A Note on Japanese Policy at the Back-end of Nuclear Fuel Cycle: Past and Present[1]

Shunsuke Kondo
Chairman
Japan Atomic Energy Commission (JAEC)

Summary

(1) One of the major reasons Japan started the research, development and utilization of nuclear energy in the latter half of 1950s was to assure a future energy source in response to its heavy dependence on precarious foreign oil supplies. The JAEC that was established in 1956 pointed out that in order to pursue energy security by way of nuclear energy utilization, it is important for Japan to aim at establishing an independent closed fuel cycle and recommended to start the R&D of advanced power reactors that utilize plutonium recovered from the reprocessing of spent LWR fuel. The Government established in 1967 the Power Reactor and Nuclear Fuel Development Cooperation (PNC) and tasked it to promote the R&D of both advanced thermal reactor (ATR)[2] and fast breeder reactor (FBR) as power reactors in the future, both of which utilize mixed oxide (MOX) fuel. The PNC started the constructions of both the prototype ATR FUGEN in Tsuruga and the experimental sodium cooled FBR JOYO in O-arai in 1970 and the construction of the Tokai Reprocessing Plant (TRP) in 1971. These R&D were promoted under close cooperation with Canada, France, Germany, the United Kingdom and the United States.

(2) The major entity to start the nuclear energy utilization in Japan was, however, the electric power companies that believed that nuclear would be one of the major electricity generation technologies in the future. They started nuclear power generation in 1960s by introducing GCR technology from the United Kingdom at first and then switching to LWR technology introduced from the United States. Meeting with various troubles, they have spurred the nuclear reactor vendors to sophisticate and standardize the technology as well as overcome various initial failures and technological difficulties in corporation with the United States. Thus they have increased the capacity steadily to the current level of 48 GWe that is composed of 30 BWRs and 24 PWRs. If nuclear is taken into account, Japan's energy self-supply ratio rises from mere 4% to 16%. The Government is now expecting the electric power companies to supply about 50% of electricity by nuclear in 2030 for combating global warming.

[1] Submitted to President Obama's Blue Ribbon Commission on America's Nuclear Future as a background material of the author's presentation at the Commission on November 15, 2010.
[2] Heavy water moderated boiling light water cooled pressure tube type reactor

(3) In 1970s the electric power companies jointly decided to invest into the reprocessing business in Europe so as to assure a necessary amount of reprocessing service for the time being and to start the construction of a commercial reprocessing plant in Rokkasho, Aomori, i.e. the Rokkasho Reprocessing Plant (RRP) by establishing Japan Nuclear Fuel Ltd, (JNFL). In the end of 1990s, they decided to start the use of MOX fuel in one-third of their LWRs, utilizing the plutonium recovered in Europe. Today three plants are loading MOX fuel. The number will rise to five in a year and eventually these LWRs will load MOX fuel fabricated using plutonium recovered at the RRP, as they started the construction of a MOX fuel fabrication plant this October.

(4) Through the US-Japan negotiation on the startup of the TRP, Japan recognized it essential for the promotion of plutonium utilization to assure international confidence in observing the commitment of nuclear nonproliferation. Therefore before starting the construction of the RRP, Japan developed an adequate concept and technologies for the IAEA safeguards to large bulk-plutonium handling facilities, in cooperation with the IAEA, the United States, France and other countries that were interested in it. And it has accepted at the RRP the IAEA safeguards activities based on them. Japan also actively contributed to the realization of the Additional Protocol in the IAEA and became the first country with a nuclear fuel cycle program in which the IAEA started the implementation of Integral Safeguards. In addition, in order to increase transparency, Japan has published the quantities and the locations of separated plutonium it hold annually since 1997, and since 2005, the electric power companies, the JNFL and the Japan Atomic Energy Agency (JAEA: the successor of the PNC) have published at the beginning of every fiscal year the objectives of the reprocessing (when and how to use the plutonium recovered) to be executed in the year, based on the recommendation of the JAEC. The JAEC is continuing the review of their effectiveness from the viewpoint of increasing confidence in Japan.

(5) In parallel with the start of the construction of the TRP, the JAEC asked in 1976 relevant research organizations to study the technical feasibility of geological disposal of high level radioactive waste (HLW) separated from spent fuel during reprocessing. Considering that Japan is located in a tectonically active zone and therefore complex geology is expected in most of the country, they developed a concept of realizing a multi-barrier system with particular emphasis on near-field performance provided by a massive engineered-barrier system and a suitable geological environment at a depth greater than 300 m below the surface. And they reported to the JAEC in 2000 that this approach is appropriate to make the safety case for the disposal. Based on this positive result, the Government established in the same year the Nuclear Waste Management Organization of Japan (NUMO), an organization that would undertake the HLW disposal program in Japan. The NUMO adopted an open solicitation approach to find candidate areas for the feasibility study of locating a geologic repository from countrywide municipalities in 2002, aiming at starting the repository operation late 2030. In this

approach, areas to be surveyed or investigated will be selected carefully by a stepwise process consisting of literature survey, preliminary investigation and detailed investigation, respecting opinions of the concerned local communities at each step. Although no mayor of municipalities has succeeded in applying for the study yet, NUMO is currently committing to communication activities to achieve mutual understanding with the public on the necessity and the safety of geological disposal enthusiastically, working closely with the Government and electric power companies.

(6) The advanced power reactor and fuel cycle technology R&D activities have not been going smoothly, and commitment and perseverance have been required for the Government in promoting them. When a demonstration ATR was proposed as a next step to commercialize the ATR in 1995, the electric utilities rejected to participate in the project due to the unattractiveness of its economy. As a result, the operation of the prototype ATR, FUGEN was terminated soon. It was after persistent efforts over more than 6 years by the operator in communicating with local community on the safety and the importance of FBR that the construction of prototype FBR MONJU was started in 1985. Although it began operation in 1994, the leakage of secondary sodium occurred in 1995, after two months' operation at 40% of its rated power. A great deal of operator's effort was necessary before the operator recovered the trust of the people around the plant and was permitted to start necessary modification of the plant. It was in 2010 when MONJU could resume its operation.

(7) At the beginning of the 2000s, a dispute whether to suspend the hot operation of the RRP got considerable media attention, presumably because of the weakening of a sense of direction of nuclear energy policy in the public mind due to the abandonment of the ATR project, the JCO criticality accident, delay in the start of the use of MOX fuel in LWRs due to quality assurance issues at home and abroad, the difficulties in the restart of MONJU and so on. The JAEC took up the issue in its committee in 2004 and pursued the argument in an open and transparent way. In the process, the committee evaluated four policy options including a direct disposal option from various viewpoints. The committee concluded based on this exercise that, though the electricity generation cost in the case of pursuing the reprocessing will be about 10% higher than that of pursuing direct disposal, the reprocessing option is superior to the direct disposal option from the viewpoint of the importance of pursuing energy security and a sound material-cycle society and assuring measures to cope with future uncertainties. Based on this conclusion, the JAEC recommended the operation of the RRP, pointing out to electric power companies the importance of securing sufficient at-reactor and or away-from-reactor capacities of spent fuel storage considering the limit of the capacity of RRP as well as the risk of nuclear power generation being disturbed by the troubles in the RRP, promoting the use of MOX fuel in LWRs and supporting the activities to determine the site for geologic disposal of the HLW. At the same time, the Government established a special fund based on fees to

be collected from all electric customers in order to make sure all life-cycle costs of the RRP will be covered.

(8) The JAEC also asked the JAEA to step up the activity to promote the research and development of fast reactor and its fuel cycle technology, specifying goals in economy, safety and reliability, waste management and proliferation resistance and physical protection from the viewpoint of making it a sustainable energy technology. Currently, in cooperation with electric power companies and nuclear reactor vendors, the JAEA is exploring innovative technologies and reviewing their effectiveness in realizing innovative fast reactor and its fuel cycle systems in which not only plutonium but also minor actinides are recycled. The JAEC hopes that the JAEA and others will jointly propose a feasible design of the system before 2015, in close cooperation with like-minded countries including the United States and France, as it is a global interest and a duty of major nuclear energy users to make nuclear energy more sustainable.

1. Introduction

The area of Japan is about of 378, 000km^2 and the population is about 127 million in 2010. The population density is 337.2/km^2. About 70% to 80% of the country is forested, mountainous, and unsuitable for agricultural, industrial, or residential use. This has resulted in an extremely high population density in the habitable zones that are mainly located in coastal areas. Naturally many industrial zones are located in the neighborhood of highly populated area. One of the results due to this fact is the people's demands for stringent control of SOX and NOX emission: most of the fossil power plants in Japan have been equipped with an expensive desulfurizer and denitrizer since early 1990s when few electric power producers in major industrialized countries have done so, even though they have been using imported fuels of relatively high cost.[3]

At the same time, Japan is poor in indigenous energy resources and its source of foreign exchange that supports economy is the added-value trade, namely importing raw materials and exporting manufactured products. Therefore energy security has been one of the most important policy issues in Japan. This is the reason the Japan Atomic Energy Commission (JAEC) that was established in 1956 has recommended in its successive long term programs of research, development and utilization of nuclear energy that Japan should pursue the

[3]Average emission rates in 2005 are 0.2gSOX/kwh and 0.2gNOX/kwh in Japan. On the other hand those in the US are 3.3gSOX/kwh and 1.2gNOX/kwh.

establishment of its own nuclear fuel cycle for better utilization of resources and the saving in foreign currency along with the promotion of nuclear power generation. The purpose of this note is to outline how this recommendation has been pursued so far in more than 50 years, dividing this into three periods.

2. 1956-1979

The Government established the Japan Atomic Energy Research Institute (JAERI) and the Nuclear Fuel Corporation (NFC) just after the establishment of the JAEC as entities to promote the R&D of nuclear reactor and fuel cycle technology in accordance with the first recommendation of the JAEC. However, after the Japan Atomic Power Company (JAPC) that was established by electric power companies in 1957 decided to construct the Tokai nuclear power plant (NPP), by introducing gas-cooled reactor (GCR) technology from the United Kingdom (UK), the Commission decided in 1962 that the NFC should construct a reprocessing plant of which capacity is 0.7ton/day by way of introducing the technology from abroad, with a view to preparing for the generation of spent fuel in due time.

In the construction of Tokai NPP that began in 1960, the JAPC struggled with the increase of the construction cost due to the need for introducing innovative technologies to make the graphite core resistant to a design basis earthquake input far higher than that in UK and to equip the plant with the secondary shutdown system. The completion of the construction was delayed also because of the quality problem of materials supplied. The plant started operation in 1966.

In 1960s, electric utility companies switched nuclear power reactor technology over to light water reactors (LWR), based on the lessons learned from the JAPC's struggle, and the operation experience of Japan Power Demonstration Reactor (JPDR), a small BWR that the JAERI had constructed and operated since 1963. The constructions of Tsuruga-1 BWR and Mihama-1 PWR began in 1966 and 1967, respectively and both started operation in 1970. Since then the nuclear power generation capacity has grown every year and currently 54 units that consist of 30 BWRs and 24 PWRs are in operation, supplying about 30% of electricity generated in Japan. The energy self-supply ratio rises from mere 4% to 16% if nuclear is taken into account in the evaluation. The Government is now expecting the electric power companies to supply about 50% of electricity by nuclear in 2030 for combating global warming.

In 1966, the NFC concluded a contract with France to construct a reprocessing plant of which capacity was 0.7 tons of spent LWR fuel/day in Tokai (Tokai Reprocessing Plant: TRP). The JAPC then concluded a contract with UK to reprocess the spent fuel from Tokai NPP in UK and started to ship the spent fuel to UK in 1968.

In 1967, the Government established the Power Reactor and Nuclear Fuel Development Cooperation (PNC) and tasked it to promote the R&D of both advanced thermal reactor (ATR)[4] and fast breeder reactor (FBR) as power reactors in the future, both of which utilize mixed oxide (MOX) fuel. The PNC started the constructions of the prototype ATR FUGEN in Tsuruga and the experimental sodium cooled FBR JOYO in O-arai in 1970. These R&D programs were promoted under close cooperation with the United States (US), UK, Canada, France and Germany. As the NFC was integrated into the PNC, it became also the responsibility of the PNC to construct the TRP. The construction of the TRP began in 1971.

Entering into the 1970s, electric power companies began to recognize the importance of implementing spent fuel reprocessing as well as uranium enrichment[5] in face of rapid rise in the enrichment price. So they jointly decided in 1974 to share the cost of constructing reprocessing plants in UK and France so as to assure the reprocessing services for some time and start the construction of a large-scale commercial reprocessing plant in Japan. Based on this decision, they made contracts of reprocessing 4700 tons of spent fuel shipped to Europe from Japan with UK and France and established in 1980 the Japan Nuclear Fuel Services, which later became the Japan Nuclear Fuel Limited (JNFL), to task it to construct and operate a commercial reprocessing plant.

JOYO went critical in 1977 and FUGEN in 1978. The TRP that should supply plutonium to these reactors became ready to start reprocessing in 1977. However, as US President Carter indicated in 1977 that US would attempt to persuade other nations to adopt policies similar to the then new US nonproliferation policy, Japan and US went through extensive negotiations about the startup of the TRP, since the US-Japan Nuclear Cooperation Agreement had been amended in 1973 to include a requirement for a joint decision by the two countries to permit startup of a new reprocessing plant, giving US the right to intervene in the project.

The result was that US agreed to allow the operation for two years under the condition that Japan would halt the conversion of separated plutonium solution into oxide during this period and conduct a study on co-extraction process with a view to applying it to TRP. Both countries also agreed to promote R&D for improving safeguards technology for reprocessing plant. As a result, the TASTEX (Tokai Advanced Safeguards Technology Exercise) was executed by the IAEA, Japan, US and France from 1978 to 1981. Two years later the PNC succeeded in demonstrating an innovative co-conversion technology that enhances the proliferation resistance of the plant. Based on this success, two countries agreed on the extension of TRP operation beyond two years.

---

[4] Heavy water moderated boiling light water cooled pressure tube type reactor

[5] A short history of enrichment activity in Japan is given in Appendix 1.

3. 1981-2004

In 1984, the JNFL decided to construct a reprocessing plant of which capacity is 800 ton /year in Rokkasho, Aomori (the Rokkasho Reprocessing Plant: RRP), introducing the technologies of UP-3 reprocessing plant of COGEMA in France and those developed in UK and the PNC. In the preparation for the construction of the RRP, a lot of efforts were made to assure the safety, security and nonproliferation of the plant. As a result, its construction increased significantly and the construction began in 1993, 10 years after the decision of its construction.

As for the assurance of safety, a significant amount of efforts were made to strengthen the building against the military aircraft crash though the plant is at a sufficiently long distance from the nearby airbase. As for nonproliferation, it was recognized as essential for Japan's promotion of plutonium utilization to assure international confidence in observing the commitment of nuclear nonproliferation. Based on this recognition, Japan promoted during the period of 1988 through 1992 a multilateral forum called LASCAR (Large Scale Reprocessing Plant Safeguards) in cooperation with the IAEA, US , UK, France, Germany and EURATOM that aimed at developing an adequate concept and technologies for international safeguards to large bulk-plutonium handling facilities. This forum concluded that an effective and efficient safeguards function for such facilities could be established by adding advanced technologies including Near Real-Time Material Accountancy System (NRTA), a network-based integrated data collection and evaluation system and the on-site laboratory for rapid verification measurement to the safeguards technology already established. The safeguards system for RRP was developed based on this finding, in consultation with the IAEA and with US consent.

The experimental FBR JOYO has been used as a unique fast neutron irradiation facility in the world, increasing its thermal output from 50MW to 100MW in 1983 and 140MW in 2003. However, it is has been shutdown since 2007 due to a damage of upper feature of instrumented assembly in the core, of which repair will take time.

As for the prototype FBR MONJU, its construction was decided in 1979 based on the results of extensive R&D activities carried out at the O-arai Engineering Center of the PNC. However, it was after persistent efforts by the PNC over period of 6 years in communicating with local communities on the safety and the importance of FBR that the PNC could start its construction of in Tsuruga in 1985.

On the other hand, the JAERI has promoted the basic research on alternative fast reactor system based on advanced separation and transmutation technologies, including accelerator driven system for transmutation. Recovery of uranium from sea water has been also the favorite research topic of the JAERI and its Takasaki Radiation Chemistry Laboratory, in particular.[6]

The MONJU began operation in 1994. After two months' operation at 40% of its rated power, however, MONJU experienced a secondary sodium leakage event in 1995. The mismanagement of the information activity under intense media attention on this event forced the PNC to suspend the operation of MONJU and it took a significant period of time to get the consent of municipalities around the plant on the making of necessary modification for the restart. It was May this year that the plant started its zero power operation.

FUGEN had been operating smoothly since 1978, loading significant number of MOX fuel in the core. However, when the PNC proposed a project to construct a demonstration ATR as a next step toward the commercialization of ATRs, electric power companies rejected to participate in the project due to the unattractiveness of its economy in 1995. As a result, the operation of FUGEN was terminated in 2003. The total number of MOX fuel assemblies irradiated in FUGEN amounted to 772, about 40% of cumulative number of MOX fuel assemblies irradiated in the world at that time.

The MOX fuel for FUGEN, JOYO and MONJU has been fabricated at Plutonium Fuel Fabrication Facility of the PNC in Tokai, utilizing plutonium shipped from Europe and that recovered at the TRP. In 1997, a fire occurred at the Bituminization Demonstration Facility of TRP, where low-level liquid waste is solidified with asphalt for permanent storage. Due to the consecutive occurrence of significant events at the PNC's facilities, the PNC was restructured into the Japan Nuclear Fuel Cycle Development Institute (JNC) in 1998, of which mission was reduced to the promotion of the development of the advanced technology required for establishing the complete nuclear fuel cycle. By this time, electric power companies postponed the decision to start the construction of a demonstration FBR due to difficulty in finding a satisfactory scenario to commercialize it.

The JNC had experienced another restructuring when the Government decided to reorganize government-funded organizations in 2001. The new organization, the Japan Atomic Energy Agency (JAEA) was established in 2005, integrating JNC and JAERI. Along with this restructuring, the mission of TRP was changed into a reprocessing technology R&D facility.

In 1999, a criticality accident occurred at the Uranium Conversion Facility of JCO Co. Ltd. It was Japan's first criticality accident, exposing three workers to high radiation levels and causing exposure to some members of the general public adjacent to the facility. The cause of this accident appears to have been the use of illegal procedures. This accident had grave ramifications for nuclear safety in Japan.

---

[6] A short history of this activity is given in Appendix 2.

The IAEA Board of Governors approved a program of enhanced nuclear safeguards in 1997, the first major expansion of the agency's monitoring and inspection powers in 25 years. The new measures are embodied in a model additional protocol that will substantially expand IAEA access to information and facilities, thereby improving the agency's ability to verify that non-nuclear-weapon states that are parties to the Nuclear Nonproliferation Treaty (NPT) are not conducting clandestine nuclear weapons programs. Japan contributed actively to the realization of this additional protocol in the IAEA and its implementation. After its establishment, Japan has been inducing other countries to conclude the Additional Protocol with the IAEA. Japan itself accepted the Additional Protocol as the first country that is operating nuclear power plants and became the first country with a nuclear fuel cycle program in which the IAEA started the implementation of Integral Safeguards.

Furthermore, to demonstrate to the international community transparently that civil nuclear facilities and materials are not being used for undeclared purposes, Japan has published the quantities and the locations of separated plutonium it currently hold annually since 1997, and since 2005, the electric power companies, the JNFL and the JAEA have published at the beginning of every fiscal year the objectives of the reprocessing (when and how to use the plutonium recovered) to be executed in the year, based on the recommendation of the JAEC. The JAEC is continuing the review of their effectiveness from the viewpoint of increasing confidence in Japan.

Electric power companies had decided in the late 1990s that they would use the plutonium recovered and stored in Europe in their LWRs, fabricating it into MOX fuel in Europe. However, as the electric power companies that were to precede in this activity stumbled over the quality assurance issues in Europe and their own organizations, the start of the utilization of the MOX fuel was delayed into 2000s. Today three plants are in operation with MOX fuel and the number will become five within a year. In addition, an ABWR of which core is to be loaded fully with MOX fuel will start operation in four years. At the same time, as it became clear that the annual rate of spent fuel discharge will exceed the reprocessing capacity of the RRP, the Government recommended electric power companies to assure the storing capacity for spent fuel at reactor and or away from reactor for some time. At present one away-from-reactor interim storage facility is under construction in Mutsu, Aomori.

The PNC had started the R&D of geological disposal of high-level waste (HLW) from the reprocessing in parallel with the start of the construction of TRP based on the suggestion of the JAEC in 1976 and published the first report on the feasibility of geological disposal of HLW in Japan in 1992. The report discussed the feasibility of disposing a vitrified HLW that is stored for 30 to 50 years to allow cooling in a geologic repository based on a multi-barrier system in stable geology at a depth greater than three hundred meters below ground surface. The report supports the following major points:

- A sufficiently stable deep geological environment to ensure the performance of the multi-barrier system can be found in Japan, even though the country is located in a tectonically active zone:
- The repository can appropriately be designed and constructed based on presently available engineering technologies:
- Long-term safety can be ensured, based on the performance of the multi-barrier system, with particular emphasis on near-field performance provided by a massive engineered barrier system, taking into account the complex geology expected in Japan.

Recognizing that this report lacked sufficient information on geological environment, JAEC recommended the PNC to promote further generic R&D to increase confidence in the technical basis for disposal and thereby increase flexibility in future siting. The PNC pursued R&D following this comment to provide more reliable data on geological conditions at two study sites, and completed the second progress report in 1997.The JAEC judged that this report should provide a technical basis for promoting the general public's understanding of HLW disposal activity.

Based on this judgment, the JAEC recommended the Government regarding disclosure of information, securing of funds for disposal activities, the concept for establishing the implementing organization, and the development of a reliable and transparent system for the selection of a potential disposal site. After extensive public information activities for two years, the Government enacted the "Specified Radioactive Waste Final Disposal Act" in June 2000 and thereby established the Nuclear Waste Management Organization of Japan (NUMO) in October 2000, which is the implementing organization responsible to pursue the overall HLW disposal program in Japan, and a special fund for HLW final disposal that is based on fees collected from all electric customers to make sure all life cycle costs of the NUMO will be covered.

Under the Act, the Ministry of Economy, Trade and Industry (METI) is responsible for establishing the basic policy and final disposal plan for a 10-year term and renewing the plan every 5 years. The activities of NUMO assigned include selection of the repository site, developing licensing applications, construction, operation and closure of the repository as well as collection of fund. According to the present schedule, repository operation will start as early as the 2030s.

Because of highly public and long-term nature of the geological disposal project, which extends to about 100 years, the NUNO considered that the voluntary decision by the local communities was the top priority. Hence, the NUMO has adopted and started an open solicitation approach to find candidate areas for the feasibility study of final repository from countrywide municipalities in 2002. Areas to be investigated will be selected carefully by stepwise process consisting of literature survey, preliminary investigation and detailed investigation, respecting opinions of the concerned local communities at each step. Although no mayor of municipalities has succeeded to apply the study yet, the NUMO is enthusiastically committing to communication activities to achieve mutual understanding on necessity and safety of geological disposal, working closely with the government and the electric power companies who are major waste generators.

4. 2005-

When the electric power companies started to collect the fee for decommissioning the reprocessing plant as well as the HLW disposal activity in accordance with the progress in the deregulation of electric utilities, there occurred a dispute as to whether to suspend the hot operation of the RRP, reflecting the political atmosphere of pursuing the reduction of electricity rate at that time and the weakening of a common sense of direction of nuclear energy policy in the public mind due to the abandonment of the ATR project, delay in the start of the use of MOX fuel in LWRs due to quality assurance issues at home and abroad, difficulty in the restart of MONU and so on.

The AEC took up the issue in its committee set up for deliberating its new long term program in 2004 and pursued the argument in an open and transparent way. The committee evaluating the following four policy options from the viewpoints of technical feasibility, safety, economy, energy security, flexibility to adapt to a possible future development, environmental protection, nonproliferation, international relation, impact on the nuclear power generation due to the policy change, etc.;

- Pursue the reprocessing of all the spent fuel:
- Pursue direct disposal of the spent fuel that cannot be reprocessed at the RRP:
- Pursue direct disposal of all the spent fuel, abandoning the RRP:
- Suspend the operation of the RRP and store all the spent fuel for 40 years in which a new policy is to be deliberated.

The conclusion of the debate was that, though the electricity generation cost in the case of pursuing the reprocessing will be about 10% higher than that of pursuing direct disposal, the reprocessing option is considered superior to the direct disposal option from the viewpoint of the importance of pursuing energy security and a sound material-recycling society and assuring measures to cope with future uncertainties.

Based on the conclusion, JAEC recommended in 2005 to start the operation of RRP, pointing out to the electric power companies that it is important for them to promote the use of MOX fuel in LWRs, support the activities to determine the site for geologic disposal of the HLW and secure sufficient at-reactor and or away-from-reactor capacities of spent fuel storage, considering the limit of the capacity of RRP as well as the risk of nuclear power generation being disturbed by the troubles in the RRP. On the other hand, the Government established in the same year a fund for spent fuel reprocessing, in addition to the fund for HLW final disposal established in 2000, by collecting fees from all electric customers to make sure all life cycle costs of the RRP will be covered.

The JNFL has started in 2006 the hot operation of the RRP as a part of its commissioning activity. Until today, it has reprocessed 425 tons of spent fuel, recovered 3.3ton of plutonium in the form of MOX and produced 117 canisters of vitrified HLW. During the operation, however, they encountered various difficulties including that in determining the operating procedure of a large-scale liquid-fed ceramic melter (LFCM) for vitrifying the HLW liquid. The company announced recently that it will finish the test operation in two years, based on the result of research using a large-scale mock-up facility at JAEA Tokai Laboratory and modeling and simulation technique.

JAEC also reconfirmed the importance of promoting the R&D of fast reactor and its fuel cycle technology and asked the JAEA and electric power companies to explore innovative technologies and review their effectiveness in realizing innovative fast reactor and its fuel cycle systems that satisfy the goals in economy, safety and reliability, waste management and proliferation resistance and physical protection from the viewpoint of making it a sustainable energy technology in the latter half of the 21 century and propose a feasible design of the system before 2015. The commission is encouraging the JAEA to promote this activity in close cooperation with like-minded countries including the United States and France, believing that it is a global interest and a duty of major nuclear energy users to make nuclear energy more sustainable.

JAEC is currently in preparation for the revision of the Framework of Nuclear Energy Policy, If the work starts, the deliberation should be started on the reprocessing of the spent fuel that will be stored for the time-being, taking into consideration the progress in the FBR and its fuel cycle technology R&D and the discussion about desirable nuclear fuel cycle activities in the future.

Appendix 1: A Short History of Uranium Enrichment Activity in Japan

In the face of rapid rise in the enrichment price, the JAEC decided in 1972 that the R&D of centrifuge enrichment technology should be speeded up, aiming at the operation of a pilot plant in ten years based on the R&D of the technology at the NFC and the PNC. The PNC started the operation of a pilot plant in 1982 and based on the experience obtained by this plant, it started the operation of a prototype plant of which capacity was 200 ton SWU in 1989. In 1998, the JNFL started the operation of Rokkasho Enrichment Plant of which capacity was 1050 ton SWU/ y. Currently the JNFL is to start to install advanced centrifuge machines as replacer of initial machine, aiming at the capacity of 1500 ton SWU/ y within 10 years.

The R&D of enrichment technologies other than centrifuge had been also promoted by the Government and industries. The Asahi Chemical Company developed an ion-exchange process that uses the chemical isotope effect between two valences (U_4^+ and U_6^+) of uranium. In this process, the aqueous phase flows through the stationary resin (proprietary ion-exchange resin) held in a column, and the net effect of all the chemical reactions is a "band" of uranium that moves through the ion-exchange column. The Company started the operation of a proof-of-principle facility of uranium enrichment based on this method in 1988. Though the facility demonstrated the feasibility of the technology, the project was terminated due to the lack of investors. As for laser isotope separation, the JAERI - the electric utilities group and the PNC - RIKEN group promoted the development of an atomic vapor laser isotope separation (ALVIS) system and a molecular laser isotope separation (MLIS) system, respectively since 1985. In 2000, a process demonstration test based on ALVIS was started by the former group partly supported by the Government. The team finished the activity by demonstrating the feasibility of the technology in 2002.

Appendix 2: Uranium Recovery from Sea Water[7]

Researchers at Takasaki Radiation Chemistry Research Laboratory of the JAERI discovered that a cloth made of hydrophilic amidoxime fivers synthesized by radiation-induced graft polymerization is an excellent uranium adsorbent cloth in seawater. They demonstrated the adsorbent performance of 0.5 g U/kg adsorbent, soaking it in seawater for 20 days. They also discovered that the performance could be improved by factor 2 by making the fiver into braids. Based on these results, they made a design study of a uranium recovery system of which capacity is 1,200 ton U/y, assuming the performance of 2 g/kg adsorbent soaked in sea water in 60 days. The durability of adsorbent was assumed to be 6 cycles. Total weight of

---

[7] Data in this section is taken from Masao TAMADA et al., " Cost estimation of uranium recovery from seawater with system of braid type adsorbent", *Japanese Journal of Atomic Energy Society of Japan*, 5-4, p.358-363 (2006).

adsorbent required was 100, 000 ton, of which total length was 100,000 km. This amount of adsorbent should be distributed over 134 km^2 sea surface. 116 work ships of 1000 ton load are necessary to distribute and collect the adsorbent braids over this area. The cost of uranium in this case is about 90, 000 yen/kg. Since 70% of the cost comes from the production of the adsorbent, if the performance of adsorbent can be a promising value of 4 g/kg and the durability of braid type adsorbent can be extended from 6 to 18 times, the cost of uranium will become 25, 000 yen/kg. Based on this result, the JAEC believes that the priority of research should be given to the improvement of the adsorbent and its performance and durability, in particular.