It is planned that 300 tHM/yr of storage capacity will be added at Mutsu interim storage facility from 2010, which will be used by TEPCO only until 2027 when the JAPC (Tsuruga site) is expected to run out of storage capacity.

We have therefore estimated when PWR and BWR sites will run out of storage capacity in the absence of reprocessing taking these constraints on Japan's away-from-reactor storage into account (see Figure 3.3).[38] At PWR sites, storage pools will be filled up by 2014, although storage capacity for PWR spent fuel will still be available at the Mutsu facility. BWR sites will be filled up by 2019, since Mutsu storage capacity of 4,000 tHM will not be built by then. If we assume high burn-up spent fuel, PWR sites will not fill until 2016 while BWR sites can have capacity beyond 2020.

Thus, while the need for reprocessing can be significantly reduced by optimum storage capacity management, this analysis illustrates the complex nature of spent fuel management in Japan.

In addition, the local politics of spent fuel storage are so complex and difficult that finding additional storage capacity would not necessarily eliminate the needs for reprocessing. For example, as a condition of allowing spent fuel storage there, Aomori prefecture demanded that the Central Government guarantee that it would maintain its reprocessing policy. The prefecture's concern is that spent fuel might stay there forever if there is no reprocessing.[39] The Japanese utilities argue that those political conditions do not allow them to delay the start up of the Rokkasho reprocessing plant. In addition, there is an economic incentive for utilities to start up the reprocessing plant, as they can draw money from the newly established reprocessing fund.

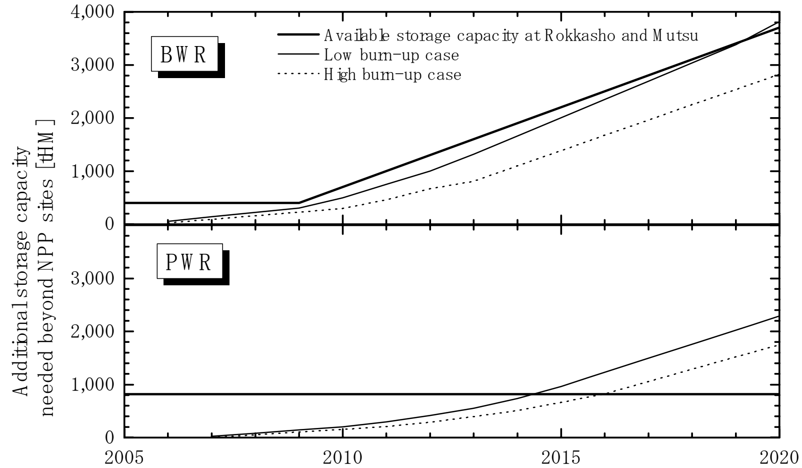

Figure 3.3. Additional storage capacity needed beyond NPP sites

Analysis of Plutonium Balance

Current stockpile. Figure 3.4 shows the current situation of Japan's plutonium stockpile as of March 2004.[40] This is based on the information given by the Government answering to the question raised by a Member of Parliament (Mr. Tetsuo Inami).

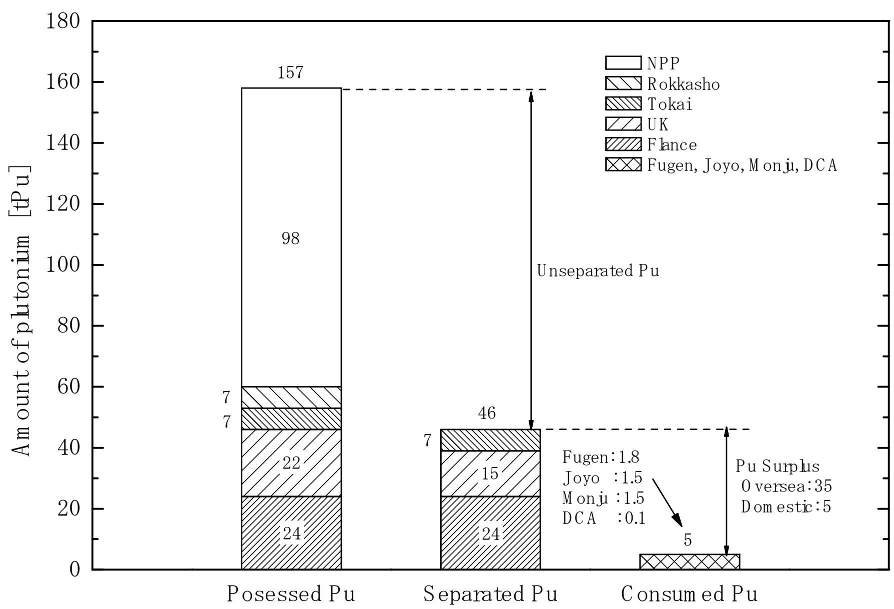

Figure 3.4. Japan's management of plutonium (as of March 2004)

Japan owned a total of 157 tons of plutonium, of which 98 tons was still in spent fuel in the storage pools of nuclear power plants. The remaining 60 tons had been transported to reprocessing plants, out of which 46 tons had been separated from spent fuel (7 tons in Japan and 39 tons in Europe). Fourteen tons delivered to the reprocessing plants (7 tons in Europe and 7 tons at Rokkasho) was still in spent fuel.

Out of the 46 tons of separated plutonium (see center column), only 5 tons had been fabricated into fuel and loaded into reactors. The major consumers of plutonium had been: Fugen (ATR prototype reactor), which was closed in March 2003 and the Monju prototype breeder reactor, which has not operated since 1995 due to a sodium leak accident (see Table 2.7). No plutonium had been recycled into commercial reactor fuel. Of the unirradiated separated plutonium, 35 tons was in Europe and 5 tons in Japan[41] (see right column).

Future projection and possible options. Figure 3.5 shows a projection of Japan's plutonium stockpile until 2020 based on current plutonium supply and demand plans.[42] Under the current plan, Japan's total plutonium stockpile would increase to about 81 tons by 2011, and then decline to about 70 tons in 2020 (see Figure 3.5(a)).[43] If Japan uses the plutonium stored in Europe first, all of Japan's stockpile of separated plutonium will be in Japan by 2020. Alternatively, if Japan's utilities use domestic plutonium stocks first, the plutonium stockpile in Japan would peak at 37 tons in 2011 and decline to about 20 tons in 2020 [see Figure 3.5(b)].

If the Rokkasho plant starts its operation as planned but Japan's plans for recycling plutonium in commercial power plants remained stalled, Japan's plutonium stockpile could increase up to 160 tons by 2020.

Japan's storage capacity for separated plutonium is reported to be about 50 tons (30 tons at Rokkasho, 20 tons at Tokai). This limited storage capacity, if unchanged, could constrain Japan's reprocessing operations (see Figure 3.5(b)).

To minimize Japan's plutonium stockpiles, it would be best to defer operation of the Rokkasho plant [see Figure 3.5(c)]. If this were done and Japan's plutonium recycle plan actually goes ahead as planned, it would take until 2015 to consume Japan's current stockpiles of separated plutonium in Japan and in Europe.[44] Deferring operation of Rokkasho until 2015 would not require additional spent fuel storage capacity for Japan as a whole.

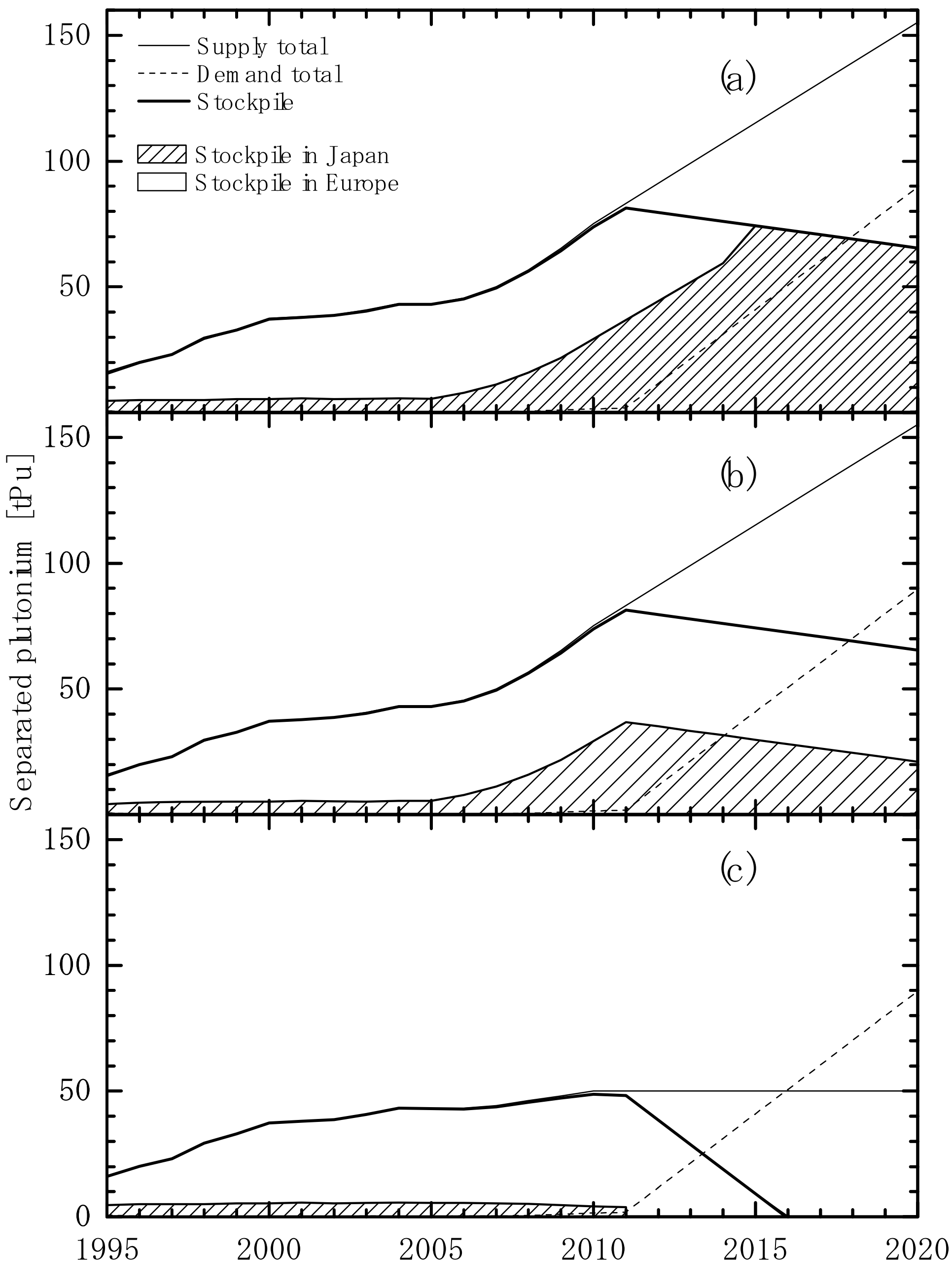

Figure 3.5. Three scenarios for Japan's separated plutonium: a) and b) assume that the Rokkasho reprocessing plant operates as planned. In: a) plutonium stockpile in Europe is consumed first; b) only stockpile in Japan is consumed while stockpile in Europe is left in Europe; and c) operation of the Rokkasho reprocessing plant is deferred.

IV. Conclusions

Despite the clear economic disadvantage, Japan's Atomic Energy Commission has decided not to change its requirement that spent fuel be reprocessed. The Rokkasho reprocessing plan therefore started active testing on March 31, 2006.

The financial risk to Japan's nuclear utilities from operating the Rokkasho plant has been significantly reduced by the establishment of a "reprocessing fund" that is, in effect, a tax on all Japan's electric-power consumers – not just consumers of nuclear-power – to pay the costs. The risk has not been eliminated entirely, however. Losses due to accidents or operational problems will probably not be covered by the fund.

Japan's spent fuel management and fuel cycle program are now at a critical stage. Our analysis suggests that there will be sufficient spent fuel storage capacity until 2025 (low burn-up case) or 2028 (high burn-up case). There is therefore no need from this perspective for reprocessing until the mid-2020s. Without any reprocessing, there would be a need for up to 30,000 tHM of AFR spent fuel storage capacity (the equivalent of six more Mutsu type facilities) by 2050.

But, the political constraints are severe. Spent fuel transfer among NPP sites and the siting of AFR storage facilities would both be opposed by local authorities. Also, because TEPCO owns the PWR spent fuel storage capacity at Mutsu, PWR sites, storage pools owned by some other utilities would be filled up by 2014, although Mutsu storage capacity for PWR would still be available. And the BWR sites would be filled up by 2019, since Mutsu storage capacity of 4,000 tHM will not be built up by then. This analysis illustrates the complexities of spent fuel management in Japan. However, the need for reprocessing could be significantly postponed by optimum storage capacity management.

Japan's recovered plutonium is to be recycled in mixed-oxide (MOX) fuel and in Japan's Fast Breeder Reactor (FBR) R&D program. Due to delays of the MOX and FBR programs, however, Japan has accumulated a large stockpile of separated plutonium. If the Rokkasho plant starts its full scale operation in 2007, Japan's plutonium stockpile will likely to grow to more than 70 tons by 2020 from 43 tons in 2005. Deferring operation of the Rokkasho plant with optimal spent-fuel storage, at least until the plutonium stockpile has been worked down to the minimum required level, would also minimize international concern about Japan's plutonium stockpile. We recommend postponing the full scale operation of Rokkasho for about a decade, and we find it is feasible even under the current spent fuel storage management planning. This would give Japan sufficient time to re-consider plutonium and spent fuel management.

Endnotes

[1] On 5 September 2006, the JAEC released data on the plutonium stockpile updated to December 2005. The new data show the total plutonium held by Japan at that time to be 43.8 tons compared to 42.8 tons at the end of 2004, an increase over the year of about 1 ton. The new information came too late to be incorporated in the analysis presented in this paper, which is based on the December 2004 totals.

[2] Source: The Federation of Electric Power Companies of Japan.

[3] Japan Nuclear Fuel Ltd., www.jnfl.co.jp/english/index.html.

[4] This plant was closed down on 31 March 2006. 1,116tU of spent fuel was reprocessed since 1977. In the future, it will be used as an R&D facility.

[5] This plant was closed down on 31 March 2006. 1,116tU of spent fuel was reprocessed since 1977. In the future, it will be used as an R&D facility.

[6] Source: www.taisei.co.jp/eng_new/energy/energy05.html.

[7] Japan Atomic Energy Commission, www.aec.jst.go.jp/jicst/NC/eng/index.htm.

[8] Japan Atomic Energy Commission, Subcommittee on Nuclear Fuel Recycling, "Nuclear Fuel Recycling in Japan," 1991. It said, "It is a principle of Japan's policy that Japan will not possess plutonium more than it is needed". In 1994, JAEC's long term program explicitly introduced a "no plutonium surplus" policy. In 2004, JAEC's White paper dropped the expression of "no surplus" while maintaining the principle of its original 1991 policy.

[9] In this paper, we measure separated plutonium by "total" weight, including both fissile and non-fissile plutonium unless otherwise stated.

[10] Source: JNFL, *op. cit*.

[11] Source: The Federation of Electric Power Companies of Japan.

[12] Source: Japan Atomic Energy Commission, White Paper on Nuclear Energy 2005 (in Japanese).

[13] Of the 1,776 tHM, 1,096 tHM from BWRs and 680 tHM from PWRs.

[14] www.athome.tsuruga.fukui.jp/event/atombus/plant/plant9_2.html.

[15] www.mext.go.jp/b_menu/houdou/11/03/990325s.htm.

[16] Before this regulatory change in 1998, spent fuel storage was allowed only at NPP sites and/or at reprocessing plants.

[17] Recyclable-Fuel Storage Company, www.rfsco.co.jp/ (in Japanese).

[18] *ibid.*

[19] English version is available at www.aec.jst.go.jp/jicst/NC/tyoki/taikou/kettei/eng_ver.pdf.

[20] HLW: High Level Radioactive Waste, TRU: Transuranics.

[21] There were a total of 10 criteria for the evaluation. They were 1) Assurance of safety; 2) Technical feasibility; 3) Economic viability; 4) Energy security; 5) Environmental protection; 6) Nuclear non-

Proliferation; 7) International trends; 8) Issues resulting from policy change; 9) Social acceptability; and 10) Assurance of choice (adaptability to future uncertainty).

[22] Some critics formed an independent study group, the International Critical Review Committee (ICRC) to challenge this policy evaluation process. ICRC published its final report in October 2005.

[23] "Since there are uncertain factors such as technical trends and international situations over the long term, we expect that the Government, research and development institutions and operating entities will independently and/or collectively pursue surveys and research concerning direct disposal of spent fuel in an appropriate manner, which enables flexible considerations for policy choices in response to circumstantial changes." JAEC Framework for Nuclear Energy Policy, 2005, p.34.

[24] Details are, Reprocessing cost: ¥11 trillion; Returned TRU waste management: ¥560 billion; TRU waste deep geological disposal: ¥810 billion; Uranium enrichment facility back-end cost: ¥240 billion.

[25] The sub-committee on nuclear energy policy of the METI advisory committee on energy policy submitted its interim report on 30 May 2006 in which they propose an additional financial scheme to recover future reprocessing costs beyond Rokkasho reprocessing plant.

[26] Source: Cabinet Office, Ministry of Education, Culture, Sports, Science and Technogy (MEXT) and Ministry of Economy, Trade and Industry (METI), 6 September 2005.

[27] The subsidy is one billion yen per year for the next five years.

[28] Press Release of Kyushu Electric Power Company, 28 April 2006.
www1.kyuden.co.jp/press_r_20040428_20040428_100001_1003, (in Japanese).

[29] Framework for Nuclear Energy Policy.

[30] Source: Website of JAEA and Fugen, Monju, www.jaea.go.jp/, www.133.53.8.211/04/fugen/index.html, www.jnc.go.jp/04/monju/index.html.

[31] Amount of spent fuel is estimated using this equation:

$$\text{Spent Fuel} = \frac{\text{Net nuclear capacity[MWe]} \times 365\text{[days]} \times \text{Capacity factor[\%]}}{\text{Thermal to electrical efficiency[\%]} \times \text{Average dischrge burn up[MWd/tHM]}}$$

Capacity factor is 80%, Thermal to electrical efficiency is 34.5% and Average discharge burn up [MWd/tHM] are 45,000 - 55,000 (BWR), 48,000 - 55,000 (PWR), 50,000 - 55,000(ABWR).

[32] Spent fuel storage capacities that we assumed are as follows:

- NPP Storage: 16,940 tHM at the 53 plants operating through 2004, 490 tHM per new plant (x15 new plants) coming on line thereafter. We assume average storage capacity of new NPPs as 490 tons/plant, on the average of the published figures for spent fuel storage capacity at Hamaoka #5 (628 tons) and Higashi-dori#1 (353 tons).
- Rokkasho storage pool : 3,000 tHM (since 1998)
- Mutsu interim storage : 5,000 tHM (becomes available at 300 tHM/year starting in 2010)

Spent fuel storage for MOX fuel is not considered.

[33] The total cost of interim storage options would be much less than total reprocessing options as JAEC comparison clearly suggested. (See JAEC comparison of option 1 vs. option 4, i.e. 5.2¥/kWh and 4.7-4.8¥/kWh.)

[34] The law on final disposal of specific radioactive waste (HLW), 2000. Chapter I, Article 2, defines "specific radioactive waste" as "vitrified waste which comes out of reprocessing of nuclear spent fuel ."

[35] Its storage capacity is 6,840 tHM for pool and 408 tHM for dry cask facility as of December 2005. Source: www.tepco.co.jp/nu/f1-np/data_lib/pdfdata/bk502-j.pdf.

[36] Fukushima prefecture accepted these additional storage facilities based on the promise that TEPCO would remove spent fuel to the *second* reprocessing plant after Rokkasho. When they found that the new Long Term Program published in 1994 postponed the 2nd reprocessing plant beyond 2010, they informed TEPCO that they would no longer accept additional spent fuel storage facility on-site.

[37] Source: Kenji Yamaji ed., "Dousuru Nihon no Genshiryoku," Study Group on Future of Nuclear Energy, Nikkan Kogyo Shinbun Ltd., 1998, p.46, (in Japanese).

[38] We assume that the Rokkasho storage pool has a capacity of 1,500 tHM of BWR and 1,500 tHM of PWR. 1,096tHM of BWR and 680 tHM of PWR spent fuels had been shipped to the Rokkasho pool by the end of April 2006. If Tsuruga 3 and 4 are not built as planned, the Tsuruga site will run out of storage capacity by 2017. We do not assume inter-site transfer of spent fuel. See notes for Figure 3.1 for other assumptions.

[39] *Memorandum of Aomori Prefecture*, Rokkasho Village and JNFL, 29 July, 2003.

[40] Source: Ministry of Economy, Trade and Industry (METI) and Ministry of Education, Culture, Sports, Science and Technology (MEXT), "Answers to the Questions Raised by Inami Tetsuo," (The House of Representatives member) for the plutonium management in Japan, August 2004. The numbers have been rounded.

[41] As of the December 2004, there are 37.1 tons of separated plutonium overseas and 5.7 tons in the country (see Table 2.6).

[42] Assumptions are as follow: 1) Before 2004: actual data; 2) After 2005: Demand: MOX fuel: After 2012, 0.52 tPu/yr/t x18 plants = 9.3 tons/yr, Monju: re-start after 2010, 0.47 tPU/yr. Supply: Tokai reprocessing plant: stop in 2004, Rokkasho reprocessing plant: start from 2006 (8 tPu/yr). Pu separation ratio of Rokkasho (JNFL) is assumed 1% of spent fuel. Amount of consumed Pu is followed by the MOX plan of FEPC Japan, January 2006.

[43] According to AREVA, MELOX plant supplies MOX fuel for 20 LWRs at a capacity of 101 tHM/yr, which was increased to 145 tHM/yr in 2003 to meet additional 8 LWRs for unspecified future plan. Furthermore, in September 2004, MELOX submitted an application to increase its output to 195 tHM/yr. Therefore, we assumed MOX fabrication capability in Europe is sufficient to meet to Japanese demand.

Appendix I. Power Reactors Operating, Under Construction and Planned in Japan

Owner	Plant Name	Type	Gross Output [MWe]	Date of Commercial Operation	Plant Status (as of 2006.1)
Hokkaido	Tomari-1	PWR	579	1989	OP
	Tomari-2	PWR	579	1991	OP
	Tomari-3	PWR	912	2009	UC
Tohoku	Onagawa-1	BWR	524	1984	OP
	Onagawa-2	BWR	825	1995	OP
	Onagawa-3	BWR	825	2002	OP
	Higashidori-1	BWR	1,100	2005	OP
	Higashidori-2	ABWR	1,385	2017	PL
	Namie Odaka	BWR	825	2017	PL
Tokyo	Fukushima I-1	BWR	460	1971	OP
	Fukushima I-2	BWR	784	1974	OP
	Fukushima I-3	BWR	784	1976	OP
	Fukushima I-4	BWR	784	1978	OP
	Fukushima I-5	BWR	784	1978	OP
	Fukushima I-6	BWR	1,100	1979	OP
	Fukushima I-7	ABWR	1,380	2012	PL
	Fukushima I-8	ABWR	1,380	2013	PL
	Fukushima II-1	BWR	1,100	1982	OP
	Fukushima II-2	BWR	1,100	1984	OP
	Fukushima II-3	BWR	1,100	1985	OP
	Fukushima II-4	BWR	1,100	1987	OP
	Kashiwazakikariwa-1	BWR	1,100	1985	OP
	Kashiwazakikariwa-2	BWR	1,100	1990	OP
	Kashiwazakikariwa-3	BWR	1,100	1993	OP
	Kashiwazakikariwa-4	BWR	1,100	1994	OP
	Kashiwazakikariwa-5	BWR	1,100	1990	OP
	Kashiwazakikariwa-6	ABWR	1,356	1996	OP
	Kashiwazakikariwa-7	ABWR	1,356	1997	OP
	Higashidori-1	ABWR	1,385	2014	PL
	Higashidori-2	ABWR	1,385	2016	PL
Chubu	Hamaoka-1	BWR	540	1976	OP
	Hamaoka-2	BWR	840	1978	OP
	Hamaoka-3	BWR	1,100	1987	OP
	Hamaoka-4	BWR	1,137	1993	OP
	Hamaoka-5	ABWR	1,380	2005	OP
Hokuriku	Shika-1	BWR	540	1993	OP
	Shika-2	ABWR	1,358	2006	OP
Kansai	Mihama-1	PWR	340	1970	OP
	Mihama-2	PWR	500	1972	OP
	Mihama-3	PWR	826	1976	OP
	Takahama-1	PWR	826	1974	OP
	Takahama-2	PWR	870	1975	OP
	Takahama-3	PWR	870	1985	OP
	Takahama-4	PWR	870	1985	OP
	Ohi-1	PWR	1,175	1979	OP
	Ohi-2	PWR	1,175	1979	OP
	Ohi-3	PWR	1,180	1991	OP
	Ohi-4	PWR	1,180	1993	OP

Owner	Plant Name	Type	Gross Output [MWe]	Date of Commercial Operation	Plant Status (as of 2006.1)
Chugoku	Shimane-1	BWR	460	1974	OP
	Shimane-2	BWR	820	1989	OP
	Shimane-3	ABWR	1,373	2011	UC
	Kaminoseki-1	ABWR	1,373	2014	PL
	Kaminoseki-2	ABWR	1,373	2017	PL
Shikoku	Ikata-1	PWR	566	1977	OP
	Ikata-2	PWR	566	1982	OP
	Ikata-3	PWR	890	1994	OP
Kyushu	Genkai-1	PWR	559	1975	OP
	Genkai-2	PWR	559	1981	OP
	Genkai-3	PWR	1,180	1994	OP
	Genkai-4	PWR	1,180	1997	OP
	Sendai-1	PWR	890	1984	OP
	Sendai-2	PWR	890	1985	OP
Japan Atomic Power Company	Tokai	GCR	166	1966	CD
	Tokai-2	BWR	1,100	1978	OP
	Tsuruga-1	PWR	357	1970	OP
	Tsuruga-2	PWR	1,160	1987	OP
	Tsuruga-3	ABWR	1,538	2014	PL
	Tsuruga-4	ABWR	1,538	2015	PL
J Power	Ohma	ABWR	1,383	2012	PL

Source: Ministry of Economy, Trade and Industry, Outline of Electricity Supply Plan in 2006 (in Japanese).
OP: in operation
UC: under construction
PL: planned
CD: closed down
FY: Japanese fiscal year (from April to March)

Appendix II. History of Japan's Plutonium Programs from 1980 to 2006

Year	Date	
1980	Mar 1	Japan Nuclear Fuel Service established
1984	Nov15	Plutonium shipment from France under U.S. Navy escort
1985	Mar 1	Japan Nuclear Fuel Limited (JNFL) established
	Apr 18	Aomori, Rokkasho, accepts siting of nuclear fuel cycle facilities
1988	Jul 17	New Japan-U.S. nuclear agreement effective
1993	Jan 5	Plutonium shipment from France under Japanese escort ship
	Apr 28	Rokkasho reprocessing plant starts construction
1994	Apr 5	Monju goes critical. Letter from Science and Technology Agency Minister (Chairman of JAEC) to Aomori Prefecture assuring that "Aomori Prefecture will not be the final disposal site of HLW without consent of the governor."
1995	Apr 26	First HLW shipment from France arrives at Rokkasho
	Dec 8	"Monju" sodium leak accident
1997	Feb 21	Federation of Electric Power Companies of Japan (FEPCJ) announces the MOX plan for 11 power companies
	Mar 11	JNC Tokai waste incineration plant explosion accident
1998	Jun 11	MITI's committee publishes report on "Interim Storage of Spent Fuel" which leads to amendment of regulation to allow AFR (other than reprocessing plant)
	Jul 29	MOU between Aomori Prefecture/Rokkasho Village and JNFL signed which says that, "If reprocessing project faces serious difficulties, after mutual consultations among Aomori Prefecture, Rokkasho Village and JNFL, JNFL will take appropriate measures including removing spent fuel out of the facility without delay."
	Nov 2	Fukushima Prefecture approved MOX recycling program (TEPCO)
	Oct 1	Power Reactor and Nuclear Fuel Development Corporation (PNC) reorganizes to become Japan Nuclear Cycle Development Institute (JNC)
	Oct 6	Spent fuel cask data falsification incident
1999	Sep14	BNFL MOX fabrication data falsification incident, canceling MOX program at Takahama (Kansai) and Fukushima (TEPCO)
	Sep 30	Tokai JCO criticality accident
2000	Apr 31	HLW Disposal Law passed
2001	May 27	Public Referendum on MOX recycling at Kariha-Village (Niigata), rejecting MOX program of TEPCO
	Aug 10	Rokkasho spent fuel pool water leak incident (leak continued until 2004)
2002	Aug 29	TEPCO Fukushima Inspection data falsification incident (revealed by whistleblower)
	Sep 26	Governor of Fukushima Prefecture withdraws his earlier agreement with TEPCO on MOX-fuel application for the Fukushima I-3 plant
	Nov 1	Chemical test begins in the Rokkasho reprocessing plant
2003	Jan 27	Anti-Nuclear Group win the legal suit against Monju (over safety licensing process flaw) Government appealed to Supreme Court
	Mar 29	Operation of Advanced Thermal Reactor (ATR) "Fugen" ceases
	Apr 15	All TEPCO nuclear plants (17 units) shutdown due to series of disclosure of mismanagement and illegalities in inspection activities
2004	Aug 9	Steam pipe explosion at Mihama Nuclear power plant killing two inspection engineers
	Dec 21	Uranium test begins in the Rokkasho reprocessing plant
2005	Oct 1	Amended nuclear reactor regulation law becomes effective and regulations on physical protection of nuclear material are strengthened.
		Fund for reprocessing of spent fuel is introduced
	May 30	Government wins the suit against "Monju" administrative law
	Jun 6	Second Rokkasho spent fuel pool water leak incident
	Oct 1	JNC and Japan Atomic Energy Research Institute (JAERI) integrate to form Japan Atomic Energy Agency (JAEA)
	Nov 21	Mutsu and TEPCO/JAPC agree to build a Recyclable-Fuel Storage Company (RFS, 5000 tons capacity) in Mutsu city (commissioning expected to be in 2010)
2006	Mar 31	Rokkasho reprocessing plant starts active testing

Appendix III. Japan's Back-End of Nuclear Fuel Cycle Costs

[¥100 billion is about $1 billion]

Project	Detail	Cost	
		Detail	Project Total
Reprocessing	Operation (Main part)	70.6	110
	Operation (Vitrified waste management)	4.7	
	Operation (Vitrified waste storage)	7.4	
	Operation (LLW management and storage)	7.8	
	Waste transport and disposal by operation	4.0	
	Decommission	15.5	
Returned HLW Management	Waste transport	0.2	3.0
	Waste storage	2.7	
	Decommission	0.1	
Returned LLW Management	Waste transport	1.4	5.7
	Waste storage	3.5	
	Waste transport to disposal site	0.3	
	Waste disposal	0.2	
	Decommission	0.4	
HLW Transport	HLW transport	1.9	1.9
HLW Disposal	HLW disposal	25.5	25.5
TRU Waste Geological Disposal	TRU waste geological disposal	8.1	8.1
Spent Fuel Transport	Spent fuel transport	9.2	9.2
Spent Fuel Interim Storage	Spent fuel interim storage	10.1	10.1
MOX Fuel Fabrication	Operation	11.2	11.9
	Waste transport and disposal by operation	0.1	
	Decommission	0.7	
Uranium Enrichment Facility Back-end	Waste treatment by operation	1.7	2.4
	Waste transport and disposal by operation	0.4	
	Decommission	0.4	
Total		**188**	

Sources : Materials from The Atomic Energy Commission etc.
LLW: Low Level Waste
HLW: High Level Waste
TRU: Transuranics

Appendix IV. Plans for Utilization of Plutonium to be Recovered at the Rokkasho Reprocessing Plant in FY2005 and 2006

Owner	Amount of Spent Fuel to be Reprocessed (tU) [a]		Amount of Plutonium Expected to be Allocated (tPuf) [b d]		Place to be Used as LWR Fuel [c]	Estimated Annual Usage Rate (tPuf per year) [d e]	Timing of the Start of Utilization [f] and Estimate of the Period Required for Utilization [g]
	FY2005	FY2006	FY2005	FY2006			
Hokkaido EPCo	-	-	-	0.0	Tomari Power Station	0.2	From FY2012 or later for a period equivalent to 0.5 years
Tohoku EPCo	-	-		0.0	Onagawa Nuclear Power Station	0.2	From FY2012 or later for a period equivalent to 0.5 years
Tokyo EPCo	-	60	-	0.5	Three to four Tokyo EPCo units, based on continued efforts by Tokyo EPCo to regain public trust from local communities at sites	0.9-1.6	From FY2012 or later for a period equivalent to 0.3-0.6 years
Chubu EPCo	-	-	-	0.1	Hamaoka Nuclear Power Station Unit 4	0.4	From FY2012 or later for a period equivalent to 0.3 years
Hokuriku EPCo	-	-	-	0.0	Shika Nuclear Power Station	0.1	From FY2012 or later for a period equivalent to 0.2 years
Kansai EPCo	-	102	-	0.3	Units 3 and 4 at Takahama Power Station and one or two units at Ohi Power Station	1.1-1.4	From FY2012 or later for a period equivalent to 0.3-0.4 years
Chugoku EPCo	-	-	-	0.1	Shimane Nuclear Power Station Unit 2	0.2	From FY2012 or later for a period equivalent to 0.5 years
Shikoku EPCo	-	-	-	0.1	Ikata Power Station Unit 3	0.4	From FY2012 or later for a period equivalent to 0.3 years
Kyushu EPCo	-	63	-	0.2	Genkai Nuclear Power Station Unit 3	0.4	From FY2012 or later for a period equivalent to 0.5 years
Japan Atomic Power Company (JAPC)	-	13	-	0.1	Tsuruga Power Station Unit 2 and Tokai Daini Power Station	0.5	From FY2012 or later for a period equivalent to 0.2 years
Subtotal	-	***238***	-	***1.4***		***4.4-5.4***	
Electric Power Development Company (EPDC)			Amount to be transferred from other utilities[h]		Ohma Nuclear Power Station	1.1	
Total	**238**		**1.4**			**5.5-6.5**	

Source: Federation of Electric Power Companies of Japan, 3 April 2006

These plans shall be updated in more detail as future progress is made in the Pluthermal Program, such as the start of fuel fabrication at Rokkasho MOX fuel plant, etc.

[a] "Amount of reprocessing" is based on JNFL's reprocessing program. Amount of recycling in FY2005 is zero (-).

[b] "Amount of plutonium" represents the estimated amount of plutonium to be allocated from reprocessing at JNFL's RRP in FY2005 and FY2006. Recovered plutonium is to be allocated to the utilities in proportion to the amount of fissile plutonium contained in the spent fuel they have delivered to RRP. Therefore, plutonium will also be allocated to the utilities whose spent fuel is not actually reprocessed in FY2005 and FY2006. However, plutonium will eventually be allocated in proportion to the amount of fissile plutonium contained in the spent fuel contracted for reprocessing by each utility.

[c] In addition to use as LWR fuel, some plutonium may be transferred to JAEA for R&D purposes. Specific amounts of plutonium to be transferred by each utility will be made public once such amounts have been determined.

[d] The amount of plutonium is described as the amount of fissile plutonium (Puf). (Total amount of plutonium may not add up owing to rounding to the first decimal place.)

[e] "Estimated Annual Usage" represents the average annual amount of plutonium contained in MOX fuel to be loaded into power reactors according to each utility's Pluthermal program. In some cases, the estimate may include plutonium recovered from overseas reprocessing.

[f] "Timing of the Start of Utilization" is stated as from FY2012 or later, when the Rokkasho MOX fuel fabrication plant, to be constructed adjacent to RRP, is scheduled to begin operation. Until then, plutonium will be stored at RRP in the form of uranium-plutonium mixed oxide powder.

[g] "Estimate of the Period Required for Utilization" is "Amount of Plutonium" divided by the "Estimated Annual Usage." (It does not necessarily reflect the actual period of use, because some plutonium is expected to be transferred to EPDC and JAEA, and in some cases the "Amount to be Used" may include the use of the plutonium recovered from overseas reprocessing.)

[h] The specific amount to be transferred to EPDC by the utilities will be made public once it has been determined.

About the Authors and Acknowledgements

Tadahiro Katsuta (Tokyo, Japan) has a PhD in plasma physics from Hiroshima University (1997). He is currently a Research Associate at the University of Tokyo. From 1999-2005 he did research on the economics of nuclear power relative to other sources of electrical power as an analyst at the Citizens Nuclear Information Center in Tokyo.

Tatsujiro Suzuki (Tokyo, Japan) has a PhD in nuclear engineering from Tokyo University (1988). He is a Senior Research Scientist in the Central Research Institute of [Japan's] Electric Power Industry in Japan as well as a Senior Research Fellow at the Institute of Energy Economics of Japan and Project Professor at the Graduate School of Law and Politics, University of Tokyo. He was Associate Director of MIT's International Program on Enhanced Nuclear Power Safety from 1988-1993 and a Research Associate at MIT's Center for International Studies (1993-95) where he co-authored a report on Japan's plutonium program. For the past 20 years, Suzuki has been deeply involved in providing technical and policy assessments of the international implications of Japan's plutonium fuel-cycle policies and in examining the feasibility of interim spent-fuel storage as an alternative. He was appointed as a member of the Working Group on International Affairs of the Japan Atomic Energy Commission's Long Term Planning Committee and now is a member of the of the Ministry of Economy, Trade and Industry's Advisory Committee on Energy (Nuclear Policy Subcommittee).

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Princeton University
221 Nassau Street, 2nd Floor
Princeton, NJ 08542, USA