FUTURE PERSPECTIVE BASED ON THE JAEA'S EXPERIENCE IN MOX FUEL TRANSPORT

Takafumi Kitamura
Director, JAEA Vienna Office

Noboru Tadokoro
Deputy General Manager, Nuclear Material Management Office

Yuichiro Ouchi
Nuclear Material Management Office

Kan Shibata
Nuclear Material Management Office

Yuji Yamashita
Nuclear Material Management Office

ABSTRACT

Over 35 years, the Japan Atomic Energy Agency (JAEA) to promote nuclear basic research and nuclear fuel cycle done by its predecessors; JAERI and JNC (PNC) has been accumulating experiences to transport wide range of nuclear materials: MOX fuels and powder for fast breeder reactors, MOX spent fuel for post irradiation examination and uranium fuel elements for test / research reactors, etc..

This paper introduces our experiences in transporting MOX fuels and powder, and additionally technology and system in terms of transport method, emergency preparedness and quality assurance developed reflecting trends in Japan and world, then shows one of future perspectives for MOX transport.

In order to attain the safe and secure MOX fuel transport, not only safety measures complying with domestic regulations which incorporates the IAEA safe transport regulations; TS-R-1 but also physical protection measures corresponding to the Category I requirements by INFCIRC/225/rev4 as well as additional demands are considered and secured to a transport system as a whole. Those include emergency preparedness in accidents, training and exercise for transport workers, information control, etc. Development of packages which relate to transport methods also should be addressed. .

INTRODUCTION

Japan Atomic Energy Agency (JAEA) was established in October, 2005, as a result of the consolidation of Japan Atomic Energy Research Institute (JAERI) and Japan Nuclear Cycle Development Institute (JNC). JNC succeeded the Power Reactor and Nuclear Fuel Development Corporation (PNC) in 1998.

To support a wide variety of activities concerning the use of atomic energy, JAEA has accumulated experience of transporting various nuclear materials. Firstly the outline of experience is described focusing mainly on experiences in transporting plutonium uranium mixed oxide (MOX) fuel necessary for the research and development of nuclear fuel cycle. Then, consideration will be given to a future perspective and challenges lying ahead based on those experiences.

A nuclear fuel cycle consists of the activities: refinement of uranium ore, conversion to uranium hexafluoride (UF6), enrichment of UF6, fabrication of uranium fuel, power generation at nuclear power plants, reprocessing of spent fuel, storage and utilization of recovered uranium, MOX fuel fabrication using plutonium recovered from spent fuel, power generation both in fast breeder reactors (FBRs) and light water reactors (LWRs), reprocessing of MOX spent fuel, and treatment, storing and disposition of low level and high level wastes that are generated through those activities.

Transport of nuclear material between those activity sites is indispensable in smoothly progressing those activities.

The MOX fuel transport is needed mainly for the downstream activities following spent fuel reprocessing. In addition, a small amount of standard sample for fuel fabrication as well as removal sample derived from safeguard activities at MOX facilities are carried as MOX transport.

Japan plans to steadily promote the development of FBRs based on the Framework for Nuclear Energy Policy which was decided by the Atomic Energy Commission in Japan, which includes operation of a demonstrational FBR starting from around 2025 for which JAEA is now undertaking R&D, and commercialization of FBR power generation in around 2050. In pursuing an advanced technology, it is planned to contain some nuclides (minor actinide (MA), etc.) into MOX fuel which entails transport of MOX with MA.

To support those various R&D efforts, it is thought that the MOX transport would increasingly be important. And for the transport, it is thought that we need to provide safety measures with a top priority along with nuclear security measures, ensured transparency and accountability of the plan to provide public relief and economical rationality.

This paper introduces an outline of MOX transport and elaborates experiences held by JAEA, and based on them, the challenges as well as future perspectives of MOX transport are considered. I sincerely hope that this paper would serve as a reference to related countries' organizations and eventually will lead to even closer cooperation with them.

HISTORY OF MOX FUEL TRANSPORT BY JAEA

➢ Overview of nuclear fuel transport by JAEA

JAEA procures various forms of uranium fuel necessary for utilization of nuclear energy, safety research, and technological development of the nuclear fuel cycle by using research and test reactors. Basically, powder form uranium, low enriched less than 20%, is procured for both fabrication of aluminum cladding assembly fuel for research and test reactors and blending into MOX fuel. Those are transported by sea from foreign countries to Japan.

The spent fuel from research and test reactors, on the other hand, is transported by sea to the U.S. under their Acceptance Policy. A small amount of nuclear material collected from the IAEA safeguards activities or needed as a standard for fuel fabrication is transported by air between Japan and foreign countries.

Furthermore, sea transport of MOX with MA nuclides is planned as an activity for joint research among Japan, U.S. and France in the future for the purpose of research to improve fast reactor technology.

➢ Transport of MOX fuel assembly, etc.

JAEA fabricates the MOX fuel assembly using MOX or plutonium powder that was recovered from the reprocessing plants of JAEA and other countries, and transports them to the experimental FBRs "Joyo" and the prototype "Monju", as well as to the Advanced Thermal Reactor "Fugen" (now under decommissioning). From the past records, transports of MOX fresh fuels have been implemented to: "Joyo" (118 times in total from 1977 through 2008, about 7.9 tons of MOX), "Fugen" (45 times in total from 1976 through 2002, about 134 tons), and "Monju" (13 times in total from 1992 through 2008, about 9.6 tons).

In addition to those above, transports of spent fuel from "Fugen," fresh fuel for irradiation test, fuel and materials for post-irradiation examinations, recovered uranium, uranyl nitrate solutions, etc., have been made by JAEA.

- **Details of MOX transport to and from Japan**

  - **A shift of transport mode from air to sea**

From the late 1960s, JAEA has procured offshore plutonium necessary for its R&D for MOX fuel. Initially the transport of plutonium was done by foreign consignors by air on their responsibility, but since around 1975, the method of transport has shifted to sea transport.

In October 1984, JAEA transported raw material of about 280kg of plutonium dioxide (PuO_2) powder from the reprocessing plant in France to supply fresh fuel to "Joyo". It was carried by sea through the Panama Canal to Japan under the JAEA's responsibility by using a dedicated vessel "Seishin Maru".

  - **Developing air transport package**

The sea transport in 1984 eventually provided an opportunity to steer toward a decision to adopt air transport from the point of view of the physical protection of nuclear material. JAEA started development of the plutonium air transport package commensurate with the NUREG-0360 criteria with cooperation from Battelle Memorial Laboratory and Sandia National Laboratories (SNL). After two years of high-speed impact tests for the package conducted at SNL starting from 1986, technological perspective to meet the criteria was obtained. However, at the end of 1987 when Peaceful Use of Nuclear Energy Cooperation Agreement between Japan and U.S. had already been effective, Senator Murkowski submitted his amendment to the bill under the deliberation of Congress which requires confirmation of safety of the plutonium air packages that fly over the territory of the U.S. The bill was approved as Public Law on December 22.

  - **Revival of sea transport**

The requirements specified in the law were standardized by the U.S. Nuclear Regulatory Commission (NRC) and the Lawrence Livermore National Laboratory with a financial support by JAEA. The standard requires crash tests taking the worst case of an actual aircraft accident into consideration, which are much more severe than the NUREG-0360 criteria. Therefore, after testing conducted by using the newly designed packages, both countries reached a consensus that it would be difficult to develop the package early. It was a shared view that sea transport would be more appropriate until an air transport package for plutonium is developed.

Because JAEA needed MOX raw powder to produce reloaded fuel for "Monju" at that time, it was decided to use the returnable plutonium that was recovered at the reprocessing plant of COGEMA from the spent fuel of the LWRs in Japan. JAEA having the responsibility of transport based on the Atomic Energy Commission decision transported about 1.7 tons of PuO_2 raw material by sea using the dedicated vessel "Akatsuki Maru" with cooperation of the Governments and electrical power companies in 1992. This was the first transport under the new Japan-U.S. Agreement and then a sea transport in every several years afterward was expected, but repeated accidents and troubles at the JAEA nuclear facilities have seriously hindered planning of the next sea transport of large amounts of plutonium.

On the other hand, in order to use the returnable plutonium as fuel for the LWRs, the electrical power companies in Japan recently were successful in starting sea-transport of MOX fuel assemblies fabricated in Europe by using MOX recovered from their spent fuel with the cooperation of the governments of Japan, France, the U.K. and the U.S.

- ✓ **Domestic procurement and transport of MOX raw powder**

Most of the 1.7 tons of PuO2 above mentioned has been used for the initial load fuel for "Monju" and reload fuel for "Joyo." "Monju" had stopped operation since the accident in December 1995 because of sodium leakage from a temperature sensor which was installed at the secondary cooling system. However it resumed the operation in June 2010, after 14 years' cessation. A series of tests will be carefully repeated to ensure a 100% power operation in two years' time. A relatively large amount of fissile plutonium (around 500kg) will be needed at that time, so JAEA and the electrical power companies are agreeing on a procurement of MOX fuel from the reprocessing plant owned by Japan Nuclear Fuel Ltd. (JNFL) located in Rokkasho, Aomori for JAEA's facility in Tokai, Ibaraki.

The development of the transport system consisting of the packages and the transport containers is now underway. Transport will be made by sea using a dedicated ship, which is a multipurpose vessel now on duty.

In addition, JAEA plans to fabricate the fuel assembly at the MOX fuel fabrication plant in Tokai and then continuously transport them by land.

DEVELOPING MOX FUEL PACKAGE

Major MOX fuel packages developed by JAEA are shown below.

- **TN6-4 and TN6-5 packages**

  TN6-4 and 6-5 packages were developed for transport of irradiated MOX fuel material and employed for overseas transport. It can also hold MOX fuel for the high burn-up of fast reactor fuels and high amount of neutron irradiation.
- **P3S(12T) package**

  This model was developed for the transport of irradiated fuel that had been tested and cut out at the sites including post-irradiation examination facilities, to the reprocessing plant in Tokai.
- **PIE-SA package**

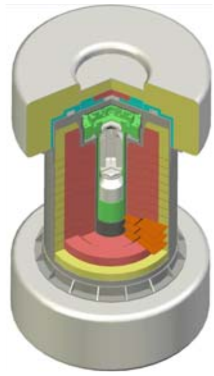
  This model was developed to transport the fuel assembly etc. irradiated by "Monju" to the post-irradiation examination facilities.
- **MONJU-F package**

  This package is for shipping type B fissile material, which holds the core fuel assembly for the prototype fast breeder reactor "Monju."12 packages were fabricated, and started to be used since the initial fuel loading in July, 1992. The appearance of new fuel package (MONJU-F model) for "Monju" is shown below.
- **Rokkasho MOX raw powder package**

  JAEA is currently developing a type B fissile package for the future transport of MOX raw powder for reload fuel for "Monju" and "Joyo." The transport will be made from the Rokkasho Reprocessing Plant to the Tokai fuel fabrication facility. Safety demonstration tests were completed in 2008.
- **"Monju" spent fuel package**

  JAEA is now developing a shipping package intended for the future transport of the spent fuel assembly from "Monju" to the reprocessing facility. But because of the delay in the facility planning, the development has temporarily been suspended at the phase of prototype package production.

MONJU-F package



Rokkasho MOX raw powder package

ESTABLISHING EMERGENCY COUNTERMEASURES FOR TRANSPORT

The Type B packages for MOX fuel transport containing fissile materials have to comply with the regulatory requirements of the regulations in Japan, into which the IAEA TS-R-1 has been incorporated. In addition, it is a common practice to establish the emergency countermeasures in preparation for the event of traffic accidents. JAEA has prepared a Transport Control Center (TCC) early on during the MOX fuel transport. The TCC is usually set up before and during the transport in order to secure a prompt communication among the transport convoy, the local police and relevant organizations and the TCC in the event of emergencies. In addition, an array of convoy vehicles is arranged to follow the instruction by the relevant competent authorities regarding escort vehicles with specialists, professionals for safety of packages, radiation and contamination due to leaked nuclear material and security guards in the front and rear of the convoy.

Japanese governments established the Special Law on Nuclear Disaster Countermeasures which was enacted in December 1999 just 2 months after the nuclear criticality accident happened at a uranium fabrication facility (JCO). The accident accelerated the law formulation.

This law assumes the possibility of serious accidents at nuclear facilities and nuclear material transports taking the accident of JCO into account. In order to take the appropriate measures to an upgrading and expanding requirement, JAEA reinforced the emergency equipment to be carried and a logistical support system to prepare for a possible nuclear material leakage.

ESTABLISHMENT OF MEASURES FOR PHYSICAL PROTECTION OF NUCLEAR MATERIALS DURING TRANSPORT

When plutonium or enriched uranium is transported, a similar consideration as that to the facilities has been paid from the stand point of the physical protection of nuclear material during transport. The locks and seals are required as hardware measures by the Japanese regulations to the packages containing particular nuclides of a certain amount.

As for the software measures, the regulations requests a series of measures: the confirmation on an agreement among a consignor, a consignee and an entity who is responsible for the transport; the establishment of transport documents carried by the accompanying responsible person for the transport; and the establishment of communication and notification system for monitoring the transport, notification of transport routes and dates and the preparation of a contingency plan.

With regard to handling transport information, the standard reference document titled “The Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Rev.4)” describes a necessity of limiting advance knowledge of transport information to the minimum number of persons.

The Ministry of Economy, Trade and Industry (METI), the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), which are responsible for regulating physical protection of nuclear facilities including nuclear materials transport and nuclear material, have incorporated the above document into the Japanese regulations in 2005, which eventually resulted in stricter requirements for physical protection on transport of nuclear material. The three major points in the incorporation are these: the inspection on physical protection measures, the obligation to protect physical protection secrets, and the design basis threat (DBT). In compliance with the regulatory requirements JAEA strengthened physical protection measures taken to nuclear facilities and transports.

ESTABLISHMENT OF SYSTEM OF QUALITY ASSURANCE FOR TRANSPORT AND PACKAGE

An inappropriate handling of shielding material data, which was used for fabricating a spent fuel package was revealed in 1998 in Japan. MEXT (the then-Science and Technology Agency) decided to improve the quality assurance system for fabricating the package and publicized a guideline in February 1999. Then the succeeding MEXT also made public a quality management guideline for fabrication of the package in July 2002. Based on those steps JAEA has enhanced the quality assurance of nuclear facilities and nuclear transport.

FUTURE PERSPECTIVE

- **Trend hereafter**

Almost all countries are now working hard and giving priority to countermeasures against global warming, to achieve a low carbon society with policies varying from one country to the next. Those countries regard nuclear power generation as a practical, stable and extensive technology to provide a solution, pay attention to and pursue development on it. In line with such a trend, transport of raw uranium, uranium fresh fuel, and spent fuel from LWRs are expected to increase hereafter. In fact, Japan is planning to start operating an additional eight LWRs eight years in the future, while currently 55 LWRs are operating.

In addition to the above, Japan is positively promoting utilization of plutonium as energy resources derived from LWR power generation. JAEA's resource utilization technology on MOX fuel is under R&D.

On the other hand, on some occasions of MOX transport JAEA has experienced being monitored or has encountered protests by certain groups, because the plutonium transport has drawn substantial social attention in and out of Japan. To prepare well for the situation, JAEA conducted activities for appropriate explanations of the safety of transport before and after the transports at its own initiative or as requested. Due to so high social attention there were some denials from carriers to accept the material to transport in order to avoid negative impact on them or compensation issues that might occur in case of an accident.

In addition, transport requirements for nuclear material such as MOX fuel are becoming stricter and more complicated year after year. In the past decade, the regulations including physical protection of nuclear material, nuclear security, quality assurance, and contingency planning have become diversified and complicated, to say nothing of the safety standard. The Government of

Japan endeavors to continuously and proactively support any establishment of safe transport regulations, or TS-R-1. JAEA is willing to reflect its knowledge and experiences gained in transporting nuclear material including MOX fuel.

With the social situation surrounding the nuclear power in mind, securing safe and smooth transport of the nuclear material will be ever more important in the future. Japan plans for full-scale utilization of the MOX fuel in the fast reactors from around the mid-twenty-first century on. To prepare for this, it is deemed important that to pursue an appropriate accountability and take an appropriate response to another transport requirement including physical protection and nuclear security, as well as to improve transport technology for MOX fuel.

- **Challenges**

Challenge 1: Achieving a good balance between the combination of accountability of the MOX transport and appropriate information control

MOX is normally used for peaceful application of nuclear energy. But if the application plan is not sufficiently clear or if any misconduct occurs, skepticism may be induced regarding possible military utilization, which would likely become a fatal barrier for the usage of nuclear energy. To avoid such a situation beforehand, the Government of Japan has willingly released, on the homepage of the Atomic Energy Commission, the plan concerning the use of MOX derived from reprocessing.

The entire picture of nuclear material transport is thought to be necessary information for the public to know about the safety and the necessity of transports.

Safety related data such as package specifications, emergency systems and countermeasures that explain the safety of the packages as well as method of transport are essential to provide the public with a sense of relief.

As for the information related to the necessity, annual data of mass transport necessary for MOX power generation is available to the public, so that they can understand and accept the transport. This information links to individual unit mass, dates, and routes of transport. As mentioned before, the information on the physical protection of nuclear material during the transport should be appropriately managed. The Law of Regulations for Nuclear Reactors etc. and Nuclear Materials especially stipulates the obligation of confidentiality for the physical protection secret with penalty against an intentional information leakage. According to the law, the in-depth information including dates and routes cannot be made public. The related transport information other than those falls within different levels of protection, which are properly managed by organizations concerned including JAEA.

Consequently, information concerning safety and necessity should be handled differently. Safety information may be released in detail, while data concerning necessity includes confidential information that can not be made available to the public in view of the physical protection of nuclear material, which, in fact, should not be disclosed.

What should be considered here is to what extent the information should be released. The point is to achieve a good balance between protection and disclosure of the information and to carefully exclude those that should not be made open to the public. There is some information that cannot clearly be categorized into the safety or necessity. So it is important to examine the both aspects of information to be integrative as a whole.

Ensuring a good balance between the combination of the accountability on the MOX transport and the control of the relevant information is expected to be even more important in the future. To do that, close cooperation with power companies will be required, for inland transport of MOX will soon be conducted by both organizations in Japan. Furthermore, creating and implementing effective and efficient information distribution system for the public is needed under consultation with the relevant authorities.

Challenge 2: Maintenance and enhancement of the measures for safety, physical protection of nuclear material, and nuclear security

Challenge 1 was about the handling of information. Challenge 2 focuses on the technical aspect.

IAEA has created a practical safety standard of TS-R-1 in its long history, by which a possible impact on humans and environment will be confined below the allowable level.

As for the physical protection of nuclear material during transport, a series of IAEA recommendations in INFCIRC/225 has provided the necessity and concept of physical protection over the years. The fifth edition, which is underway, will include technical issues. As a matter of fact, TS-R-1 does not include any technical requirements related to the physical protection, which should be maintained in the future. This is because firstly, TS-R-1 specifies required performance of packages from five viewpoints of analyses for structural, thermal, containment, shielding and sub-criticality, and secondly, a package is designed as a single structure incorporating all those five requirements, and then finally, to add another structural requirement into those means a fundamental change of the whole design; which implies the level of safety assured by TS-R-1 may be changed.

Then, the issue is how measures for physical protection and nuclear security should be incorporated.

In general, it can be said that the package has a potential margin in the structural strength. This margin naturally depends on each package, and depends on the phenomena to be considered. The MOX package has tolerance against accidents, such as type B packages containing fissile materials, which normally indicates a strong construction.

Accordingly, the requirements in view of physical protection of nuclear material and nuclear security should be considered based on the potential strength of the package, considering the reporting and supporting system for guarding and emergency that are incorporated as a system in the transport, so that the allowable level of nuclear security is assured. This indicates the necessity for the development of the assessment and design methods correspond to the various requirements that may emerge in the future.

Challenge 3: Establishing an effective system to correspond to incidents for atomic energy disaster prevention, training and educating private and national organizations, and reflecting the improvements

Emergency planning for nuclear transport is speculated in TS-G-1.2, a guidance of IAEA. Japan has constructed a system to correspond to incidents during transport. Efforts are now being made to make the system effective and efficient. As increasing number of nuclear power plants is expected to appear in many countries, establishing systems to correspond to transport emergency suitable to respective country will become critical.

As it is also true that for MOX fuel transport, it is necessary to make effective the emergency planning system established by JAEA, and to do that, training and education of the relevant persons will increasingly become important. In addition, it is required that newly acquired knowledge should be reflected on the next review of the planning system by the entities and organizations.

Challenge 4: Developing the transport system on the premise of safety, and securing appropriate economic efficiency

Needless to say, ensuring safety is a top priority for the transport system development. And it is considered that the labor put into transport of nuclear materials which connects the nuclear fuel cycle is comparatively large. This is because the package design is specified by both the safety factors for contents and the mass and the interface factors with the facilities at departure and destination. Setting transport specifications after facility requirements were established is technically difficult. When the transport system is developed as a logistics system including facilities, it is essential for the development of a well balanced transport system to have checks and feedback in early stages of the specifications concerning the interactions between facilities, packages, and other transport equipments. This concept is also a fundamental to quality assurance. Consequently, the transport system would also become effective in terms of economic efficiency.

Therefore, it is necessary to proceed in setting specifications, trying at the same time to grab the whole idea of transport including the facilities in the early stages, which is also related to the challenge 1.

Challenge 5: Improvement and maintenance of transport technology. Fostering human resource and recruiting those who have the technology and knowledge, and educating and training the relevant persons

The technology development for the shipping package for nuclear material has been promoted in many countries along with the progress of TS-R-1, so the technology has already been established. However, as stated in the above challenges, the technology should be advanced and maintained as transport technology to correspond to newly emerging requirements, advanced level of safety, handling capability, and economic efficiency. More importantly, because it is a matured technology, younger generations who would succeed the technology should not be dwindled. Considering increasing nuclear power generation, to maintain a certain level of technology is necessary and indispensable. From this view point, continuous efforts to foster and recruit human resource are required.

Challenge 6: Continuous review of adoption of air transport safety standards for MOX fuel, and its level

Air transport takes less time than surface transport and sea transport, and therefore it is indispensable for the transport of nuclides whose half-life is short. Moreover, it is believed to be better in terms of physical protection compared with other methods of transport, which is why JAEA has pursued the development of the shipping package for plutonium.

However, once an airplane crashes, the result would be far more serious than that of surface or sea transports. Considering the concerns, the air transport standard for the nuclear material has been prepared by many countries. The United States has its own air transport standard for plutonium. JAEA has placed efforts on developing plutonium air packages to meet the standards, which has not yet arrived at the final stage. The safe transport standard TS-R-1 of IAEA provides a standard for the type C package. When this standard was considered for incorporation into Japanese regulations, the needs of the standard was discussed. Currently the incorporation has been reserved due to no demands for plutonium air transport of a great amount of fissile nuclides such as plutonium.

Therefore, it will be necessary in the future to examine which safety standards should be employed for the nuclide package that is suitable to air transport, as well as the safety level combination with other modes of transports.

The designing technology, knowledge and experiences that we have accumulated in developing air transport technology for MOX fuel is deemed useful when considering the necessity of air transport of radioisotopes in the future.