INTERNATIONAL PANEL ON FISSILE MATERIAL

Japan's Civilian Nuclear Fuel Cycle And Nuclear Spent Fuel Management Issue

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June 2006

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1. Background and Objective

1.1 History and Overview of Nuclear Fuel Cycle Program

The Japanese commitment to nuclear fuel recycling has been maintained since the introduction of nuclear power to Japan and is specified in its Long Term Program since 1956. Japan has 55 Nuclear Power Plants (NPPs) in operation (50.5 GW), 2 NPPs under construction and 11 NPPs in planed as of March 2006 (See Appendix I).

Under the Japanese nuclear regulatory requirements, utilities must submit the evidence that nuclear spent fuel will be reprocessed when they load nuclear fuel. Besides, they also committed to the local community to ship spent fuel out of the local site to reprocessing plants. Therefore, there was no choice for utility companies but to make reprocessing contracts. As a result, during the 1970s, Japanese utilities made long term contracts with European reprocessing companies (COGEMA of France and BNFL of UK) since Japanese reprocessing capacity was not large enough to accommodate increasing spent fuel arisings. In 1980, Japanese utilities established a commercial fuel cycle company, Japan Nuclear Fuel Ltd.[3] (JNFL), and decided to build a large reprocessing plant in Rokkasho-village, in addition to the domestic Tokai reprocessing pilot plant[4] (nominal capacity 90t/year). On March 31, 2006, after a long delay and policy debate, the Rokkasho reprocessing plant started active testing. It is planned that plutonium recovered from reprocessing contracts will be used by MOX recycling and R&D program of Fast Breeder Reactor (FBR). But due to delays of MOX and FBR programs Japan has accumulated separated plutonium.

At the end of 2004, Japan had 37.4t of separated plutonium in Europe recovered from their long-term contracts with BNFL and COGEMA and about 5.7t from its domestic Tokai reprocessing pilot plant. International shipments of plutonium from the France and the UK and the increasing stockpile of plutonium in Japan have increased international concern over Japan's plutonium programs.

In order to reduce this concern, the Japan Atomic Energy Commission[5] (JAEC) introduced a "no plutonium surplus" policy, i.e. there shall be no plutonium stock in Japan that has no projected specific use. In addition, the Japanese government decided to disclose details on its plutonium stockpile and its locations annually in order to increase transparency.

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3 Japan Nuclear Fuel Ltd., http://www.jnfl.co.jp/english/index.html
4 This plant was closed down on March 31, 2006. 1,116tU of spent fuel was reprocessed since 1977. In the future, it will be used as an R&D facility.
5 Japan Atomic Energy Commission, http://aec.jst.go.jp/jicst/NC/eng/index.htm

We summarized history of Japan's plutonium programs from 1980 to 2006 in Appendix II.

1.2 Purpose of This Paper

On March 31, 2006, Rokkasho reprocessing plant started its active testing and it will start commercial operation in 2007. If the Rokkasho reprocessing plant operates at nominal capacity, about 8t[6] of plutonium will be recovered annually. Japanese utilities plan to recycle all plutonium, including the 37.4t in Europe, into existing Light Water Reactors (LWRs), but no single reactor has been loaded with MOX fuel as of February 2006. Therefore, it is likely that more plutonium will be accumulated once the Rokkasho plant starts operating.

It is thus important to understand the current status and future trends of Japanese reprocessing and plutonium programs, in order to assess non-proliferation implications. In this paper, we analyze the future requirements of spent fuel storage and examine possible options to minimize future plutonium stockpile in Japan without compromising Japan's energy security.

[6] In this paper, we measure separated plutonium in "total", i.e. both fissile and non-fissile plutonium unless otherwise stated.

2. Current Status and Policy Debate of Japan's Nuclear Fuel Cycle Program

2.1 Current Status of Nuclear Fuel Cycle Policy

Overview of Rokkasho reprocessing plant

JNFL has five facilities in Rokkasho village on Aomori prefecture, 1) Reprocessing plant, 2) MOX fuel fabrication facility, 3) Uranium enrichment facility, 4) High level radioactive waste storage and management center and 5) Low level radioactive disposal center. Table 2.1 shows the outline of three facilities except two radioactive waste center[7].

Table 2.1 Outline of Nuclear Fuel Cycle Business of JNFL
(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 disposal center
Method	Wet process (Purex process)	-	Centrifugal method	-	-
Size	800tU/year of reprocessing. 3,000tU of spent fuel capacity. 4,000tU of Uranium Oxide and 60 t(U+Pu) of MOX for Product stock.	130tHM/year	1,500tSWU/year (Final goal)	1,440 canisters of capacity (2,880 canisters capacity in the future)	1 million drums of 200litter (3 million drums of 200 litter in the future)
Current Status	Under construction	Planned	Operation (1,050tSWU/year)	1,016 rods	181,715
Construction Cost	¥2.14 Trillion	¥120 billion	¥250 billion	¥80 billion	¥160 billion
Operation Year	2007 (plan)	2012 (plan)	1992	1995	1992

Status of spent fuel management

Japanese utilities are under pressure to deal with accumulating spent fuel. Table 2.2 shows the current status of fuel storage at each site[8]. In this table, we estimate the year when storage capacity is filled up. According to this data, storage pools at some NPP sites like Fukushima II, Takahama and Hamaoka, will be already filled up by the end of 2006. However, as the Rokkasho reprocessing plant has been receiving spent fuel from NPP sites since 1999, these NPP sites can escape from spent fuel storage shortage. As of April 2006, the Rokkasho reprocessing plant already received 1,776 tU[9] of

[7] Source: JNFL Web site, etc.
[8] Source: Japan Atomic Energy Commission, White Paper on Nuclear Energy 2005(in Japanese).
[1] ESC=SC-(1 Full core + AD), hence ESC: Effective storage capacity, SC: Storage Capacity, AD: Annual discharge.
[2] $Y_f=Y_{2004}+(ESC-SF)/AD$, hence Y_f: Year when storage capacity is filled up for NPP site, Y_{2004}: year of march 2004, SF: Amount of spent fuel.
[9] In the 1,776 tU, 1,096 tU for BWRs and 680 tU for PWRs.

spent fuel.

Table 2.2 Amount of Spent Fuel At Each Site
(As of the end of March 2004)

Electric power companies	Plant name	No. of plants [tU]	1 Full core [tU]	Annual discharge [tU]	Amount of spent fuel [tU]	Effective storage capacity[1] [tU]	Year when storage capacity is filled up[2] [year]
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**

In order to solve future shortage problem, Japanese utilities decided to build an interim storage plant away from reactor (which is now allowed after the regulation change in 1998[10]). A first facility will be built at Mutsu city in Aomori prefecture projected to start operation in 2010. Recyclable-Fuel Storage Company[11] was established in November 2005 for managing this interim storage facility. Table 2.3 shows the outline of this plan[12].

Table 2.3 Mutsu interim storage

Method	Dry storage
Size	5,000tU
Current status	Plan
Construction cost	¥100 billion (include cost of dry cask)
Operation	2010 (plan)

10 Before this regulatory change in 1998, Spent fuel storage was allowed only at NPP sites and/or at reprocessing plants.
11 Recyclable-Fuel Storage Company, http://www.rfsco.co.jp/ (Japanese)
12 Source: Recyclable-fuel storage company web site.

2.2 Policy Debate over Nuclear Fuel Cycle Options

Comparison of fuel cycle options by JAEC

In November 2005, JAEC finished its deliberation process, which started from June 2004, for the latest Long Term Program for Peaceful Use of Nuclear Energy (now it is re-named as Framework for Nuclear Energy Policy[13]). One of the most urgent and controversial issues was whether Japan should maintain its commitment to the nuclear fuel recycling policy or not. In particular, the focus was on the economic assessment of the reprocessing vs. the once-through fuel cycle.

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

Table 2.4 Contents of four scenarios

Scenarios	**Assumptions**
Scenario 1: Full reprocessing	All spent fuel will be reprocessed. Spent fuel quantities that are beyond the capacity of the Rokkasho plant will be reprocessed in the future following interim storage. The fast breeder reactor cycle is assumed for the future.
Scenario 2: Partial reprocessing	All spent fuel will be reprocessed. Spent fuel quantities that cannot be reprocessed due to a lack of capacity of the Rokkasho plant will be directly disposed of following interim storage for cooling.
Scenario 3: Full direct disposal	All spent fuel will be directly disposed of following interim storage for cooling.
Scenario 4: Temporary storage	All spent fuel will be sent to interim storage and the decision on reprocessing will be delayed.

As you can see in Table 2.5, the economic analysis of the nuclear fuel cycle clearly shows that direct disposal is less expensive than the recycling option. However, JAEC assumed that there would be additional costs due to policy change. It was estimated that cancellation costs of Rokkasho reprocessing plant would be 0.2 Yen/kWh and the alternative fuel cost would be 0.7 to 1.3 Yen/kWh. The latter cost was calculated based on the assumption that all nuclear plants would be shut down eventually due to shortage of spent fuel storage capacity without the Rokkasho plant, and new fossil plants would be built to compensate loss of nuclear power plants. Consequently, the costs of scenario 3 and 4 were estimated at 5.4-6.2 yen/kWh and 5.6-6.3 yen/kWh respectively which make them more expensive than scenario 1 and 2.

Moreover, evaluations from other aspects like energy security and non-proliferation were carried out[14].

[13] English version is http://aec.jst.go.jp/jicst/NC/tyoki/taikou/kettei/eng_ver.pdf

[14] There were total 10 criteria for evaluations. They were 1) Assurance of Safety, 2) Technical Feasibility, 3) Economic Viability, 4) Energy Security, 5) Environmental Protection, 6) Nuclear Non-Proliferation, 7) International

Compared with economical analysis, other evaluations were not well discussed and its analysis was weak[15]. At the end, however, the JAEC concluded that reprocessing option is superior to other three options.

Table 2.5 Cost comparison for four scenarios[16]

			Scenario 1: Full reprocessing [Yen/kWh]	**Scenario 2: Partial reprocessing** [Yen/kWh]	**Scenario 3: Full direct disposal** [Yen/kWh]	**Scenario 4: Temporarily storage** [Yen/kWh]
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	-	0.12-0.21 (0.09-0.21)[2]	0.19-0.32 (0.14-0.32)[2]	0.09-0.16 (0.07-0.16)[2]
	Total		1.6 (1.5)[1]	1.4-1.5	0.9-1.1	1.1-1.2
Generation cost[3]			**5.2 (5.1)[1]**	**5.0-5.1**	**4.5-4.7**	**4.7-4.8**
Cost for Policy Change[4]			-	-	**0.9-1.5**	
Total Cost			**5.2 (5.1)**	**5.0-5.1**	**5.4-6.2**	**5.6-6.3**

Consequently, the JAEC decided to maintain its recycling policy in November 2005 and operation testing using with uranium fuel ("cold testing") was carried out at the Rokkasho reprocessing plant in the following month.

Cost Recovering Scheme of Reprocessing: 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) finished the discussion about the back-end cost of nuclear fuel cycle. First, they concluded that nuclear power generation costs would be competitive (¥5.3/kWh) compared to electricity generated by fossil power plants (¥6-10/kWh), and its back end fuel cycle cost would be around ¥0.8/kWh.

Trends, 8) Issues resulting from Policy Change, 9) Social Acceptability, 10) Assurance of Choice (Adaptability to Future Uncertainty).

15 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.

16 HLW: High Level Radioactive Waste, TRU：Transuranics

[1] Cost of the second reprocessing plant is assumed to be half that of the Rokkasho reprocessing plant.

[2] Including the cost of horizontal setting.

[3] Cost excluding fuel cycle (ex. Capital cost, Operation and management cost) is assumed as 3.6 Yen/kWh in all scenarios.

[4] 1) Construction cost of Rokkasho reprocessing plant: ¥0.2/kWh, 2) Thermal power generation cost that replace nuclear power plants which would be shut down due to shortage of spent fuel storage capacity: ¥0.7-1.3/kWh.

At the same time, the Government 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 plant and MOX fuel fabrication (see Appendix III). Under the liberalized electricity market, it is argued that utilities cannot afford such high economic risks so that a new cost recovery system is needed.

The Government committee decided to exclude 6.1 trillion yen (MOX fuel fabrication cost, spent fuel interim storage cost, and high level waste disposal cost which is covered by the existing fund) out of total back-end cost (18.8 trillion yen). Therefore, total of 12.7 trillion yen[17] out of 18.8 trillion yen is only allowed to be recovered under the new scheme. This cost mainly covers lifetime cost of Rokkasho reprocessing plant (construction, operation, decommissioning cost) and TRU waste disposal cost.

The fund will be collected through transmission cost charge as well as retail electricity rate. The law to establish the new "reprocessing fund" was passed by the Diet in May 2005 (see Fig.2.1).

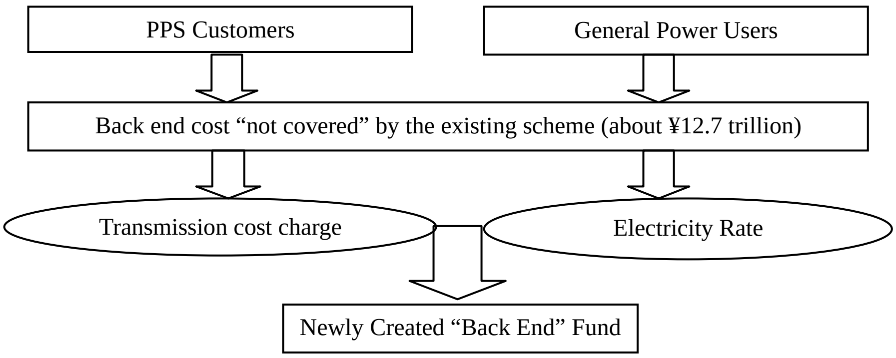

Fig.2.1 New scheme for the establishment of a reprocessing fund

However, this does not eliminate financial risks of reprocessing option entirely. The fund only covers reprocessing costs of 32,000t 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[18]. Besides, fund retrieval is subject to the approval by METI and it is assumed that loss due to accidents and adverse circumstances caused by the operators will not be covered by the fund. Therefore, even with this scheme, utilities may face future financial risk associated with reprocessing option.

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

[18] Sub committee on nuclear energy policy of METI advisory committee on energy policy submitted its interim report on May 30, 2006 in which they propose additional financial scheme to recover future reprocessing costs beyond Rokkasho reprocessing plant.

2.3 No plutonium surplus policy and its implementation

Management of Plutonium Separation

Table 2.6 shows the current stockpile of separated plutonium as of the end of December 2004[19]. Japan has 37.1t in UK and France and 5.7t in Japan.

Table 2.6 The Current Stockpile of Separated Plutonium in Japan
as of the end of December 2004

Unit: kgPu
( ): As of December 2003

1. The separated plutonium in domestic storage

Reprocessing Plant	JNC Reprocessing Plant	Plutonium nitrate, etc. [1]	562 (478)
		Plutonium oxide [2]	275 (218)
	Total		**837 (695)**
		Pu fissile in total	569 (474)
Fuel Fabrication Plant	JNC Plutonium Fabrication Plant	Plutonium oxide [2]	2,422 (2,465)
		Plutonium in the stage of test or fabrication	686 (739)
		Products for new fuel	433 (331)
	Total		**3,562 (3,536)**
		Pu fissile in total	2,499 (2,488)
Power Plants, etc.	Joyo	Plutonium that stored for new fuel in the plants, and that supplied to R&D	85 (18)
	Monju		367 (367)
	Fugen		0 (0)
	Commercial		415 (415)
	R&D [3]		445 (445)
	Total		**1,311 (1,244)**
		Pu fissile in total	976 (928)
Total			**5,710 (5,475)**
	Plutonium fissile in total		4,045 (3,889)

2. The separated plutonium in foreign storage [4]

Recovered Pu in UK		15,897 (13,614)
Recovered Pu in France		21,503 (21,554)
Total		37,400 (35,168)
	Plutonium fissile in total	25,285 (23,838)

3. The status of the oxide plutonium usage in the separated plutonium

Supply	Recovered oxide plutonium from the JNC Reprocessing plant	171 (167)
	Transferred oxide plutonium from overseas	0 (0)
Usage [5]	Monju, Joyo , Fugen etc.	130 (270)

[19] Source: Cabinet Office, Ministry of Education, Culture, Sports, Science and Technology(MEXT) and Ministry of Economy, Trade and Industry(METI), September 6th, 2005.
[1] After the separation before mixture and conversion.
[2] Stored as mixed oxide powder in container
[3] Fast Critical Assemblies (FCA), etc.
[4] Basic policy is to fabricate this plutonium into MOX fuel in Europe and to use it in LWR in Japan.
[5] It is defined as the amount of plutonium that is moved from the storage process zone to the fabrication process zone in the fuel fabrication facilities.
The number is rounded off to one decimal. The number shows the total plutonium element weight (fissile and non-fissile plutonium) except for the numbers in the broken line (which is fissile only).

New policy guideline

In August 2003, JAEC announced its new guidelines for plutonium management. Under the new guidelines, utilities are expected to submit their plutonium use plan annually *before* separation of plutonium.

Such a plan is supposed to include information on:

(1) Planned amount of reprocessing and of recovered plutonium during the year

(2) Estimated amount of plutonium inventory at the end of previous year

(3) Planned site or power plant for use of recovered plutonium

(4) Estimated amount of plutonium use during the year

(5) Estimated timing and duration of plutonium use

(The following information can be added later)

(6) Planned amount of MOX fabrication and number of fuel assemblies during the year

(7) Planned timing of MOX loading and the name of power plant

On January 6, 2006, all electric companies who plan to use plutonium, published their utilization plan for plutonium, which will be recovered at the Rokkasho reprocessing plant during active testing (FY2005, 2006). According to this plan, 238t of spent fuel will be reprocessed and 1.4tPuf plutonium fissile will be separated during the active testing by the end of March 2007. Beyond active testing, annual consumption rate of 5.5-6.5 tPuf is being expected after 2012 (See Appendix IV). It should be noted that this plan does not include the information on MOX program for plutonium recovered in Europe.

Status of MOX program

Officially, the Federation of Electric Power Companies (FEPCO) of Japan still has a plan to use MOX fuel in 16 to 18 nuclear power plants by 2010 primarily for plutonium recovered in Europe. However the plan has been delayed mainly due to a series of nuclear accidents, scandals and mismanagement, such as 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. In order to facilitate the MOX programs, METI also decided[20] to increase its subsidy (kofu-kin) to local governments that will accept a MOX program. There are signs that some smaller utilities (Kyusyu, Shikoku and Chugoku electric power company) may start MOX program sooner than those two largest utilities. For example, Kyusyu electric power company announced that it will load MOX fuel at Genkai power station as early as 2010[21].

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

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

JAEA, owner and operator of the “Monju” fast breeder prototype reactor (280MWe), is now preparing for restart after almost 10 years of negotiations with local the government. Opposition groups’ legal fight against Monju was lost when the Supreme Court in 2005 made the final decision to endorse the safety licensing of Monju. Therefore, there are no legal and political barriers to restart Monju. JAEA plans to restart Monju at around 2010[22], but its future operational schedule has not been finalized yet. There are other smaller reactors owned by JAEA which use plutonium as primary fuel (see Table 2.7) [23].

Table 2.7 Fugen, Joyo and Monju
(as of the end of May 2006)

	Fugen	Joyo	Monju
Type	Advanced Thermal Reactor (ATR) Prototype Reactor	Fast Reactor (FR) Experimental Reactor	Fast Breeder Reactor (FBR) Prototype Reactor
Output(MWt/MWe)	557/165	140/-	710/280
Critical year	1978	1977	1994
Plutonium use (kgPu)	1845	85[1]	367[1]
Current status	Closed Down(2005)	Operation	Stopped

[22] Framework for Nuclear Energy Policy.
[23] Source: Website of JAEA and Fugen, Monju (http://www.jaea.go.jp/, http://133.53.8.211/04/fugen/index.html, http://www.jnc.go.jp/04/monju/index.html) etc.
[1] As of the end of March 2004.

3. Analysis of future spent fuel and Plutonium management

3.1 Analysis of Spent Fuel Management

Future projection

In order to clarify the needs and timing of away from reactor (AFR) spent fuel storage, we estimate future generation of spent fuel and storage capacity at reactor sites as well as at reprocessing plant.

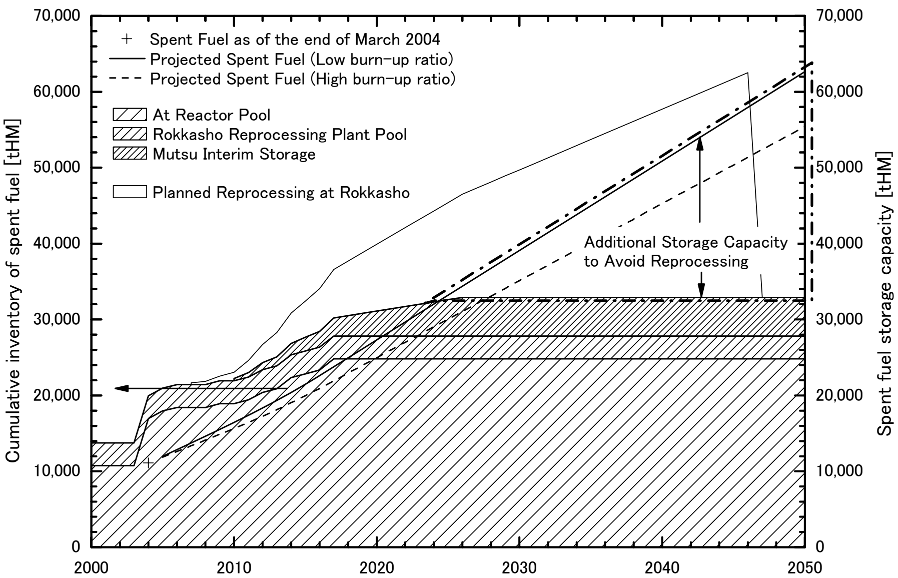

Fig.3.1 Cumulative inventory and management of spent fuel in the future

We calculate the cumulative inventory amount of spent fuel up to 2050[24] and compare those with the storage capacity up to 2050[25]. Fig. 3.1 shows the result of calculations. The cumulative amount of spent fuel stored at NPP sites as of the end of 2004 is 11,100 tU (See Table2.2). In the future, cumulative spent fuel arising is expected to increase to 30,000 tU at 2020 and 38,000 tU at 2030. On

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

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

Hence, 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).

[25] Spent fuel storage capacity that we assumed are as follows,

1) NPP Storage: 16,940 tHM / 53 plants (up to 2004), 490 tHM / new plants (x15 new plants)(since 2005)
We assume average storage capacity of new NPPs is 490 tons/plant, based on the published figures of spent fuel storage capacity of Hamaoka #5 (628 tons) and Higashi-dori#1 (353 tons).
2) Rokkasho storage pool : 3,000 tHM (since 1998)
3) Mutsu interim storage : 5,000 tHM (since 2010, 300 tHM/year)

Spent fuel storage for MOX fuel is not considered.

the other hand, total spent fuel storage capacity (including capacity at NPP sites, Rokkasho storage pool and Mutsu interim storage facility) will reach at 33,000 at year of 2026 and will stay the same afterwards. We do not consider expanding storage capacity at NPP sites.

This figure shows that there will be sufficient spent fuel storage capacity up to year of 2025(low burn-up ratio case) or 2028(high burn-up ratio case). Therefore, there is no urgent need for reprocessing until mid 2020s. Without reprocessing, there will be a need for maximum of 30,000 t of AFR spent fuel storage capacity (six more Mutsu type facilities) by 2050. Total cost of such storage is estimated at around 0.7 trillion yen. This is much less expensive compared with reprocessing cost of Rokkasho plant (18.8 trillion yen). In addition, if we increase fuel burn up ratio, it reduces generation of spent fuel by 10%, which will eliminate AFR storage capacity of one Mutsu size storage facility.

Barriers for spent fuel storage

But, political constraints are severe. The above analysis does not consider difficulties of spent fuel storage such as spent fuel transfer among NPP sites and siting of AFR storage facilities.

First, it is possible that some utilities face shortage of spent fuel storage if transfer of spent fuel is not allowed. By the year of 2020, 10 NPPs will run out storage space in the case of low burn-up fuel. The list of those plants and the year of filled up (in parenthesis) are; BWR: FukushimaII(2006), Kashiwazakikariwa (2010), Tokai (2010), Hamaoka (2013), Fukushima I(2020), PWR: Takahama(2007), Genkai(2011), Mihama(2013), Sendai(2013), Ohi(2015). After those storage pools will be filled up, it is planned that spent fuel will be shipped to Rokkasho storage pool. Storage pool at Rokkasho plant has a capacity of 3,000tU in total, but it is divided into three sections; 1,000tU of PWR spent fuel, 1,000tU of BWR spent fuel and 1,000tU for either type of spent fuel. Besides, while Mutsu interim storage facility will have 5,000 tU spent fuel storage capacity, its availability can be limited because of its ownership. TEPCO is entitled to ship total of 4,000tU and JAPC is entitled to ship total of 1,000tU. It is planned that 300tU/year of storage capacity will be added at Mutsu interim storage facility from 2010, which will be used by TEPCO only until 2027 when JAPC (Tsuruga site) is expected to run out of storage capacity.

Given those conditions, we estimate when PWR and BWR sites will run out of storage capacity without reprocessing[26]. Fig.3.2 shows our estimate. At PWR sites, storage pool will be filled up by

[26] Calculation condition is the same as Fig.3.1.
We assume Rokkasho storage pool has a capacity of 1,500tU of BWR and 1,500tU of PWR. 1,096tU of BWR and 680tU of PWR spent fuels have been shipped to Rokkasho pool by the end of April 2006. If Tsuruga 3 and 4 will not be built as planned, Tsuruga site will run out of storage capacity by 2017.

2014, although Mutsu storage capacity for PWR will still be available. Meanwhile BWR sites will be filled up by 2019, since Mutsu storage capacity of 4,000tU will not be built up by then. If we assume high burn-up spent fuel, PWR sites can hold until 2016 while BWR sites can have enough capacity even beyond 2020. This analysis illustrates complicated nature of spent fuel management in Japan while the need for reprocessing can be significantly reduced by optimum storage capacity management.

Second, local politics of spent fuel storage is complex and difficult to manage, and finding additional storage capacity does not necessarily eliminate the needs for reprocessing. For example, Aomori prefecture demanded that the Government guarantees maintaining of reprocessing policy since there is a concern that spent fuel will stay forever if there is no reprocessing[27]. Those political conditions forced utilities to maintain their commitment to start up of Rokkasho reprocessing plant.

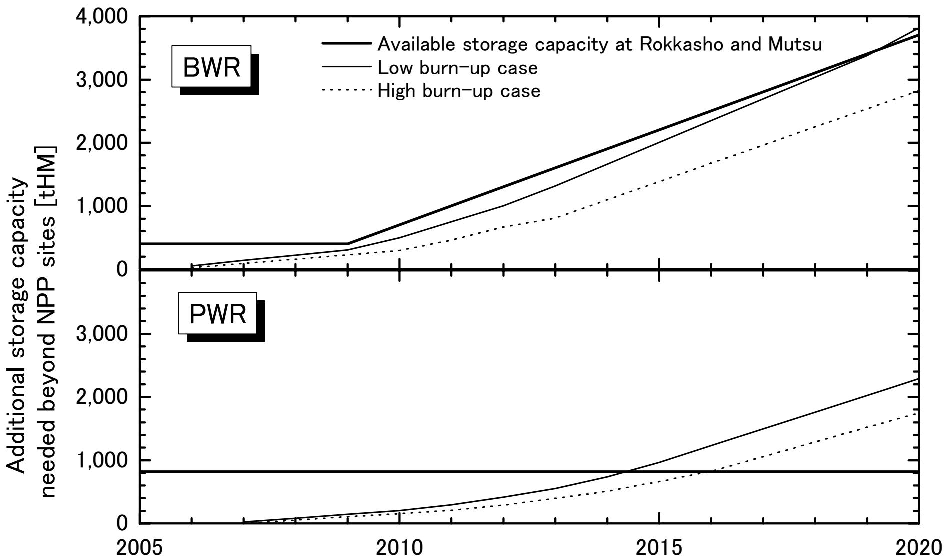

Fig. 3.2 Additional storage capacity needed beyond NPP sites

3.2 Analysis of Plutonium Balance

Current stockpile

Fig.3.3 shows the current situation of plutonium stockpile (as of March 2004) [28]. This is based on

[27] Memorandum of Aomori prefecture, Rokkasho village and JNFL, 29 July, 2003.

[28] 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 are rounded off to one decimal.

the information given by the Government answering to the question raised by a Member of Parliament (Mr. Tetsuo Inami).

Japan owned a total of 157t of plutonium, of which 98t (62% of total) was stored in the storage pools of nuclear power plants in the form of spent fuel. 60t of plutonium (38% of total) contained in spent fuel was transported to reprocessing plants, out of which 46t (30% of total) of plutonium was separated from spent fuel. Only 7 tons were separated in Japan and 39 tons were separated in Europe. Remaining 14t (7t in Europe and 7t at Rokkasho) were not reprocessed yet.

Out of the 46t of separated plutonium (see center column), only 5t was consumed and plutonium stockpile in Europe was 35t and domestic plutonium stockpile was 5t[29] (see right column). The major consumers of plutonium were: Fugen (ATR Prototype reactor), which was closed in March 2003 and Monju (FBR Prototype reactor), which has been stopped since 1995 due to a sodium leak accident. So far, there has been no consumption by MOX use in commercial reactors.

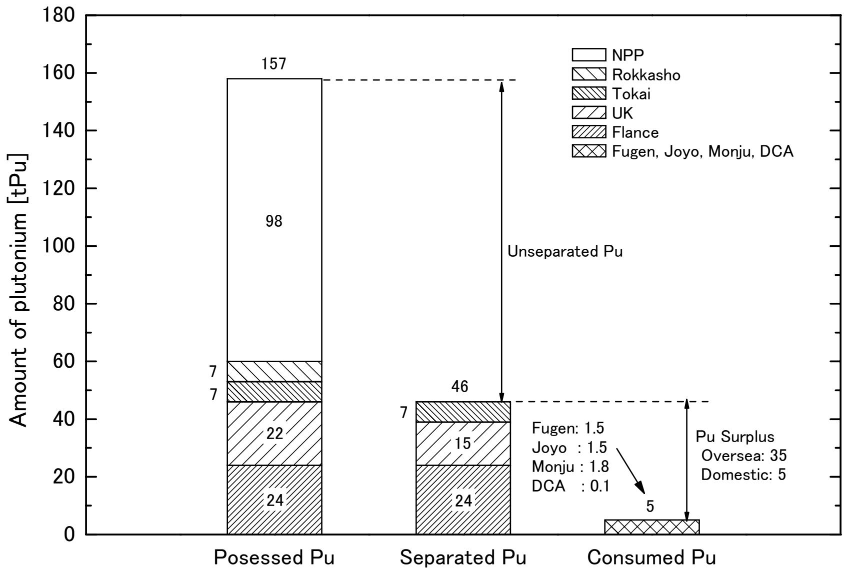

Fig.3.3 The management of plutonium (As of March 2004)

Future projection and possible options

Fig. 3.4 shows the future plutonium stockpile until 2020 based on the current plutonium supply and

29 As of the December 2004, there are 37.1t of separated plutonium is in oversea and 5.7t of it in domestic (See Table 2.6).

demand plans[30]. Under the current plan, Japanese plutonium stockpile will be expected to increase to about 80t by 2012, and then will decline to about 70t in 2020[31]. Alternatively, Japanese utilities could use domestic plutonium stocks first and leave plutonium in Europe as they are now. In this case, with current MOX recycling programs, Japanese plutonium stockpile would not go beyond 50t and can decline to about 30t (see Fig.3.5) in 2020.

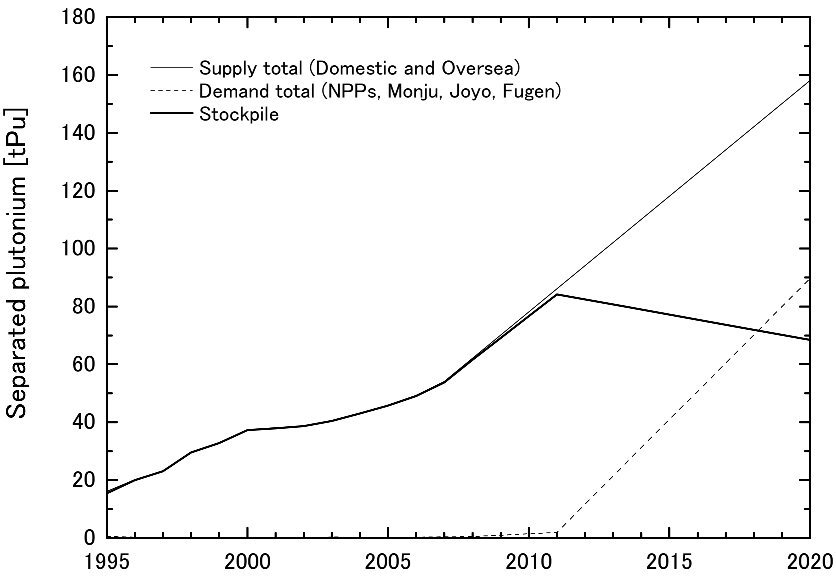

Fig.3.4 Cumulative separated plutonium balance between plutonium supply from foreign and domestic reprocessing and Plutonium demand of commercial NPPs(MOX), etc.

If the Rokksho plant starts its operation as planned without any progress in MOX recycling programs, Japan's plutonium stockpile could increase up to 160t by 2020. Meanwhile, plutonium storage capacity in Japan is reported to be about 50t (30t at Rokkasho, 20t at Tokai), and thus it is possible that reprocessing operation may be constrained by this physical capacity limit.

In order to minimize plutonium stockpiles, deferring operation of Rokkasho plant would be best. Still, it would take until 2015 to consume current plutonium stockpile in Japan and in Europe[32] (see Fig. 3.6). Deferring operation of Rokkasho until 2015 would not require additional spent fuel storage

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30 Assumption are as follows, 1) Before 2004: actual data, 2) After 2005: Demand: MOX fuel: After 2012, 9.3 tPu/year/plants x18 plants, Monju: re-start after 2010, 0.47tPU/year, Supply: Tokai reprocessing plant: stop in 2004, Rokkasho reprocessing plant: start from 2006 (8 tPu/year). 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 (Jan. 2006).

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

capacity for Japan as a whole.

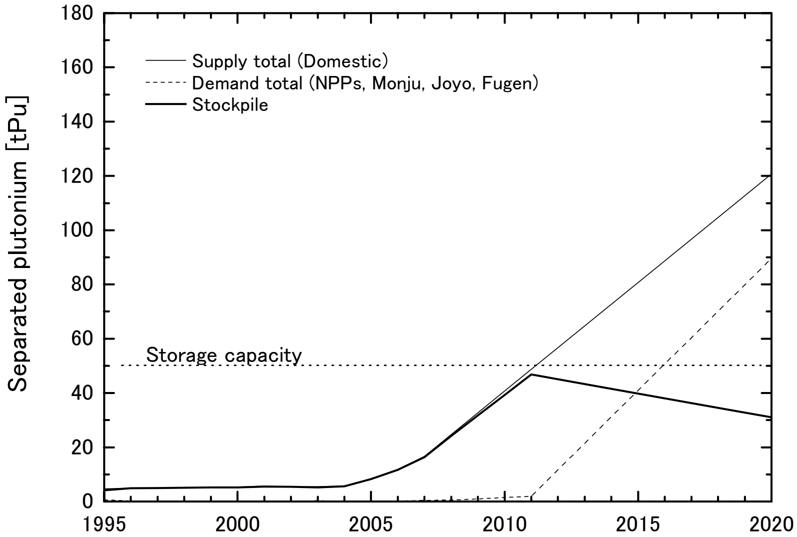

Fig.3.5 Cumulative separated plutonium balance between plutonium supply from domestic reprocessing and plutonium demand of commercial NPPs(MOX), etc.

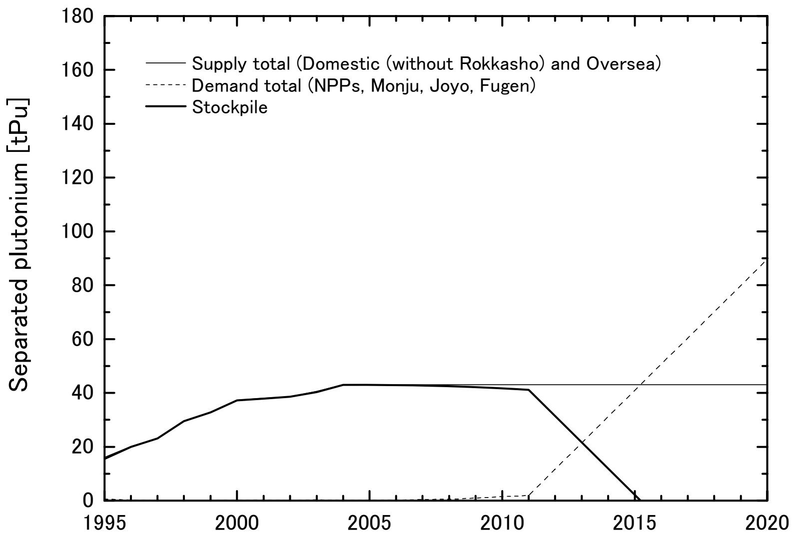

Fig.3.6 Cumulative separated plutonium balance between plutonium supply from foreign reprocessing and Plutonium demand of commercial NPPs(MOX), etc.

4. Conclusion

In order to assess non-proliferation implication, we examined that the current status and future trends of spent fuel management and plutonium programs.

Despite clear economic disadvantage of reprocessing option compared with direct disposal or storage option, JAEC decided to maintain reprocessing policy in the latest Framework for Nuclear Energy Policy. Following the Government decision, the Rokkasho reprocessing plan has started its active testing on March 31, 2006.

The financial risk to Japan’s nuclear utilities of operating the Rokkasho plant has been significantly reduced by the establishment of a “reprocessing fund” as all electric-power consumers -- not just nuclear-power consumers -- will bear the costs. Still, the risk is not entirely eliminated. Losses due to accidents or operational problems are unlikely to be covered by the fund.

Japan’s spent fuel management and its fuel cycle programs are now at critical stage. Our analysis on future spent fuel management suggests that there will be sufficient spent fuel storage capacity up to year of 2025(low burn-up ratio case) or 2028(high burn-up ratio case). Therefore, there is no urgent need for reprocessing until mid 2020s. Without reprocessing, there will be a need for maximum of 30,000 t of AFR spent fuel storage capacity (six more Mutsu type facilities) by 2050. Total cost of such storage is estimated at around 0.7 trillion yen. This is much less expensive compared with reprocessing cost of Rokkasho plant (18.8 trillion yen).

But, political constraints are severe. The above analysis does not consider difficulties of spent fuel storage such as spent fuel transfer among NPP sites and siting of AFR storage facilities. Our analysis shows that at PWR sites, storage pool will be filled up by 2014, although Mutsu storage capacity for PWR will still be available. Meanwhile BWR sites will be filled up by 2019, since Mutsu storage capacity of 4,000tU will not be built up by then. This analysis illustrates complicated nature of spent fuel management in Japan while the need for reprocessing can be significantly reduced by optimum storage capacity management.

If the Rokkasho plant starts operation as planned, Japan’s plutonium stockpile will likely to grow to more than 70 tons by 2020 from the current 43 tons in 2005. On the other hand, if the Rokkasho plant does not operate as planned, its spent fuel storage capacity will likely run out by 2020. This is why the nuclear utilities are desperate to start operation of Rokkasho and also to find interim storage sites.

Deferring operation of the Rokkasho plant with an appropriate spent-fuel storage plan, at least until the plutonium stockpile had been worked down to the minimum required level, would be the best. We conclude that such strategy is feasible if spent fuel management and MOX program are better coordinated by the utilities. This would reduce pressure on utilities and minimize proliferation concern with Japan's plutonium programs.

Appendix I

Status and long-term nuclear power supply plan 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
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. (Japanease).
OP: in operation
UC: under construction
PL: planned
CD: closed down
FY: Japanease fiscal year (from April to March)
FY YEAR-: i.e., after April YEAR

Appendix II

History of Japan's plutonium programs from 1980 to 2006

1980	Mar. 1	Japan Nuclear Fuel Service established
1984	Nov.15	Pu shipment from France under US Navy escort
1985	Mar. 1	Japan Nuclear Fuel Limited (JNFL) established
	Apr. 18	Aomori, Rokkasho accepted siting of nuclear fuel cycle facilities
1988	Jul. 17	New Japan-US nuclear agreement effective
1993	Jan. 5	Pu shipment from France under Japanese escort ship
	Apr. 28	Rokkasho reprocessing plant start construction
1994	Apr. 5	Monju became 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	HLW shipment from France arrived
	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 published Report on "Interim Storage of Spent Fuel" which led to amendment of regulation to allow AFR (other than reprocessing plant)
	Jul. 29	MOU between Aomori Prefecture/Rokkasho village and JNFL signed which says "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 Japan Nuclear Cycle Development Institute (JNC)
	Oct. 6	Spent fuel cask data falsification incident
1999	Sep.14	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 about 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 won the legal suit against MONJU (for safety licensing process flow), 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 illegal 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 become effective and Physical

		protection of nuclear material is reinforced.
		Fund for reprocessing of spent fuel is introduced.
	May 30	Government wins the suit against "Monju" administrative law.
	Jun. 6	The second Rokkasho spent fuel pool water leak incident.
	Oct. 1	JNC and Japan Atomic Energy Research Institute (JAERI) integrates to form Japan Atomic Energy Agency (JAEA).
	Nov. 21	Mutsu and TEPCO/JAPC agrees to build a Recyclable-Fuel Storage Company (RFS, 5000 tons) in Mutsu city (commissioned expected to be 2010).
2006	Mar. 31	Rokkasho reprocessing plant starts to its Active Test.

Appendix III

Total Cost of Back End of Nuclear Fuel Cycle

[¥10 billion]

Project	Detail	Cost Detail	Cost Project Total
Reprocessing	Operation (Main part)	706	1,100
	Operation (Vitrified waste management)	47	
	Operation (Vitrified waste storage)	74	
	Operation (LLW management and storage)	78	
	Waste transport and disposal by operation	40	
	Decommission	155	
Returned HLW management	Waste transport	2	30
	Waste storage	27	
	Decommission	1	
Returned LLW management	Waste transport	14	57
	Waste storage	35	
	Waste transport to disposal site	3	
	Waste disposal	2	
	Decommission	4	
HLW transport	HLW transport	19	19
HLW disposal	HLW disposal	255	255
TRU waste geological disposal	TRU waste geological disposal	81	81
Spent fuel transport	Spent fuel transport	92	92
Spent fuel interim storage	Spent fuel interim storage	101	101
MOX fuel fabrication	Operation	112	119
	Waste transport and disposal by operation	1	
	Decommission	7	
Uranium enrichment facility back-end	Waste treatment by operation	17	24
	Waste transport and disposal by operation	4	
	Decommission	4	
Total		1,880	

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

Appendix IV

Plans for the utilization of plutonium to be recovered at the Rokkasho reprocessing plant in FY2005 and 2006

Owner	Amount of reprocessing *1 Amount of spent fuel to be reprocessed (tU)		Amount of plutonium *2 Amount of plutonium expected to be allocated (tPuf) *4		Purpose of Use (as LWR fuel) *3		
	FY2005	FY2006	FY2005	FY2006	Place to be used	Amount to be used (Estimated annual usage *5 in tPuf per year) *4	Timing of the start of utilization*6 and estimate of the period required for utilization*7
Hokkaido EPCo	-	-	-	0.0	Tomari Power Station	0.2	From FY 2012 or later for a period equivalent to 0.5 years
Tohoku EPCo	-	-		0.0	Onagawa Nuclear Power Station	0.2	From FY 2012 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 FY 2012 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 FY 2012 or later for a period equivalent to 0.3 years
Hokuriku EPCo	-	-	-	0.0	Shika Nuclear Power Station	0.1	From FY 2012 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 FY 2012 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 FY 2012 or later for a period equivalent to 0.5 years
Shikoku EPCo	-	-	-	0.1	Ikata Power Station Unit 3	0.4	From FY 2012 or later for a period equivalent to 0.3 years
Kyushu EPCo	-	63	-	0.2	Genkai Nuclear Power Station Unit 3	0.4	From FY 2012 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 FY 2012 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*8		Ohma Nuclear Power Station	1.1	
Total	238		1.4			5.5-6.5	

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

*1 "Amount of reprocessing" is based on JNFL's reprocessing program. Amount of recycling in FY2005 is zero(-).

*2 "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.

*3 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.

*4 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.)

*5 "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.

*6 "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.

*7 "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.)

*8 The specific amount to be transferred to EPDC by the utilities will be made public once it has been determined.