14th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2004), Berlin, Germany, September 20-24, 2004

Paper # 037

SAFE TRANSPORT OF SPENT FUELS AFTER LONG-TERM STORAGE

Masanori ARITOMI[1)], Tomoyuki TAKEDA[2)] and Susumu OZAKI[3)]

1) Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology,
2-12-1 Ohokayama, Meguro-ku, Tokyo 152-8550, JAPAN.
Tel: +81-3-5734-3063, Fax: +81-3-5734-2959, E-mail: maritomi@nr.titech.ac.jp
2) Tokyo Electric Power Company,
1-1-3 Uchisaiwai-cho, Chiyoda-ku, Tokyo 100-0011, JAPAN.
Tel: +81-3-3511-8111, FAX: +81-, E-mail:
3) OCL Company Ltd.,
2-11-6 Nichi-Shinbashi, Minato-ku, Tokyo 105-0003, JAPAN.
Tel: +81-3-3502-0126, FAX: +81-, E-mail: ozaki@ocl-corp.co.jp

ABSTRACT

Considering the scarcity of energy resources in Japan, a nuclear energy policy pertaining to the spent fuel storage has been adopted. The nuclear energy policy sets the rules that spent fuels generated from LWRs shall be reprocessed and that plutonium and unburnt uranium shall be recovered and reused. For this purpose, a reprocessing plant, which has a reprocessing capability of 800 ton/yr, is under construction at Rokkasho Village. However, it is anticipated that the start of its operation will be delayed. In addition, the amount of spent fuels generated from nuclear power plants exceeds its reprocessing capability. Therefore, the establishment of storage technology for spent fuels becomes an urgent problem in Japan in order to continue smoothly the LWR operations. In this paper, the background of nuclear power generation in Japan is introduced at first. Next, the policy of spent fuel storage in Japan and circumstances surrounding the spent fuels in Japan are mentioned. Furthermore, the major subjects for discussions to settle and improve *'Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility'* in Atomic Energy Society of Japan are discussed, such as the integrity of fuel cladding, basket, shielding material and metal gasket for the long term storage for achieving safe transport of spent fuels after the storage. Finally, solutions to the unsolved subject in establishing the spent fuel interim storage technologies are introduced accordingly.

1. INTRODUCTION

In Japan, the pressurized water reactor (PWR) and boiling water reactors (BWR) had first been introduced from the United States of America as commercial power reactors. Afterwards, Japan independently developed and improved the reactors. In 1975, the *'Improvement and Standardization Program for Light Water Reactors (LWRs)'* started under the sponsorship of the Ministry of International Trade and Industry (MITI). Since then, the operating performance of LWRs has been improved in the first and the second phases of the program. In the third phase of the program, an advanced pressurized water reactor (APWR) and advanced boiling water reactor (ABWR) were developed as standard designs for large-sized LWRs and were completed in 1986. As a result, the enhancement of safety and reliability, a reduction in worker's radiation exposure and a decrease in radioactive wastes have been achieved. After finishing the program, the upgrading programs of the APWR and ABWR were continued and sponsored by Japanese utilities. The Tokyo Electric Power Company operates two ABWRs in the Kashiwazaki site and the Japan Atomic Power Company started a plant design work to construct two APWRs in the Tsuruga site.

From viewpoints of energy security, the global environment problem, and other aspects, it is believed that the LWRs will continue to play a major role as the electric power source in Japan, in the future.

In Japan, where the energy resources are limited, one of the nuclear energy options was to promote the FBR development from the long-term viewpoint, in order to make the efficient use of uranium resources. After that, the spent fuels generated from LWRs are reprocessed, and plutonium and unburnt uranium are recovered and reused. Most of the spent fuels were shipped to the overseas' reprocessing plants, COGEMA, BNFL, and a few have been done to Tokai Work of Japan Nuclear Fuel Cycle Development Co. (JNC). In addition, a reprocessing plant, whose reprocessing capability is 800 ton/yr, is under construction at Rokkasho Village.

The whole amount of spent fuel contracted as overseas reprocessing has already been shipped, and it is anticipated that the start of the reprocessing plant operation at Rokkasho Village may be delayed. Moreover, the amount of the spent fuels generated from LWRs will exceed the capability of the reprocessing plant. The operation guideline requires that the space in the pool where spent fuels corresponding to one core can be stored must be emptied. When abnormal transients or accidents occur, fuels loaded in the core must be moved into the pool. Hence, the establishment of storage technology of spent fuels is the urgent problem in Japan in order to continue smoothly the LWR operation. On February 4, 1997, the Cabinet Council decided officially the policy of interim storage for spent fuels including the facilities away from reactor. Consequently, the storage facilities away from reactor will be constructed by 2010. Japan has satisfactory experience on the spent fuel interim storage facilities at reactors and its transport. Spent fuels have been shipped safely from reactor sites to the overseas' reprocessing plants. Tokai Work of JNC and the reprocessing plant at Rokkasho Village, and interim storage facilities at Fukushima-1 and Tokai nuclear power plant sites are in satisfactory operation. Therefore, the major subjects for discussions to enact the safety assessment guideline and standards of the societies are to achieve the safe transport after the long-term storage.

In this paper, the following items are discussed:
(1) Background of nuclear power generation in Japan,
(2) Circumstances surrounding spent fuels in Japan
(3) Major subjects for discussions to settle down and improve *'Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility'* in Atomic Energy Society of Japan (AESJ) such as the integrity of fuel cladding, basket, shielding material and metal seal-ring for the long term storage to achieve safe transport of spent fuels after the long term storage.
(4) An unsolved subject to establish spent fuel interim storage technologies.

2. BACKGROUND OF NUCLEAR POWER GENERATION IN JAPAN

In Japan, there are presently fifty-two nuclear power plants in operation. Their total installed capacity is about 46 GW. The nuclear power contributes about 30% in total generated electric power in Japan.

The relation between energy demand and supply is fragile and there is a growing concern that it will become more serious international in the near future. Energy supply affects directly the daily life of the people and industrial activities, so that it is an important requirement for the energy policy to ensure a stable, efficient and economical energy supply. Furthermore, since global environment problems such as global warming are closely related to energy consumption, it is indispensable for the energy policy to consider the global environment problems.

Nuclear power generation plays a role to ease the recent demand and supply balance of energy resources such as oil and natural gas. The international relation on the demand and supply of uranium resources as fuels for nuclear power generation remains basically stable in the short and medium terms. Nuclear power generation is characterized by the fact that the generation of carbon dioxide is less than 1/20 from that of power generation using fossil fuel. Since the nuclear power generation so far has satisfied all of the requirements for the energy policy that are stable supply, economy and low environment impact, it will still play an important role in the future energy supply. In particular, the application of LWRs shares the largest installed capacity of nuclear power plants. Therefore, it is believed that the LWRs will play a more important role in the energy policy.

In Japan, with the limitation of energy resources, one of nuclear energy policies is to promote fast breeder reactor (FBR) development from the long-term viewpoint in order to make efficient use of uranium resources. Spent fuels generated from LWRs are reprocessed, and plutonium and unburnt uranium are recovered and reused. The international relation of demand and supply of uranium resources remains basically stable in the short and medium term. FBRs seem to come into practical use in 2050 from the economical and technical viewpoints.

Recently, an Advanced Combined Cycle Generation (ACC) has been developed which boasts of a high thermal efficiency of about 50%. Liquid Natural Gas, which is the fuel for the ACCs, is environmentally friendly and is kept low priced. Moreover, the ACC is an international market product, so that the electricity cost generated from the ACC becomes lower than that of LWRs. As a result, the ACC is offering serious competition to LWRs from an economical point of view. Electric power is one of the important economic sectors directly connected with the daily life of the people and industrial activities. The companies, which export their products, expect a substantial cost reduction of electric power to keep their cost competitive in the international market. Until now, the economic situation of Japan is still regretful. As the consequences, electricity demand does not increase. The liberalization of electricity must be introduced. The electric power companies has made a progress to introduce market principle into the electric power supply sector, to promote independent power plants, and to make a great effort toward the cost reduction of power supplies. It is the first priority of the electric power companies to keep economical advantage of LWRs against other power plants.

3. CIRCUMSTANCES SURROUNDING SPENT FUELS IN JAPAN

Spent fuels from 20t to 30t are generated every year from a 1,000 MWe-class LWR. After the spent fuels have been cooled longer than one year in the pool located in the reactor building, most of them were shipped to overseas reprocessing plants, COGEMA and BNFL, and a few have been done to Tokai Work of Japan Nuclear Fuel Cycle Development Co. (JNC). The whole amounts for LWRs have already been shipped. The reprocessing plant of 800 ton/yr is under construction at Rokkasho Village. Spent fuels more than 900 ton/yr are, however, generated from the LWRs. Mixed oxide (MOX) fuels are much more expensive than UO_2 ones. Moreover, transport costs of spent fuels, plutonium and HLW between Europe and Japan is much expensive and it is very difficult to get international consensus on this matter. The extension of the overseas reprocessing contract has never officially been announced by Japanese utilities.

It is the policy of nuclear energy that Japan should not keep an amount of plutonium over its demand. The FBR development has been slowed down, and then the future demand for plutonium has become unclear. The construction plan of the second reprocessing plant has never been made.

LWR plants will be constructed in the near future. It is no doubt that spent fuels generated from LWRs will exceed greatly the capability of the reprocessing plant. Each utility has individually and temporally made a plan to enhance the storage capacity of spent fuels. When abnormal transients or accidents occur, fuels loaded in the core must be moved to the pool. It is required in the operation guideline to empty the space in the pool where spent fuels corresponding to one core cycle can be stored. The old type LWRs whose capacity of pool is very narrow still exists in Japan. If the pool is filled with spent fuels, the LWR cannot continue the operation.

Each utility considers the measures for an increase in spent fuels, as follows:
(1) Reracking of baskets in pools,
(2) Expansion of pools,
(3) Transportation between reactors in the same site, (from the reactor having space enough to store spent fuels to

the reactor having no space)

(4) Construction of an independent storage facility using metal casks in the reactor site,

(5) Construction of an independent pool-type storage facility in the reactor site.

According to the circumstance of the site, it is difficult to get public perception and acceptance of local government about construction of interim storage facilities for spent fuels in the reactor sites. Under such circumstances, the establishment of interim storage technology of spent fuels away from reactor is the urgent problem in Japan in order to continue smoothly LWR operation.

In Japan, the regulation and guideline required for nuclear power development and operation have never been settled systematically. In advanced countries with nuclear power generation, the government shall decide the policy and settles systematic regulations related to development and operation of nuclear power plants, and categorizes the roles of the development into the government and private sectors. In Japan, whenever the utilities apply a new system, then the government settles only the related regulation. They settle them like patching process.

Systematic regulations and guidelines about spent fuel storage facilities away from reactors are enacted now. In addition, it is only the utilities that can apply to the government. The reactor designers cannot apply and accept licensing of newly designed cask. Therefore, it is difficult to export a new system. This fact is not consistent with international globalization. Consequently, it takes a long time to get the first licensing of a new system.

The government and utilities have understood the importance of spent fuel management for about 15 years. At the time, a construction plan of a reprocessing plant at Rokkasho Village had been made, so that they could not discussed officially about interim storage of spent fuels because that would affect badly the construction effort. On June 24, 1994, the Nuclear Subcommittee of the Advisory Committee for Energy investigated how to proceed with the development and utilization of nuclear energy technologies related to power generation and nuclear fuel recycling. The interim report entitled *'A forecast for Energy Demand and Supply in the Long Term'* was announced. Then, it was started to investigate interim storage of spent fuels including the MOX. On January 22, 1997, the Nuclear Sub-committee of the Advisory Committee for Energy notified the policy of interim storage for spent fuels that the storage facilities away from reactor would be constructed by 2010. On January 31, 1997, Japan Atomic Energy Commission followed this policy of interim storage for spent fuels. On February 4, 1997, the Cabinet Council decided officially the policy of interim storage for spent fuels including the facilities away from the reactor site. The Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors was amended in June 1999, which includes the spent fuel storage business. Private enterprises are under preparation to perform the commissioning of interim storage facilities of spent fuels away from reactor (AFR) by 2010.

4. SPENT FUEL STORAGE TECHNOLOGIES AWAY FROM REACTOR USING METAL CASK

4.1 Background

Interim storage facilities of spent fuels using metal casks are in operation at Fukushima-1 and Tokai Nuclear Power Plant sites. Moreover, spent fuels have been shipped from reactor sites to the overseas' reprocessing facilities and reprocessing facilities in Tokai and Rokkasho Village. It is, therefore, thought that the interim storage facility using metal casks is foreseen as the earliest installation. The Japan Society of Mechanical Engineers (JSME) approved *'Standard on Metal Cask Structure for Spent Fuel Storage Facility'* in 2001, and the Atomic Energy Society of Japan (AESJ) did *'Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility'* on June, 2002. The Safety Commission of Japan enacted *'Safety Assessment Guideline for Spent Fuel Interim Storage Facility Using Metal Dry Casks'* and *'Long Term Integrity of Metal Cask and Contents for Spent Fuel Interim Storage Facility'*. Then, the AESJ revises *'Standard for Safety Design and Inspection of Metal Casks for*

Spent Fuel Interim Storage Facility:2002' to satisfy the requirements in the safety assessment guideline.

Storage/Transport casks must satisfy the technological requirements of heat, shielding, sub critical and seal performances, and structure strength based on IAEA safe transportation of radioactive materials. In other word, they should not only achieve the requirements for transport casks but also satisfy seal performance for their long-term storage. For the purpose, metal gaskets and double-lid structure are adopted for the cask design and pressure between double lids is monitored. Such cask designs are the same with those in the United State of America and Europe.

Since Japan is relatively small country and has a large population, it is very difficult to get public understanding of nuclear related facilities and then to find their sites. Japanese utilities are looking for spent fuel interim facility sites and want the facility without a fuel handling facility as the design to prevent radioactive materials stored in the casks from releasing, in order to explain easily their safety to local people.

The spent fuels whose integrity is inspected first are loaded into a cask, and it is confirmed that the package meets the technical requirements for the transport regulation in preshipping tests for their shipping. In Japan, the fuels whose claddings are damaged have been contained in a can not based on the regulation but in practice, even though the failure is only very narrow pinholes and hair cracks. In a spent fuel interim storage facility without a fuel handling facility, the integrities of spent fuels and baskets cannot be directly inspected by opening the lids of casks. Under such circumstances, the main subjects, which should be considered for enacting the *'Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility'* in the AESJ, are to ensure the safety of spent fuel transport after the long term storage.

In the preshipping tests for spent fuel shipping after the long-term storage, the following subjects cannot be inspected directly from the outside of the cask: (1) the integrity of spent fuels, (2) the integrity of baskets, (3) the integrity of seal performance for metal gasket, and (4) the integrity of resin layer. Therefore, these aspects are discussed in the following sub sections.

4.2 Integrity of Spent Fuels for Long Term Storage

At first, it is considered whether the safety of spent fuel transport after the long-term storage can be achieved if the integrity of spent fuels is not inspected by opening the lids of casks. Such an inspection would create undesirable effects due the following reasons:
(1) It would inflict cold shock on their claddings because hot spent fuels should be cooled down in a reactor pool by opening the lids,
(2) It would expose the spent fuels to air which are contained in inert gas,
(3) It would expose the worker to radiation during their handling, and
(4) It would not to be able to mitigate the accident if the spent fuels fall down during the handling.
Nevertheless, there are no scientific data from which can verify the integrity of spent fuels against the long-term storage around 40 - 50 years.

The spent fuel interim storage facilities at Fukushima-1 and Tokai Nuclear Power Plant sites are in operation. Until the scientific data, which can prove the integrity of spent fuels for the long-term storage, are accumulated, gas in the casks where the spent fuels are stored should be periodically sampled and measured by a Krypton 85 (Kr-85) monitor to verify the integrity of the claddings. As for the selection of the specification of the spent fuels stored appropriately, the following representative characteristics should be considered:
(1) materials of the cladding,
(2) burn-up ratio,

(3) temperature of cladding which will be suffered inside the interim storage facilities, and
(4) stress of the claddings due to internal pressure in spent fuels.

The spent fuels whose specification can be classified into appropriately proved ones can be treated for the demonstrated term as proved ones.

If the damage of the claddings is detected, the number of failure spent fuels is counted and the cause of the damage is researched. It is not denied distinctly that the claddings are damaged not by the clear cause but statistically. For instance, the safety of spent fuel transport is enough for failure spent fuels of 0.1% by taking seal performance into consideration. The judgment criteria for the failure rate of spent fuels should be decided on the basis of the seal performance of the cask. For instance, if the failure spent fuel rate of 0.1% is allowed, the seal performance having sufficient safety margin should be designed against the source terms are calculated on the assumption of that of 1%. However, the spent fuels stored in the interim storage facilities are restricted to those whose integrity is verified by a Kr-85 monitor when they are loaded into casks in a nuclear power plant.

In the preceding verification tests, the spent fuels should be handled and stored under the same conditions as in real interim storage. What has the greatest effect on integrity of the cladding is its maximum temperature suffered during the storage and handling. It is supposed that the cladding temperature becomes highest during the operations drying the cavity of the cask and replacing with helium. Considering the temperatures which induce creep strain of 1% and which makes the irradiation curing recovered, it is recommended in the standard that the maximum cladding temperature is restricted to 305 degree C.

4.3 Integrity of Basket for Long Term Storage

From the viewpoint of effective storage for spent fuels, the cask designs are proposed that aluminum alloy mixed boron is adopted as basket material in order to increase spent fuels loaded into a cask. There are few data, which can verify that aluminum alloy can be used for long term at high temperature. Radiation damage is out of the question for basket materials of storage/transport casks. In the case where the strength data of aluminum alloys used for long term at high temperature are not enough for the safety assessment, they should be collected from mock-up tests simulating the atmosphere and temperature, which are experienced during the storage. The methods to collect the data of the allowable stress and to prove the integrity of basket used for long term storage are recommended in the standard.

4.4 Integrity of Metal Gasket for Long Term Storage

If metal gaskets are used for long term at high temperature, their restitutive force becomes much smaller due to the creep strength. The intact restorative width is almost the same as the tolerance of O-ring recess depth. As a result, the seal performance may be damaged against the impact load, which may be encountered during the shipping, even though it can be kept statically during the storage. Hence, until the data, which can verify that the seal performance can be kept after they are used for the long term storage, are collected, the metal gasket used for the outer lid should be exchanged with a new metal one or an elastic O-ring, or the third lid for transport should be added. In addition, when the primary metal gasket is damaged and the cask should be shipped from the interim storage facility to maintain the damaged one, the following structure is required for the cask design: The outer lid must be welded, or the third lid must be installed.

In the case where fracture stress due to creep is measured under uniform tensile stress conditions, Larson-Miller parameter is used as accelerating one. On the other hand, compression stress is loaded and relaxation is induced due to creep in the case of metal gaskets. In addition, although the elapsed variations of leak rate and intact restorative width are correlated with Larson-Miller parameter, a factor of the stress loading an O-ring is not incorporated in Larson-Miller parameter. The arrangements of the leak rate and intact restorative width with Larson-Miller parameter are scattered. It has never been clarified whether such a fact is caused by the tolerance of O-ring recess depth or by the applicability of Larson-Miller parameter.

4.5 Integrity of Resin Layer for Long Term Storage

There are storage/transport cask designs that the resin is adopted as neutron shielding material. In this case, metal oxide such as aluminum oxide is mixed in resin for gamma ray shielding material. If such a resin is exposed in atmosphere with high temperature, mass reduction of resin is induced because water may be dissociated from its hydrate and evaporated. The detailed data of the mass reduction have never been obtained enough for the cask design. These data will be collected soon. As a result, the pressure in resin compartments increases, so that the pressure increase should be reflected in the cask design. In addition, it is also considered for the cask design that structure materials and heat transfer fins may be corroded by elements included in resin and resolved into high temperature water.

5. FUTURE CHALLENGE

In Japan, two-step licensing methods are adopted for transport casks of Type-B; cask design certification and cask approval. As for the casks approved by Ministry of Economy, International Trade and Industry (METI), the cask approval should be renewed every three years by submitting the periodical inspection data conducted every year. On the other hand, with regard to the casks approved by Ministry of Land, Infrastructure and Transport (MLIT), the renewal of the cask approval is not necessary but it is required every three years to submit the periodical inspection data conducted every year. The periodical inspection methods are provided in *'Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility'* It has never been decided which Ministries would issue the design certification and cask approval for storage/ transport casks and how the periodical inspection data should be submitted to keep cask arrival for transport. After these problems are resolved, *'Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility'* will be revised again to meet these answers.

6. SUMMARY

In this paper, the background of nuclear power generation in Japan was introduced at first. Afterwards, circumstances surrounding spent fuels in Japan were discussed. The Japanese utilities are searching for spent fuel interim facility sites and need it without a fuel handling apparatus to explain easily their safety to people living near the site. For spent fuel interim facility without fuel handling apparatus, it is the most important aspect to ensure safety of spent fuel transport after the long term storage. The following major subjects investigated to approve *'Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility'* in the AESJ were discussed: the integrity of fuel cladding, basket, metal seal-ring and shielding material for the long term storage. Finally, the unsolved subject was introduced.

REFERENCE

[1] Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility, the Atomic Energy Society of Japan (2002.6) (in Japanese).