SAFETY RESEARCH ON THE TRANSPORT OF RADIOACTIVE MATERIALS IN JAPAN

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Abstract

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The generation of electricity by commercial nuclear power plants has been steadily growing in Japan. With the increase in nuclear power plants and facilities related to the nuclear fuel cycle, many kinds of packages are expected to be required and the transport of nuclear fuel and radioactive waste materials will increase. It becomes more and more important to secure the safety of these transports. The paper explains the nuclear fuel cycles in Japan and the schedules of the new five year safety research programme formulated by the Japanese Nuclear Safety Commission.

1. INTRODUCTION

The generation of electricity by commercial nuclear power plants in Japan is six times as much as that of ten years ago and is increasing. Moreover, new types of reactor, such as ATRs and FBRs, are under development. The proportion of nuclear power generation is expected to increase in the future.

Figure 1 shows the nuclear fuel cycles in Japan. These include the effective use of LWRs, the reprocessing of the spent fuel, the utilization of plutonium, and the enrichment of uranium. In the figure, solid arrows denote the cycles in operation (high quantity), dash-dot arrows the cycles at research stages (or lower quantity), and the dashed arrows the cycles expected to be available in the future. Uranium hexafluoride or uranium oxide from outside Japan is transported to uranium conversion and fuel fabrication facilities to be made into fuel assemblies for LWR and new type reactors. These fuel assemblies are transported to each reactor. Part of the spent fuel is sent to a reprocessing facility at Tokai, and the rest to France and the United Kingdom. Uranium and plutonium recovered from the spent fuels in these countries is to be returned to Japan, together with radioactive waste materials.

New nuclear fuel cycle facilities, involving a reprocessing plant, uranium enrichment plant and low level radioactive waste storage facility, are expected

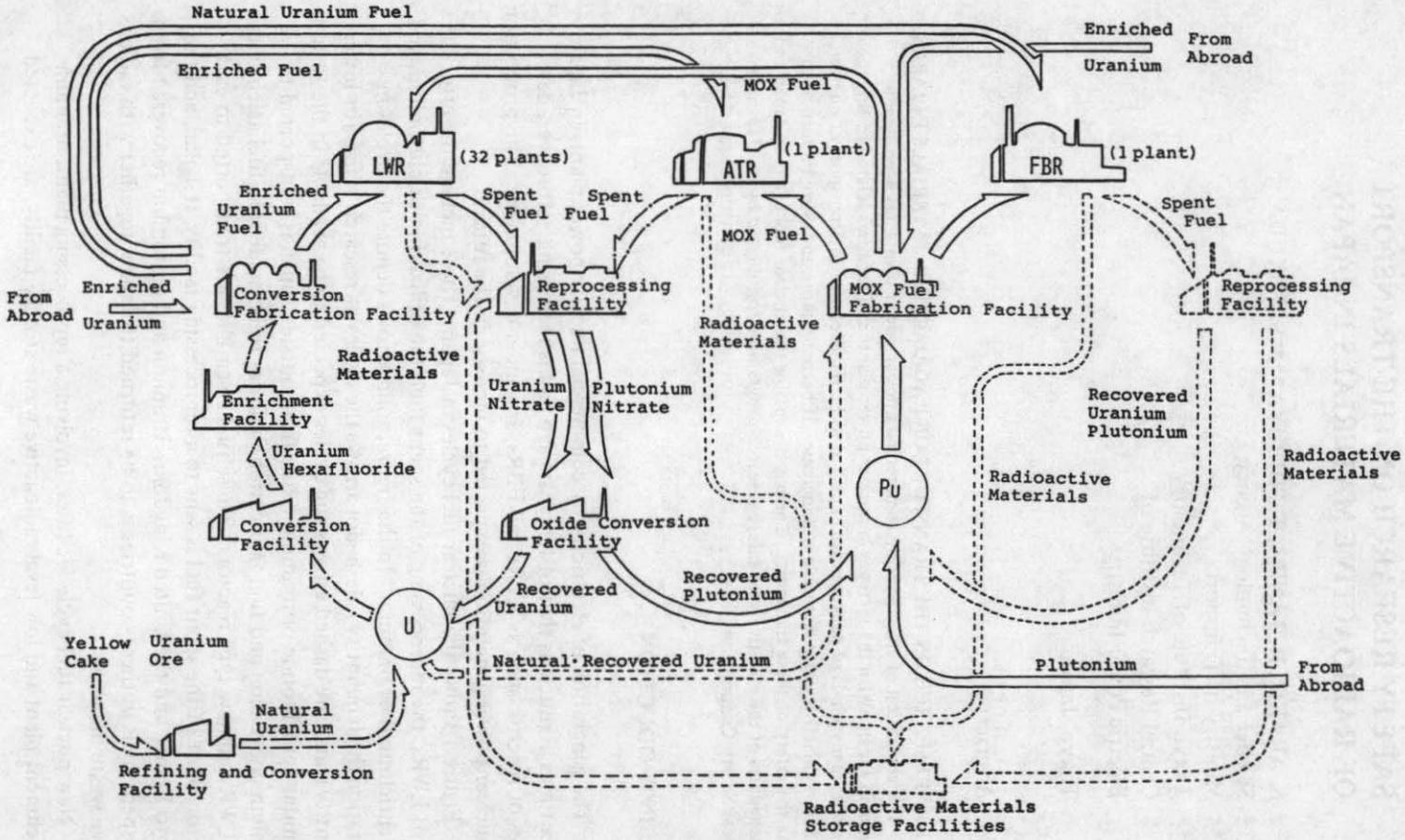


FIG. 1. Nuclear fuel cycle in Japan.

to be constructed at Shimokita in northern Japan in the early 1990s. The waste materials returned after reprocessing in France and the UK will be temporarily stored there. At that time, it will be necessary to transport new types of packages involving radioactive waste materials or natural uranium hexafluoride. With the improvement of LWRs, high burnup spent fuel packages will be needed.

Vessels and trucks using expressways are mainly used to transport the packages. Air transport is used for almost all radioisotopes for medical use.

In order to secure the safety of these types of packages and transport methods, the IAEA Regulations have been incorporated actively into Japanese regulations. Also, various research and development work in this field is being carried out by both the Government and private companies.

The Nuclear Safety Commission in Japan has formulated a new five year safety programme (1986–1990) to promote R&D coherently and comprehensively. The Government budgets in this field were $2.5 million for the 1983 Japanese fiscal year, $1.8 million for 1984, $2.1 million for 1985 and $2.9 million for 1986. Some of the main studies carried out in the past have been:

(1) Experiments on lateral collision of vehicles carrying nuclear fuel packages
(2) Experiments on secondary impact from falling with the use of scale models
(3) Evaluation of cases of fire accidents involving tank lorry trucks
(4) Demonstration tests to confirm the reliability of spent fuel packages
(5) Experiments on pressure resistance of cylinders used for shipments of UF_6
(6) Experiments on fire resistance of UF_6 packages.

Work in private companies in recent years has been concerned mainly with analyses and experiments that are necessary for evaluation of package designs for fresh and spent fuels. Also, studies related to packages for radioactive waste materials and spent fuel packages in dry condition and packagings for storage have been carried out.

Table I shows proposed research work on packages which is expected to be implemented from now on, including advanced research. The work involves computation methods on structure, heat, shielding and criticality to verify safety and experiments on the fire resistance of neutron shielding materials and on the impact characteristics of wood as a shock absorbing material. With regard to packaging design, some significant work has been done in the development of new types of packaging for the more highly enriched fuel or plutonium.

2. SCHEDULES OF SAFETY RESEARCH ON TRANSPORT OF NUCLEAR FUEL MATERIALS IN JAPAN

The safety research schedules of the new five year programme on the transport of nuclear fuel materials in Japan under the budget of the Japanese Government are shown in Table II.

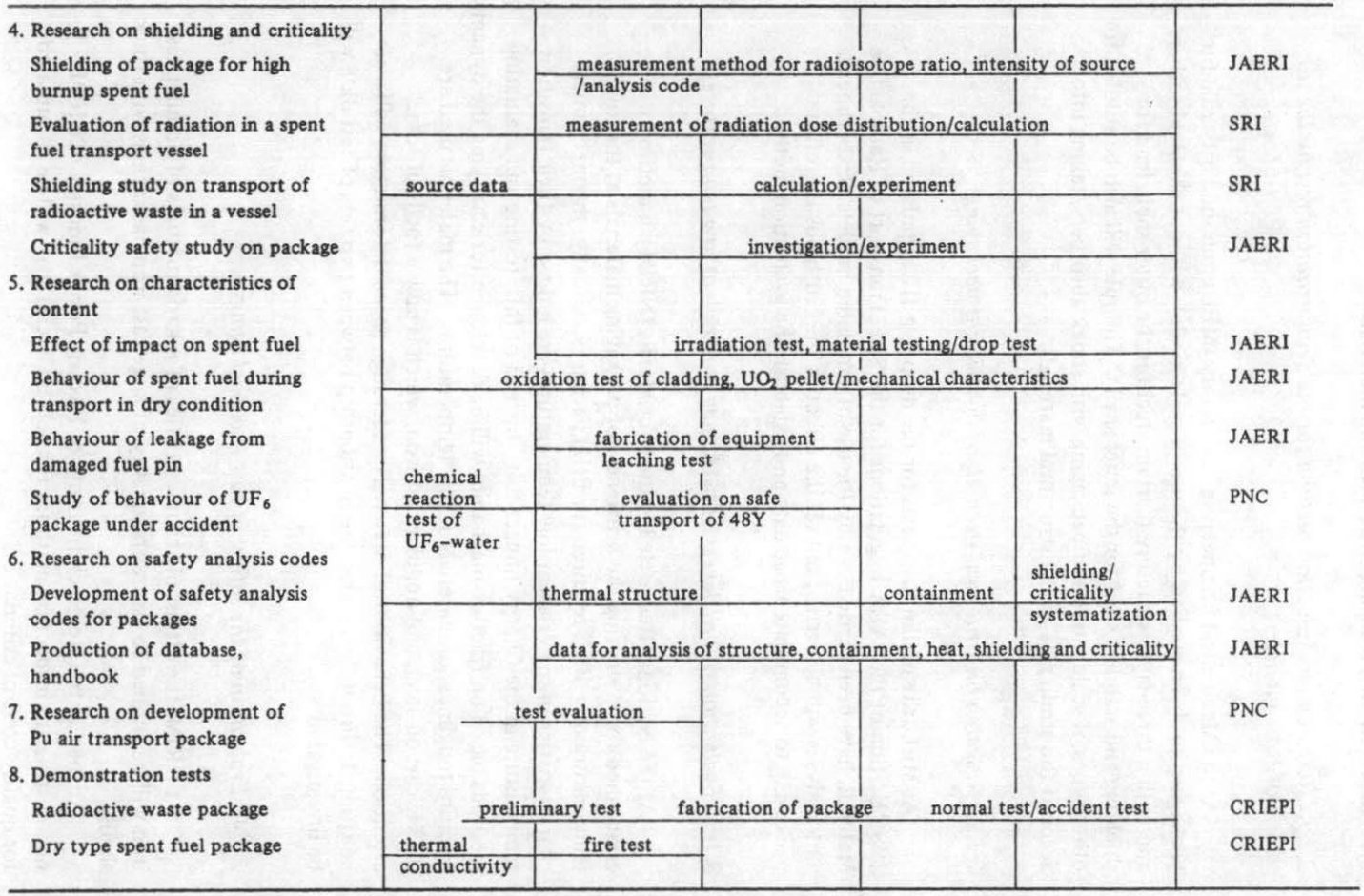
TABLE I. SUMMARY OF PROPOSED RESEARCH ON PACKAGES

Research area \ Package	Spent fuel package	UF_6 package	Plutonium package	Cast iron package	Radioactive waste package
Packaging structures and materials		Drop tests of 48Y cylinder with and without overpack Pressure test for cylinder		Characteristics of packaging materials at low, normal and high temperatures Applicability of similarity rule Evaluation based on break-down dynamics	Calculation for drop impact Tests for large TRU radio-active waste, low level solid waste package Tests of industrial package
Heat and fire resistance	Open fire test for package using resin as shielding material Overheat resistance for a short period	Fire test of 48Y cylinder with and without overpack			
Containment			Leakage test for O-ring materials		Long period sealing performance Lightweight package with double containment
Shielding and criticality	Shielding of γ-rays and neutrons emitted from high burnup spent fuel Criticality safety of high enriched fuel package		Establishment of shielding analysis system		Method for evaluation of radiation source Method for measuring neutron dose rate of re-processing radioactive waste
Characteristics of contents	Response behaviour of assembly against drop impact	Chemical reaction of UF_6–water Evaluation for leakage condition of UF_6			

Safety analysis codes	Structure analysis Thermal analysis	Containment analysis Shielding analysis	Criticality analysis Safety analysis code system, databank		
Development of Pu air transport packaging			Development of Pu package resisting air-plane accident		
Demonstration tests	Demonstration test on safety of spent fuel package				Demonstration test on safety of radioactive waste package

TABLE II. RESEARCH SCHEDULE

Research area \ Japanese fiscal year	1986	1987	1988	1989	1990	Institute/ organization
1. Research on packaging structure and materials						
Applicability of scale model	drop tests of scale models/similarity rule					MEL
Establishment of method for crush test	crush test/evaluation					MEL
Evaluation of brittleness of metal materials at low temperature	method of measurement	evaluation based on fracture toughness at low temperature/high speed deformation characteristics				NRIM
Safety evaluation of cast iron packaging	comprehension of mechanical characteristics/non-destructive analysis/			criteria for quality assurance		NRIM CRIEPI
Structural integrity of package for radioactive waste	dynamic response against impact and vibration of a vessel			static response		SRI
2. Research on heat and fire resistance						
Thermal behaviour of UF_6 package	safety of UF_6 package with and without overpack					PNC
Thermal behaviour under fire accident in tunnel	fabrication of tunnel model	fire test using scale model				FRI
3. Research on containment						
Leakage behaviour of radioactive material from packaging	basic study on leakage	experimental study method/evaluation				MEL PNC


4. Research on shielding and criticality
Shielding of package for high burnup spent fuel
measurement method for radioisotope ratio, intensity of source /analysis code
JAERI
Evaluation of radiation in a spent fuel transport vessel
measurement of radiation dose distribution/calculation
SRI
Shielding study on transport of radioactive waste in a vessel
source data
calculation/experiment
SRI
Criticality safety study on package
investigation/experiment
JAERI
5. Research on characteristics of content
Effect of impact on spent fuel
irradiation test, material testing/drop test
JAERI
Behaviour of spent fuel during transport in dry condition
oxidation test of cladding, UO2 pellet/mechanical characteristics
JAERI
Behaviour of leakage from damaged fuel pin
fabrication of equipment
leaching test
JAERI
Study of behaviour of UF6 package under accident
chemical reaction
test of UF6–water
evaluation on safe transport of 48Y
PNC
6. Research on safety analysis codes
Development of safety analysis codes for packages
thermal structure
containment
shielding/ criticality
systematization
JAERI
Production of database, handbook
data for analysis of structure, containment, heat, shielding and criticality
JAERI
7. Research on development of Pu air transport package
test evaluation
PNC
8. Demonstration tests
Radioactive waste package
preliminary test
fabrication of package
normal test/accident test
CRIEPI
Dry type spent fuel package
thermal conductivity
fire test
CRIEPI

2.1. Research on packaging structures and materials

2.1.1. Research on evaluation method for the demonstration test by the use of scale model

At the Mechanical Engineering Laboratory (MEL), the similarity rule for packaging has been studied by the use of scale models without shock absorbers and with a three-layer structure (carbon steel for the outer shell, lead for shielding and stainless steel for the inner shell). The rule will also be studied for other types of scale models of packaging with shock absorbers, taking into account the strain rate of the structural materials.

2.1.2. Research on structural strength of lightweight packagings

At MEL, the preliminary tests for the drop test III, stipulated in the 1985 Edition of the IAEA Regulations for the Safe Transport of Radioactive Material, have been carried out by the use of simulated models. Experiments and analyses will be carried out on the effect of the crush posture of the packaging to accumulate basic data and establish the evaluation method.

2.1.3. Evaluation of brittleness of packaging materials at low temperatures

At the National Research Institute for Metals (NRIM), a method will be established for evaluating the brittleness of packaging materials at the low temperature of −40°C required for B(U) packages. Usually, the mechanical characteristics of materials at low temperatures are judged by their transition temperature in the Charpy impact test. Instead of this, testing and evaluating methods based on fracture mechanics will be developed for clarifying the dynamic fracture toughness of materials at low temperatures. The materials used are 0.1%C carbon steel, and nodular cast iron, which is now a focus of some attention. The behaviour of materials under high speed deformation will also be studied. From the results, the relationship between two sets of test data will be investigated.

2.1.4. Evaluation of the safety of cast iron packagings

At NRIM, the ultrasonic characteristics of microstructures of nodular cast iron will be studied to assure the quality of large cast iron packagings with thick shells.

At the Central Research Institute of Electric Power Industry (CRIEPI), non-destructive inspection methods for defects in cast iron will be formulated for quality control criteria.

2.1.5. Research on the structural strength of packagings for returnable waste materials

At the Ship Research Institute (SRI), the dynamic response of packages to impact and vibration in vessel transport will be evaluated by the use of computer codes in relation to shipments of waste materials returned from France and the UK.

2.2. Research on heat and fire resistance

2.2.1. Evaluation of thermal behaviour of UF_6 packages

At the Power Reactor and Nuclear Fuel Development Corporation (PNC), experiments will be carried out to find the time which a UF_6 package under fire accident conditions takes to reach the design temperature with and without an overpack in order to evaluate the fire resistance characteristics of the package.

2.2.2. Evaluation of the behaviour of packages under fire accident in a tunnel

At the Fire Research Institute (FRI), the fire temperature, the thermal convection and the fire duration time in a tunnel will be studied by the use of a tunnel model to clarify the thermal behaviour during a hypothetical tunnel fire accident of various types of package on a vehicle.

2.3. Research on containment

2.3.1. Research on leakage behaviour of radioactive materials from packagings

At MEL, the evaluation method for leakage behaviour of a gas from packagings will be studied experimentally by the use of a gap model which simulates sealed boundaries. A measuring method for the leakage behaviour of powders will also be studied.

At PNC, basic studies will be done on the leakage of radioactive materials from various types of package. Experiments will be carried out to find the sealing characteristics of the O-ring structures which are generally used.

2.4. Research on shielding and criticality

2.4.1. Research on the safety of package shielding for high burnup spent fuel

At the Japan Atomic Energy Research Institute (JAERI), a measuring and estimation method will be studied for the neutron source intensity of high burnup

spent fuels resulting from LWR improvement. Computer codes will also be developed to evaluate the shielding.

2.4.2. Research on radiation shielding of spent fuel packages transported by vessel

At SRI, a method for evaluating neutrons and secondary gamma rays from high burnup spent fuel and for determining the spatial distribution of radiation dose rate will be studied in work aimed at protecting ships crews from radiation exposure from spent fuel packages transported by vessel.

2.4.3. Research on criticality safety of packages

At JAERI, experiments and evaluations will be carried out on the sub-criticality of packages in relation to the use of more highly enriched fuel for LWRs.

2.5. Research on the characteristics of contents

2.5.1. Research on impact in drop tests of spent fuel

At JAERI, the threshold values and the propagation behaviour of a pinhole or crack in the fuel cladding will be studied to examine the integrity of sealing characteristics in spent fuel package drop accidents. The behaviour of the fuel assembly due to the damaging effect of water will also be studied.

2.5.2. Research on the behaviour of spent fuel transported in a dry condition

At JAERI, the impact strength and creep strength under internal pressure of LWR fuel cladding during transport in a dry condition or for storage over a long period will be studied experimentally. Experiments will also be carried out to evaluate the effect of the oxidation of spent fuels in damaged fuel cladding in air.

2.5.3. Leakage behaviour of radioactive materials from damaged fuel cladding

At JAERI, studies will be carried out on the leakage behaviour of spent fuel materials and their fission products from fuel claddings with defects such as pinholes, so as to measure the amount of leaching and the leaching rate into water. A leaching model will be developed.

2.5.4. Research on the behaviour of UF_6 in an accident

At PNC, studies are being carried out to evaluate the impact on UF_6 packages when they fall to the bottom of the sea in a shipwreck. The studies also include

experimental clarification of the mechanism of the chemical reaction between UF_6 and seawater, and the characteristics and the diffusion of its products.

2.6. Development of safety analysis codes

2.6.1. Development of safety analysis codes for packages

At JAERI, various types of safety analysis codes will be developed in relation to the structure, containment, heat, sealing, shielding and criticality of various types of packages.

2.6.2. Compilation of safety analysis database for packages

At JAERI, data related to packages will be collected to facilitate efficient safety examination of packages.

2.7. Research on the development of plutonium air transport packaging

At PNC, experiments will be carried out on the development of packagings for plutonium in air transport.

2.8. Demonstration tests

2.8.1. Demonstration test for the safety of radioactive waste packages

At CRIEPI, demonstration tests will be carried out on packages for high level vitrified wastes, and for low or medium level wastes, under normal and accident conditions, to verify the safety of packages of returnable waste materials generated by reprocessing in France and the UK.

2.8.2. Demonstration test for the reliability of spent fuel packagings

At CRIEPI, tests will be carried out on the thermal conductivity and fire resistance characteristics of dry packagings for spent fuels.

In the field of international co-operation, Japan has been participating in co-ordinated research programmes (CRP) on the application of the INTERTRAN code. We are planning to participate in the following research tasks in a new CRP:

(a) Studies on the behaviour of UF_6 in the environment and on the heat and fire resistance of UF_6 cylinders to ensure a safety margin through assessment in a test which is more severe than that of the IAEA Regulations
(b) Studies on improvement of the thermal analysis method for spent fuel packages

(c) Studies on establishment of shielding analysis for damaged industrial packages or Type A packages.

The PNC has been implementing a research programme on the development of air transport packages with the co-operation of the nations concerned.

3. CONCLUSION

Research in Japan on the safe transport of nuclear fuel is being carried out over a wide range and the results have been used effectively in the following fields:

(1) To improve safety guidelines and to collect technical data for the evaluation of safety, and
(2) To improve the safety measures of current transport systems and their components.

In the near future it will be necessary to systematize this research, and to allocate it to private companies. Thus, research projects will be promoted rationally and efficiently and will contribute further to securing the safety of package transport. International co-operation in this field is very important. We would like to co-operate with many countries and the IAEA in order to secure transport safety on a worldwide level, to reduce costs, and to increase the efficiency of research by exchanging results.