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KAERI/AR-606/2001
KAERI/AR-583/2000, Rev.1

POST-IRRADIATION EXAMINATION AND R&D PROGRAMS USING IRRADIATED FUELS AT KAERI

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PREFACE

This document describes the post-irradiation examination and R&D programs using irradiated fuels at KAERI. The comprehensive utilization program of the KAERI's Post-Irradiation Examination (PIE) related nuclear facilities such as Post-Irradiation Examination Facility (PIEF), Irradiated Materials Examination Facility (IMEF) and HANARO is described.

In chapter I, the details of post-irradiation examination (PIE) programs derived from on-going project by employing both PIEF, IMEF, and HANARO are presented.

The safeguards program of nuclear materials covering all activities in chapter I is presented in chapter II.

GLOSSARY OF TERMS AND ABBREVIATIONS

AECL	: Atomic Energy of Canada Limited
CAL	: Chemical Analysis Laboratory
CAW	: Corrosive Active Waste
DF	: Decontamination Facility
DFDF	: DUPIC Fuel Development Facility
DUPIC	: Direct Use of Spent PWR fuel in CANDU
EPMA	: Electron Probe Microanalyzer
HANARO	: High Flux Advanced Neutron Application Reactor
HASW	: High Active Solid Waste
HAW	: High Active Waste
IMEF	: Irradiated Materials Examination Facility
JD	: Joint Determination
KAERI	: Korea Atomic Energy Research Institute
KEPCO	: Korea Electric Power Corporation
KOFA	: Korea Optimized Fuel Assembly
KSC	: KAERI Shipping Cask
LASW	: Low Active Solid Waste
LAW	: Low Active Waste
MASW	: Medium Active Solid Waste
MAW	: Medium Active Waste

NDE	:	Non-Destructive Examination
NPP	:	Nuclear Power Plant
NRU	:	National Research Universal Reactor of AECL
OFA	:	Optimized Fuel Assembly
PIE	:	Post-Irradiation Examination
PIEF	:	Post-Irradiation Examination Facility
RWTF	:	Radioactive Waste Treatment Facility
RIPF	:	Radioisotope Production Facility
SMART	:	System-Integrated Modular Advanced Reactor
SWSB	:	Solid Waste Storage Building
TEM	:	Transmission Electron Microscope
VLAW	:	Very Low Active Waste

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Chapter I.

Post-Irradiation Examination Program

1. Objectives and Necessity

The objective of this project is to perform post-irradiation examination (PIE) for the PWR irradiated fuels, CANDU fuels, HANARO fuels and test fuel materials in order to verify the irradiation performance and their integrity as well as to construct a fuel performance data base.

Since the first commercial NPP operation of Kori Unit-1 in 1978, total twelve PWRs and four CANDU NPPs are in operation today. In addition, four additional NPPs are planned for a start-up operation by 2006.

According to the fuel development and nuclear safety related research programs in Korea, consistent PIE works for the fuels and materials have been carried out in PIEF and IMEF. Both facilities are to provide PIE services for all types of nuclear fuels in Korea including the irradiated fuels and test fuel materials from HANARO.

2. Overview of Power Reactor Irradiated Fuels

Sixteen NPPs, 12 PWRs and 4 CANDUs, are now in operation with generating capacity of about 13,716 MWe which would be increased up to approximately 22,529 MWe from 24 NPPs by the year 2010.

Spent nuclear fuels discharged from NPPs in Korea have been safely stored in pools at reactor sites since the first power plant commenced its commercial operation in 1978. But according to the running out of spent fuel storage capacity in reactor sites, many efforts have been made to extend the storage capacity. Several spent fuel storage programs are underway including a plan to construct the interim storage facility by 2010s.

Seven PWR spent fuel assemblies and one defective fuel rods basket are stored in PIE facility. Maximum 15 PWR fuel assemblies were planned to be transferred to PIE facility for PIE and those fuels were to be removed from PIE facility to the interim storage facility after examination. But the interim storage facility is not ready, so it is suggested that the fuel assemblies in the PIE facility would be stored until a proper storage program is established. Three more PWR spent fuel assemblies and a couple of CANDU fuel bundles could be transported for PIE by the year 2006. In the case of fuel failure occurrences at NPPs, the defective fuel rods can be transported to PIE facility for inspection. The total number of fuel assemblies stored in PIE facility will not exceed 15 fuel assemblies as agreed mutually at the 14th Joint Determination for Post-Irradiation Examination of Irradiated Nuclear Fuels signed on March 29, 1996.

Table I-1. Current Status of PWR Spent Fuels in PIE Facility

FA No.	Transp. Date	Reactor	Cycle	Core Location	Burnup (MWD/tU)	Fuel Type	Discharge Date	Status
C15	Apr. 1987	Kori-1	1/2/3	K3/F8/H3	32,300	14x14	Apr 17, 82	Dismantled
A39	May 1987	Kori-1	1/2	K7/G7	25,300	14x14	Jan. 30, 81	Dismantled
A17	June 1987	Kori-1	1	J6	17,071	14x14	Oct. 27, 79	Dismantled
Basket	May 1988	Kori-1						
G23	May 1990	Kori-1	4/5/6/7	A8/A8/B7/D7	35,500	14x14	Oct. 24, 86	Dismantled
J14	July 1991	Kori-1	7/8/9	E9/J5/H11	37,840	14x14	Jan. 20, 89	Dismantled
F02	May 1992	Kori-1	4/5/6	B6/K9/L10	28,300	14x14	Sep. 17, 85	Intact
J44	Apr. 1993	Kori-2	7/8	C8/C7	35,018	16x16	May 29, 92	Dismantled

3. Scope of Work and Method

A. PIE of PWR Irradiated Fuels at PIE Facility

1) Transportation of irradiated fuel assemblies

The irradiated fuel assemblies for PIE will be transferred from PWR NPPs sites to the KAERI PIE facility by using a shipping cask. Seven PWR fuel assemblies and one basket containing 46 defective fuel rods were transported for PIE by 2000. A maximum of three PWR spent fuel assemblies will be transported for PIE by the end of 2006.

2) Fuel specifications

Items	Description
o Assembly type	PWR 14x14, 16x16, 17x17
o Fuel Material	-Sintered UO_2 fuel -Zircaloy-4 clad
o Initial enrichment	less than 5 wt%
o Burnup (rod average)	5 to 70 GWd/tU

3) Post-irradiation examination

A) Scope of work

A brief description is made in this document because the most of PIE items and methods are essentially the same as in the report with a title of "Post Irradiation Examination and R&D Programs using Irradiated Fuels at KAERI (KAERI/AR -417/95)" submitted already to the USA in 1995.

(1) Nondestructive examination of fuel assembly in pool

- Visual examination
- Dimensional measurement
- Measurement of relative burnup distribution by gamma scanning techniques
- Disassembling and selecting several fuel rods per assembly for detailed examination in hot cells

(2) Nondestructive examination of fuel rods in hot cells

- Visual examination and photography
- Measurement of dimensional change
- Eddy current test
- X-ray radiography
- Axial gamma scanning
- Measurement of oxide layer thickness

(3) Destructive examination of fuel rods in hot cells

- Fission gas sampling and analysis
- Burnup determination
- Retained Xe gas analysis
- Fuel bulk density measurement
- Metallography and microanalysis
- Sectional gamma scanning
- Scanning electron microscopy

B) Method

(1) Cask receiving and unloading

- Checking dose rate around the cask.
- Transferring the cask to the decontamination pit where decompression, internal and external decontamination, and cooling are performed.
- Transferring the cask to the unloading pool 9401 and removing the cask lid.
- Extracting the fuel assembly out of the cask.

(2) Fuel assembly storage

- Transferring the fuel assembly from the unloading pool 9401 to the storage pool 9402.
- Placing the assembly in the storage rack.

(3) Assembly inspection and dismantling

- Placing PWR assembly onto the visual and dimensional inspection stand (VDIS) and carrying out the inspection.
- Transferring the assembly to the dismantling machine in 9403 pool from which the head end fitting of the assembly is removed.
- Rod extraction is carried out for the fuels to be examined more precise hot cell examinations.
- The extracted rods are transferred to cell 9404 through the channel using lifting cart.

(4) Nondestructive test of rod

- Placing the fuel rod transferred from the pool 9403 on the rod examination bench in the nondestructive test cell 9404.
- Perform visual inspection and photography, profilometry, eddy current test, X-ray radiography, and axial gamma scanning, etc.
- After nondestructive examination, the rod is tilted to the horizontal position and then transferred to the rod cutting cell 9405.

(5) Fission gas puncturing and fuel rod cutting

- Fission gas sampling is carried out in cell 9405 and the sample is sent to the analytical laboratory for chemical composition analysis.
- Cutting, milling, and drilling on the fuel rod are carried out in the cell 9405. After six or seven samples (about 2 cm in length) are taken from each rod, the remaining fuel rods will be cut in 60 cm long to be stored . The rod cuts are put in a container, and then transferred to the pool 9402 for storage.

(6) Metallographic sample preparation

- Sectioning and vacuum impregnation, mounting, grinding, polishing, chemical etching and ultrasonic cleaning are performed in the sample preparation cell 9407.

(7) Metallography and microanalysis

- Optical macro and microscopic examinations are performed in the lead cell 9408.
- Microanalysis of some specimens is to be performed by EPMA and TEM in the IMEF. After examination, the specimen will be returned to PIEF.
- Microhardness test is also carried out, if necessary.

(8) Sectional gamma scanning

- Sectional(or radial) gamma scanning for the sample is conducted in the lead cell 9409.

(9) Density measurement

- The density of fuel samples is measured by using a precision balance.

(10) Burnup measurement

- The burnup is determined using fuel sample in the chemical laboratory.
- The expected amount of the cumulative quantity of separated materials for the burnup measurements during this JD period are described in the summary of PIE program in the chapter II.

(11) Retained Xe gas analysis

Retained Xe gas content in fuel specimens are determined.

(12) Scanning electron microsopy

(13) Physical and mechanical tests for irradiated materials

- Impact, tensile, burst, hardness, fatigue, SCC, and corrosion tests are performed in the IMEF.
- Thermal expansion and thermal conductivity tests are performed in the IMEF.
- The samples to be examined by using EPMA, TEM and physical/ mechanical testing devices will be transported by a small padirac cask from the PIEF's 9405 cell to the IMEF's M4 cell and returned to PIEF after examination.

4) Storage of unexamined fuel

The unexamined fuel rod cuts will be contained in Rod Cuts Container (RCC) in hot cell and stored at 9402 pool in PIE facility.

The specimens prepared for metallograpic examination will be stored in 9406 hot cell of PIE facility.

5) Radioactive waste treatment

The radioactive waste is categorized into liquid, solid, and gaseous wastes for which their treatment methods are described in the followings.

- Pool water treatment

The pool water treatment includes filtration, decontamination and cooling of the water from the unloading pool 9401, the storage pool 9402 and the inspection and dismantling pool 9403. Treatment takes place mainly for the storage pool 9402 and the water of the other pools being treated as the need arises.

◦ Filtration

The water is clarified through a cartridge filter with a precoat of crushed resins. The process is to clarify(> 25μ) and partly to decontaminate the water.

◦ Declogging

Declogging is carried out when the gauge indicates that the maximum fixed fouling level has been reached. The declogged resins are entrained towards the Radioactive Waste Treatment Facility (RWTF) by demineralized water.

◦ Decontamination

The water is subjected to thorough decontamination (below 10^{-3} μCi/ml) by passing it successively over a bed of anion resins. Periodic sampling permits to check the efficiency of the resins. According to the efficiency, regeneration of the resins is made.

Liquid wastes from the regeneration are drained to the storage tanks and then to the Radioactive Waste Treatment Facility(RWTF) through a piping system.

◦ Cooling

Finally, the water is cooled from 25 to 15 ℃(max. 35 down to 25 ℃) by means of two plate heat exchangers. One of the exchangers is on stand-by. At the end of the cycle the water is released at the bottom of the pool.

- Decontamination of the equipment

In order to reduce the radiation does to which personnel on intervention duty may be exposed, a partial decontamination must be carried out on the equipment used for the intervention. The decontamination is carried out by means of soda solution(1～1.5 N) with open or closed circuit.

During the operation the water treatment system is stopped and the sections of equipment to be decontaminated are isolated. When the preliminary decontamination is not enough, equipment is removed and transported to the

RWTF for further decontamination.

The liquid waste from the preliminary decontamination is also transported to the interim storage tanks with a capacity of 10 m^3 in the PIEF.

- Liquid waste treatment

The liquid wastes as shown in Table I-2 come mainly from the pool water treatment, hot cell and the chemical analysis laboratories.

The small quantity of liquid wastes produced in the hot cells is plastered in a can inside the cell and then treated like a solid waste.

The liquid wastes coming from the pool water treatment unit are subdivided into 3 sub-classes:

(a) low active waste($5\times10^{-6}\sim10^{-1}$ Ci/m^3);
(b) medium active waste($10^{-1}\sim10$ Ci/m^3);
(c) worn resin(< 1 Ci/m^3).

LAW and MAW are collected in a separate 10m^3 vessel, and transferred to the RWTF using a piping system installed in a concrete active duct.

Worn resins are transferred by gravity. Other wastes are transferred using pumps(10 m^3/h). The liquid wastes coming from the chemical analysis laboratories are usually corrosive and subdivided into 4 sub-classes:

(a) low active waste;
(b) medium active waste;
(c) active and very corrosive waste;
(d) inactive waste.

Several collectors in plastic material connected to 2 m^3 tank collect the low active wastes from all the benches, ventilated hoods, laundries, floor siphons and wash-rooms. Several stainless steel collectors connected to 2m^3 tank collect the medium active wastes coming from the containment enclosures. The piping-tanks unit is tight-welded and constitutes a barrier against contamination. These wastes are periodically transferred to the RWTF by means of a shielded tanker to avoid the radiation exposure.

The very corrosive active wastes which may contain ions such as chlorides, fluorides etc. are carefully selected and treated in the containment enclosure. These wastes are mixed with plaster and evacuated as solid waste.

The inactive wastes are collected and directly sent to the site dilution station.

Table I-2. Expected Amount of Liquid Wastes

Source	Volume	Activity	Salinity(g/L)
MAW CAW LAW	830 m^3/year	2.5×10^{-3} ~ 0.65 Ci/m^3	2.5 ~ 48.4
VLAW	1,000 m^3/year	5×10^{-6} Ci/m^3	
Worn Resins: Powder from water filtration	2.5 kg/week	< 6 Ci/batch	
Worn Resins: Granules from anion -cation column	Anion: 0.65 m^3/4year Cation 0.5 m^3/4year	< 1 Ci/m^3	

- Solid waste treatment

The origins of solid wastes are chemical analysis laboratories, pools and hot cells.

LASW is pumps, valves, filters, papers, packages, sludges from internal decontamination of fuel transport casks, and dust from sawing of head end fitting of fuel assembly etc.

These wastes are divided into two types:

(a) compactable solid wastes are put in vinyl bags in 100 L drum;

(b) non compactable solid wastes in bulk are put in vinyl sheets.

These two types of wastes are transferred to the RWTF by a trailer and case of pumps, valves and filters are firstly brought to the decontamination unit.

MASW and HASW are jugs, hulls, glass ware, etc. for chemical analysis laboratories.

For pools and hot cells, they are head-end fitting of dismantled fuel assembly, sludges from internal decontamination of fuel transport casks, capsules for transport of irradiated samples, dust from sawing of fuel head-end fitting and fuel rods, plastered decontamination wastes in cells etc.

Analytical laboratory wastes are plastered in cardboard drums inside the shielded lines of the laboratories.

A sorting of wastes can be performed inside the shielded lines to have a homogeneous distribution of the activity between drums. Each cardboard drum is then put in a polyethylene drum which is tight(about 25ℓ), and transferred to the RWTF using a 100 mm lead padirac cask. All the laboratory wastes are considered to be slow decay wastes and need to be stored in a shielded concrete shell filled with bitumen concrete. All active solid wastes of pools and hot cells are put in a 50 L stainless steel drum which is water-tight and introduced in a 15 mm thick lead cask from the upper part of the cells. These wastes are mainly β-γ ones and sent directly to the monolith of storage for decay of HASW(average time of storage: 6.5 years). The sorting of wastes is made in the cell before transfer in the cask. The solid wastes are transferred to the final storage area or to the treatment area only after the following operations are carried out:

(a) safety control in order to check the non-contamination of the outside of the packaging and that the dose rate is compatible with the transport conditions;
(b) marking of packages;
(c) labelling.

The transfer is then carried out by a responsible person in charge of the radioactive transports with the authorization of the health physics and the waste treatment station.

The unexamined fuel rods of dismantled assemblies, which are not subjected to PIE, are put into a stainless steel container and stored in the PIEF storage pool 9402 for the time being, and finally removed to the interim storage site when it is ready.

- Gaseous waste treatment

Gaseous wastes are treated by ventilation system including a filter and not transferred to the RWTF. Ventilated zones are considered as four types, according to their radiation and contamination levels.

(a) inactive zones : "blue" : slight over pressure
(b) working zones : "amber" : -3 to -5 mmAq
(c) intervention zones : "yellow" : -5 to -8 mmAq
(d) in-cell zones : "red" : -15 to -20 mmAq

For some analytical glove-boxes and shielded lines, depending on the operations performed in, the negative pressure may reach -25 to -30 mmAq compared with the negative pressure prevailing in the corresponding working zones.

The ventilation network only uses fresh air : no re-use or re-circulation of air is authorized. The total quantity of blown-air is so extracted from the most active areas and released to the stack through one or two filtration stages depending on the circuits : the exhaust circuits differ according to the activity prevailing in the zones from which air is extracted :

(a) the medium depression circuits, which extract the air from amber and yellow zones, have only one absolute filtration stage;
(b) the high depression circuits that extract the air from red zones and active cells(including glove-boxes) has two absolute filtration stages.

B. CANDU Spent Fuel

1) Transportation

- A maximum of three CANDU fuel bundles for post-irradiation examination will be transported from the plant site to IMEF at KAERI by using a shipping cask during the year of 2002～2006. The detailed design and manufacturing of a shipping cask will be determined later.
- In KAERI site, the CANDU fuel bundle transported from the NPP will be dismantled in the IMEF hot cell. There is no plans for the installation of the CANDU bundle end plate cutting device in the PIEF hot cell at this moment, so only the fuel rods to be examined in the PIEF hot cell will be transported from the IMEF to the PIEF hot cell after dismantling the CANDU bundle in the IMEF hot cell. HANARO cask will be used for the transportation of the fuel rods from the IMEF to the PIEF. And the unexamined fuel rods of the CANDU fuel, which are not subjected to PIE, will be put into a stainless steel container in the IMEF hot cell and transported to the PIEF fuel storage pool by using the HANARO cask.
- PIE for the fuel rods will be carried out in the IMEF and/or PIEF hot cell according to the facility operation condition and examination items. Fuel rods to be examined in the PIEF hot cell will be canned in the IMEF M2 hot cell and the can will be transported to the IMEF pool through the bucket elevator to be loaded in the HANARO cask. The HANARO cask will be transported to the PIEF fuel unloading pool (9401) on road and the can containing the fuel rods will be taken out of the cask to be sent to 9404 hot cell through the lifting cart system connecting the 9403 pool to the hot cell. The transporting passage between the 9403 pool and the 9404 hot cell of the PIEF connected by the lifting cart system is spacious enough to receive this can. So far, PWR fuel rod cuts container has been transferred from the 9404 hot cell to the 9403 pool through this passage. Then, the in-cell crane will be used for moving the can between the 9404 and 9405 hot cells. The detailed specifications of the can

for the CANDU fuel rods will be determined later, however, the general specifications and shape would be similar to the FRCC (Fuel Rod Cuts Container). In this context, there will be no modification of the PIEF facility to receive the CANDU fuel rods in the PIEF hot cell.

- For the transportation of the fuel rod cuts or chemical analysis specimens, the PADIRAC cask will be used between the PIEF and the IMEF. CANDU fuel rod cuts or chemical specimens prepared in the IMEF hot cell will be loaded into the PADIRAC cask through the back door of the IMEF M4 hot cell and transported to the PIEF hot cell on road. These fuel rod cuts will be unloaded in the cell through the back door of the PIEF hot cell 9406. This transportation route is the same route of the PWR fuel rod cuts for the DUPIC program in reverse order.

2) Fuel specification

Wolsung-1 irradiated spent nuclear fuels
Wolsung-2 irradiated spent nuclear fuels
Wolsung-3 irradiated spent nuclear fuels
Wolsung-4 irradiated spent nuclear fuels

Items	Description
o Fuel Material	-Sintered UO_2 fuel -Zircaloy-4 clad
o Initial enrichment	-Natural Uranium (0.7 wt.%), or -Slightly enriched uranium (less than 2 wt.%)
o Burnup (rod average)	1 to 10 GWd/tU

3) Post-irradiation examination

(A) Scope of work

- Nondestructive examination of fuel bundles in hot cell
  - ◦ Visual examination
  - ◦ Dimensional measurement
  - ◦ Dismantling and selecting several fuel rods per bundle for detailed examination
  - ◦ Eddy current test
  - ◦ X-ray radiography
  - ◦ Axial gamma scanning
- Destructive examination of fuel rods in hot cells
  - ◦ Fission gas sampling and analysis
  - ◦ Burnup determination
  - ◦ Fission gas analysis
  - ◦ Fuel density measurement
  - ◦ Metallography and microstructure analysis
  - ◦ Sectional gamma scanning
  - ◦ Scanning electron microscopy

(B) Method

- Cask receiving and unloading
  - ◦ Checking the dose rate close to the cask transportation trailer.
  - ◦ Transferring the cask to the pool and extracting the fuel rods can out of the cask

- Bundle inspection and dismantling
  - ◦ The bundle inspection is carried out in M1 cell of the IMEF.
  - ◦ Bundle dismantling is carried out in M2 cell (IMEF) by cutting the end plate.

- Nondestructive test of rod
  - ◦ General NDT examination for the CANDU fuel rods including visual inspection and photography, profilometry, eddy current test, X-ray radiography, and axial gamma scanning will be carried out in the PIEF/IMEF hot cell.

- Fission gas sampling and fuel rod cutting
  - ◦ Fission gas sampling is made by a puncturing device installed in connection with a vacuum system outside the cell and then sent to the analytical laboratory for chemical composition analysis.
  - ◦ Cutting, milling, and drilling on the fuel rod are carried out in the cutting cell of the IMEF/PIEF. Usually three and four samples of 2-cm in length are taken from each rod. The remaining parts which are not examined are put in a container, and then transferred to the pool 9402 in PIEF for the storage.

- Metallographic sample preparation
  - ◦ Sectioning and resin impregnation, mounting, grinding, polishing, chemical etching and ultrasonic cleaning are performed in the sample preparation cell of the PIEF/IMEF.

- Metallography and microanalysis
  - ◦ Optical macro and microscopic examinations are performed in the metallographic examination cell in the PIEF/IMEF
  - ◦ Microanalysis of some specimens is to be performed by EPMA and TEM in the IMEF.
  - ◦ Microhardness test is also carried out, if necessary.

- Sectional gamma scanning

◦ Sectional(or radial) gamma scanning for the sample will be done in the cell 9409 of the PIEF.

- Density measurement
  ◦ The density of fuel samples is measured by using a precision balance.

- Burnup measurement
  ◦ The burnup is determined in the chemical laboratory by chemical analysis. For this the specimens will be sent to the PIEF.
  ◦ The expected amount of the cumulative quantity of separated materials for the burnup measurements during this JD period are described in the summary of PIE program in the chapter II.

- Retained fission gas analysis
  ◦ Retained fission gas content and composition in irradiated fuel specimens are determined

- Scanning electron microscopy

- Physical and mechanical tests for irradiated materials
  ◦ Impact, tensile, burst, hardness, fatigue, SCC, and corrosion tests.
  ◦ Thermal expansion and thermal conductivity tests.
  ◦ The specimens to be examined by EPMA, TEM and physical/mechanical testing devices will be transported to the PIEF after examination for storage.

4) Storage of unexamined fuel

Basically the unexamined fuel rods of the dismantled CANDU bundles, which are not subjected to PIE, are put into a container and stored in the PIEF storage pool 9402 after examination. For this, HANARO cask will be used for the transportation of the CANDU elements remained after dismantling in the IMEF hot cell. For the handling of the dismantled CANDU elements during transportation and storage, a container will be fabricated. The remained parts of the CANDU bundle will be put in the container which will be loaded in the cask to be transported to the fuel unloading pool of the PIEF (9401) and stored in the fuel storage pool (9402). The detailed design and manufacturing of the container will be determined later.

5) Radioactive waste treatment

The radioactive waste treatment will be conducted by the procedures described in the section of 5) Radioactive Waste Treatment in the part A. PIE of PWR Irradiated Fuels.

C. Long-term Dissolution Behavior of Spent Fuel under Repository Condition

1) Transportation

The fuels to be examined for this work will be selected from the as-transported spent PWR fuels in PIE facility. So, no special transportation procedure will be adopted for this fuel examination.

2) Fuel specification

As described in the above section, the specifications of the fuels for this examination is the same as the conventional PWR fuels.

3) Post-irradiation examination

(A) Scope of work

To understand dissolution behavior of radionuclides from spent fuel in contact with a compacted bentonite in synthetic granitic ground water and its release modeling.

○ The interaction test of buffer, ground water and spent fuel
- Adsorption of radionuclides on domestic bentonite
- Surface alteration of spent fuel specimens
- Analysis of leachates and bentonites

○ Experiment
- Location : IMEF, PIEF hot cells and chemical laboratory
- Amount of samples per year : 3~5 PWR fuel pellets per year with different burnup.
- Specimens will be prepared at PIE facility hot cells and transferred to the IMEF by PADIRAC system for the experiments.

(B) Schedule

	2002				2003				2004				2005				2006			
	1/4	2/4	3/4	4/4	1/4	2/4	3/4	4/4	1/4	2/4	3/4	4/4	1/4	2/4	3/4	4/4	1/4	2/4	3/4	4/4
Preparation of samples (PIEF)	—		—		—		—		—		—		—		—		—		—	
Leach experiment (IMEF)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chemical analysis (PIEF)	—		—		—		—		—		—		—		—		—		—	

4) Storage of unexamined fuels

3~5 pellets per year will be selected for this work, and some of them will be prepared as specimens for the experiment. The expected amount of fuel for the specimen preparations will be 20 grams per year in average, and the total amount of fuels to be used for this experiments will not exceed 100 grams. The unexamined fuels will be stored in the PIE pool and the specimens will be stored at 9406 cell of the PIE facility.

5) Radioactive waste treatment

Solid wastes will be transferred to monolith for storage.

Wastes such as leachate and bentonite are transferred to RWTF for storage after their chemical analysis.

The radioactive waste treatment will be conducted by the procedures described in the section of 5) Radioactive Waste Treatment in the part A. PIE of PWR Irradiated Fuels.

D. Post irradiation annealing experiment

Post irradiation annealing experiment will be carried out in the PIEF to measure the amount of fission gas released from the irradiated fuel pellets by annealing (heating) the fuel pellets or fuel fragments. The expected amount of fuel to be used for this examination will not exceed 150 g in UO_2 base for the entire work period.

1) Transportation

Three kinds of pellet or fuel pellet fragments will be experimented ; spent PWR UO_2 pellet, spent PWR UO_2-Gd_2O_3 pellet, and UO_2 pellet fragments irradiated at HANARO. The UO_2 pellet fragments are taken from spent PWR fuels in the PIEF and irradiated at the HANARO, then transported to the PIEF for examination. For this, a PADIRAC system will be used for the transportation between the PIEF and IMEF.

2) Fuel Specifications

contents	descriptions
1. Spent PWR UO_2 pellet	
- burnup	10,000 ~ 40,000 MWd/tU
- amount	50 g
2. Spent PWR UO_2-Gd_2O_3 pellet fragments	
- burnup	20,000 ~ 40,000 MWd/tU
- amount	50 g
3. UO_2 pellet fragments irradiated at HANARO	
- burnup	5 ~ 70,000 MWd/tU
- amount	50 g

3) Post irradiation annealing experiment

(A) Scope of work

- Characterization of irradiated pellets
- Loading pellet fragments in a furnace

- Heating pellet fragments
- Measuring the amount of fission gas released from the pellet fragments by means of β or γ spectrometer

(B) Method

Follow the PIE procedure.

- Irradiated UO_2 fuel is weighed using a balance.
- Irradiated fuel is loaded in a furnace and then heated up to a temperature ranging from 1200 to 1700 ℃.
- Fission gas is released from the fuel during holding at a constant temperature.
- Fission gas is swept by a carrier gas consisting of helium, hydrogen, carbon dioxide, steam.
- The carrier gas then passes through a filter for trapping Cs, I etc.
- The carrier gas leave the hot cell and enter a glove box.
- The Kr-85 in the carrier gas is continuously counted with a beta counter in a glove box.
- The Kr-85 is accumulated in charcoal trap and the total amount is counted by a gamma detector.
- Finally, the fission gas is returned to the hot cell.

4) Storage of unexamined fuels

The unexamined pellets, pellet fragments and rod-cuts are put in a stainless steel container and stored in PIEF.

5) Radioactive waste treatment

The radioactive waste treatment will be conducted by the procedures described in the section of 5) Radioactive Waste Treatment in the part A. PIE of PWR Irradiated Fuels.

E. HANARO Driver Fuel

1) Transportation

The HANARO driver fuels irradiated at HANARO will be transported from the HANARO pool to the IMEF by using a shipping cask.

2) Fuel specifications

Contents	Descriptions
Bundle weight	36 el. : 2.193 kgU (433 g U^{235}) 18 el. : 1.257 kgU (248 g U^{235})
Core length	76 cm
Core diameter	6.35 mm
Composition	Al-U_3Si, 19.75 w/o U^{235}
Burnup	83,000 MWd/tU (50 a/o U^{235})
Expected Max. Pu production	14.2 g/bundle (36 el.), 6.7 g/bundle (18 el.)
U^{235}	216.3 g/bundle (36 el.), 109.3 g/bundle (18 el.)

3) Post-irradiation examination

(A) Scope of work

- Nondestructive examination in hot cell
  - ◦ Dismantling of fuel bundle
  - ◦ Visual examination and photography
  - ◦ Measurement of dimensional change
  - ◦ X-ray radiography
  - ◦ Axial gamma scanning

- Destructive examination of fuel rods in hot cell
  - ◦ Fuel rod cutting
  - ◦ Grinding/Polishing/Chemical etching

◦ Fuel density measurement

◦ Metallography

(B) Method

- Cask receiving and unloading
  - ◦ Checking of the dose rate close to the cask transport trailer
  - ◦ Transfer of the cask to the unloading pool and removing the cask lid.
  - ◦ Unloading of the fuel assembly out of the cask.

- Fuel transfer from/to hot cell
  - ◦ The fuels are transferred to the M1 cell of the IMEF through the channel connected with the pool by the use of bucket elevator.

- Fuel bundle dismantling
  - ◦ Fuel dismantling is carried out at cutting cell in IMEF.
- Nondestructive test of fuels
  - ◦ The examination is performed in M1 cell.
  - ◦ The general examination items are visual inspection and photography, profilometry, eddy current test, X-ray radiography, and axial gamma scanning.

- Fuel rod cutting
  - ◦ The cutting process is carried out in the M2 cell.
    Maximum five rods are selected from a bundle and usually five samples of 2 cm in length are taken from each rod for destructive examination.

- Blistering test
  - ◦ Blistering test is carried out in the M2 cell.

- Metallographic sample preparation
  - Sectioning, mounting, grinding, polishing, and chemical etching are performed in the M3 cell.

- Density measurement
  - The density of fuel samples is measured by using a precision balance installed in the M4 cell.

- EPMA sample preparation
  - Au/C coating on specimen surface for EPMA analysis conducted in the M4 cell.

- Burnup measurement
  - The burnup is determined by chemical process for the fuel samples using mass spectrometry.
  - Burnup measurement is performed in the chemical lab. of the PIEF.
  - The samples for the burnup determination are transported by Padirac cask from the M4 cell of the IMEF to the PIEF.
  - The expected amount of the cumulative quantity of separated materials for the burnup measurements during this JD period are described in the summary of PIE program in the chapter II.

(C) Activities for the current period

So far, 16 activated fuel bundles were examined for non-destructive examination at IMEF. After the examination, those bundles were returned to the HANARO and have been reloaded for the reactor operation. And one fuel bundle was visually examined to investigate the wear mark pattern on the fuel spacers.

The transportation, PIE, storage and waste treatment will be conducted by the procedure given in KAERI/AR-417/95.

(D) Plan for the next period (2002-2006)

During this period, two spent fuels per year are expected to be examined in IMEF to verify fuel performance and integrity. Total number of HANARO fuel bundles to be examined at IMEF will not exceed ten bundles during this period.

4) Storage of unexamined fuels

The unexamined fuel rods and rod cuts are put into a stainless steel container and sent back to HANARO pool for storage.

The storage will be conducted by the procedures described in KAERI/AR-417/95.

5) Radioactive waste treatment

Radioactive wastes are categorized into fuel specimen, liquid waste and solid waste for which their treatment methods are described in the followings;

- Fuel specimen

  Fuel specimens examined are stored in the storage rack of the M4 cell

- Solid waste
  - High level active wastes are put in 50 liter stainless steel container which is water-tight, while low level active wastes are put in plastic bags and 200 liter drum.
  - These are transferred to the RWTF for temporary storage.
- Liquid waste
  - The liquid wastes come mainly from the pool water treatment unit, are transferred to the low level active waste tanks located in the RIPF and then to the RWTF.
  - A small quantity of liquid wastes produced during fuel cutting, grinding, and polishing etc. in the hot cells is plastered in a can inside the cell and

then treated like a high level active solid waste.

◦ The low active liquid wastes which come from intervention area and other contaminated areas are sent to the low level active waste tanks located in the RIPF and then to the RWTF.

◦ In general, the radioactive waste treatment will be conducted by the procedures described in the section of 5) Radioactive Waste Treatment in the part A. PIE of PWR Irradiated Fuels.

F. HANARO Development Fuel

1) Transportation

The HANARO development fuel will be transported from the HANARO pool to the IMEF by using a shipping cask. The expected amounts of fuel transportation to the HANARO between 2002~2006 are as follows :

- three bundles for U-Mo dispersion fuel
- 1 bundle for U_3Si dispersion fuel
- 4 mini-plates for U-Mo dispersion fuel

2) Fuel specifications

(A) U-Mo dispersion fuel (Rod-type)

Contents	Descriptions
Bundle type	Bundle of 18 rods, or bundle of 36 rods
Dimensions	Same as HANARO driver fuel
Fuel material (composition) (enrichment)	 U-7 wt.% Mo, U-9 wt.% Mo (2 kinds of compositions) U-235: 19.75±0.20 wt.%
Burnup	3 irradiation tests 1) 40 at.% (bundle with 10 fuel rods) 2) 70 at.% (bundle with 12 fuel rods) 3) 60 at.% (bundle with full fuel rods)

(B) U_3Si dispersion fuel (Rod-type)

Contents	Descriptions
Bundle type	Bundle consisting of 18 standard rods and 18 reduced rods
Dimensions	Same as HANARO driver fuel
Fuel core (composition) (enrichment)	 U_3Si 19.75±0.20 wt.%
Burnup	60 a/o (bundle with full fuel rods)

(C) U-Mo dispersion fuel (Plate-type)

Contents	Descriptions
Bundle type	Bundle of 4 mini-plates
Dimensions	Same as HANARO driver fuel
Fuel core (composition) (enrichment)	 25 vol.% U-Mo 19.75±0.20 wt.%
Burnup	1 type - 60 a/o

3) Post-irradiation examination

(A) Scope of work

- Nondestructive examination in hot cell
  - ◦ Dismantling of fuel bundle
  - ◦ Visual examination and photography
  - ◦ Measurement of dimensional change
  - ◦ Axial gamma scanning

- Destructive examination of fuel rods in hot cell
  - ◦ Fuel rod cutting
  - ◦ Grinding/Polishing/Chemical etching
  - ◦ Measurement of dimensional change
  - ◦ Fuel density measurements
  - ◦ Chemical composition examinations
  - ◦ Metallography
  - ◦ Electron probe microanalysis
  - ◦ Bending test
  - ◦ Blistering test

(B) Method

- Cask receiving and unloading
  - Checking of the dose rate close to the cask transport trailer
  - Transfer of the cask to the decontamination room (IMEF), where the surface washing is performed.
  - Transferring of the cask to the unloading pool and remove of the cask lid by over-head crane.
  - Unloading of the fuel rod/fuel bundle from the cask by handling tool.

- Fuel transfer from/to hot cell
  - The fuel bundles are transferred to the M1 cell of the IMEF through the channel connected with the pool by the use of bucket elevator.

- Fuel bundle dismantling
  - Transferring fuel bundle to a dismantling machine by which the end plate of the bundle is removed.

- Nondestructive test of rod
  - Placing the fuel rods on the examination multi-bench which is vertically positioned in the M1 cell.
  - Performing visual inspection, photography, profilometry, measurement of dimensional change, and axial gamma scanning.

- Fuel rod cutting
  - The cutting of the fuel rod is carried out in the M2 cell.
    Maximum five (5) rods are selected from a bundle and usually five (5) samples of 2 cm in length are taken from each rod for destructive examination.

- Blistering test
  - Blistering test is carried out in the M2 cell.

- Metallographic sample preparation
  - Sectioning, mounting, grinding, polishing and chemical etching are performed in the M3 cell.

- Metallography
  - Microstructural observation is performed in the M7 lead cell.

- Density measurement
  - The density of fuel samples is measured by using a precision balance installed in the M4 cell.

- EPMA sample preparation
  - Au/C coating on specimen surface for EPMA analysis conducted in the M4 cell.

- Burnup measurement
  - The burnup is determined by the measurement of ^{148}Nd separated chemically from the fuel sample by means of mass spectrometry.
  - Burnup measurement is performed in the Chemical Lab. of the PIEF.
  - The samples to be analyzed are transported by a small cask from the M4 cell of the IMEF to the PIEF.
  - The expected amount of the cumulative quantity of separated materials for the burnup measurements during this JD period are described in the summary of PIE program in the chapter II.

(C) Schedule (year)

□ transportation(to IMEF) ■ PIE

Fuels	Quantity	'02	'03	'04	'05	'06	Remarks
1. U-Mo dispersion fuel	3 bundle		□■	□■		□■	Rod Type
2. U-Si dispersion fuel	1 bundle		□■				Rod Type
3. U-Mo Plate dispersion fuel	4 mini-plates		□■ □■		□■ □■		Plate Type

4) Storage of unexamined fuels

The unexamined fuel bundles, fuel rods and rod-cuts are put into a stainless steel container and then sent back to the HANARO storage pool.

5) Radioactive waste treatment

The radioactive waste treatment will be conducted by the procedures described in the section of 5) Radioactive Waste Treatment in the part A. PIE of PWR Irradiated Fuels.

G. HANARO Standard Fuel

1) Transportation

The HANARO standard fuels irradiated at HANARO will be transported from the HANARO pool to the IMEF by using a shipping cask.

2) Fuel specifications

Contents	Descriptions
Fuel core	
Composition, wt.%	61.4 wt.% U_3Si, 38.6 wt.% Al
Enrichment, wt.% U-235	19.75
Diameter, mm	6.35 (standard diameter) 5.50 (reduced diameter)
Fissile loading, g U-235/element	13.8 (standard diameter)
Cladding	
Alloy designation	Alcan 6102 (AA1060)
Thickness, mm	0.76 (standard diameter) 1.185 (reduced diameter)
Fuel element	
Outside diameter, mm	7.87
Diameter over fins, mm	9.91
Number of fins	8

Total fissile contents (U^{235}) of the 18 standard elements is 247.5 g U^{235}

3) Post-irradiation examination

The expected amount of HANARO standard bundles examined for PIE will be 10 bundles during this JD period (2002～2006)

4) Storage of unexamined fuels

The unexamined fuel bundles, fuel rods and rod-cuts are put into a stainless steel container and then sent back to the HANARO storage pool.

5) Radioactive waste treatment

The radioactive waste treatment will be conducted by the procedures described in the section of 5) Radioactive Waste Treatment in the part A. PIE of PWR Irradiated Fuels.

H. DUPIC Fuels

General description of the DUPIC program is depicted in KAERI/AR-584/2000, Rev. 1. In this section, specifically DUPIC related PIE activities will be described.

DUPIC fuel specifications and quantities described below are maximum estimated amounts of the post-irradiation examination at KAERI for DUPIC fuel development during the terms from April 2002 to March 2007. And they are estimated by considering the irradiated fuels and irradiation assembly rigs irradiated in HANARO reactor. The proposed DUPIC fuel irradiation plan is summarized as shown in Table I-3.

1) Transportation

The DUPIC fuel irradiated in rig or FTL at the HANARO will be transported from the HANARO pool to the IMEF by using the same cask as that of HANARO drive fuel. DUPIC fuel means elements, mini-elements in rig or FTL. Samples for chemical analysis, and/or metallography, optical/SEM observations, out-of-pile annealing experiments will be transported from IMEF to PIEF by using the PADIRAC system.

Table I-3. Overall DUPIC Fuel Irradiation Test Plan at KAERI (April 2002∼March 2007)

Fiscal year	Irradiation Quantity	Irradiation Test	Remarks
2002 (April 2002 ∼March 2003)	3 mini-elements × 5 pellets/element × 10 g/pellet = 150 g	1 time irradiation for a year with 3 mini-elements in a Rig at HANARO	- SPND(Self-Power Neutron Detector) - Pellet centerline temperature measurement - DUPIC and/or NU-Dy poison pellets - Target burnup:12,000 MWd/tU - Some of irradiation pellets might be made either of SIMFUEL, UO2 or NU-Dy
2003 (April 2003 ∼March 2004)	3 mini-elements × 5 pellets/element × 10 g/pellet = 150 g	1 time irradiation for a year with 3 mini-elements in a Rig at HANARO	- SPND - Pellet centerline temperature measurement - Cladding inner pressure - DUPIC and/or NU-Dy poison pellets - Target burnup: 12,000 MWd/tU - Some of irradiation pellets might be made either of SIMFUEL, UO2 or NU-Dy
2004 (April 2004 ∼March 2005)	3 mini-elements × 5 pellets/element × 10 g/pellet = 150 g	1 time irradiation for a year with 3 mini-elements in a Rig at HANARO	- SPND - Pellet centerline temperature measurement - DUPIC and/or NU-Dy poison pellets - Target burnup: 20,000 MWd/tU - Some of irradiation pellets might be made either of SIMFUEL, UO2 or NU-Dy
2005 (April 2005 ∼March 2006)	7 elements × 50 large pellets/ element× 22.5 g/pellet = 7.9 kg	1 time irradiation up to 10,000 MWd/tU at HANARO	- 10,000 MWd/tU burnup - Using Fuel Test Loop Facility to be developed at HANARO
2006 (April 2006 ∼March 2007)	7 elements × 50 large pellets/ element× 22.5 g/pellet = 7.9 kg	1 time irradiation up to 20,000 MWd/tU at HANARO	- 20,000 MWd/tU burnup - Using Fuel Test Loop Facility to be developed at HANARO

* The PIE of the last irradiated bundle (7.9 kg) in March 2006 will be postponed to the next scope of Joint Determination.

2) Fuel specifications

Table I-4 Fuel specifications

	Rig	Element	Mini-element
Weight	3.05 kg	1.125 kg	50 g
Length	980 mm	500 mm	200 mm
Stack length	960 mm	480 mm	50 mm
Diameter	60 mm	13.5 mm	12 mm
Composition	Aluminium	spent fuel	spent fuel
Remarks	For 3 mini-element	CANFLEX bundle (43 elements), or CANDU-6 bundle (37 elements) type	element assembly

3) Post-irradiation examination

(a) Scope of work

- Nondestructive examination in hot cells
  - Dismantling of DUPIC fuel
  - Visual examination and photography
  - Measurement of dimensional change
  - Eddy current test
  - X-ray radiography
  - gamma scanning
- Destructive examination in hot cells
  - Fission gas analysis
  - Out-of-pile annealing experiments
  - Cutting/Grinding/Polishing/Etching
  - Microstructure analysis (optical/SEM/EPMA)
  - Density measurement
  - Hardness
  - Chemical analysis
  - Physical properties measurement

(b) Methods

- Cask receiving and unloading
  - Checking the dose rate close to the cask transport trailer.
  - Transfer the cask to the unloading pool and remove of the cask lid by overhead crane.
  - Unloading of the fuel from the cask by handling tool
- Fuel transfer from pool to hot cell
  - The fuels are transferred to the M1 cell of the IMEF through the channel connected with the pool by the use of bucket elevator.
- Fuel dismantling
  - Transfer to a dismantling machine by which the end plate of the fuel assembly is removed
- Nondestructive test
  - Place the fuel on the rod examination multi-bench which is vertically positioned in the M1 cell
  - Perform visual inspection and photography, profilometry, eddy current test, X-ray radiography, and gamma scanning
- Fission gas collection and analysis
  - Fuel element puncturing is performed by a puncturing device installed in 9404 cell of PIEF.
  - Fission gas collection is made by a gas collection system installed outside the cell, which is connected with a puncturing device installed in 9404 cell.
  - Fission gas collected is sent to the Chemical Lab. of the PIEF for composition analysis.
  - For the study of local gas distribution inside of the irradiated pellets, out-of-pile annealing experiments of irradiated pellets would be performed at PIEF hot cell. A slice of the irradiated pellet would be transported to PIEF for this experiments.
- Fuel element cutting

- Cutting of the fuel element is carried out in the M2 cell.
- For the PIE of the bundles, elements are selected from a bundle and usually samples of 5 cm in length are taken from each element for destructive examination. The fuel segments which are not examined are put in a container and then are stored in the hot cell and/or pool for temporary storage.
- For the PIE of the elements and mini-elements, each element is cut to prepare destructive examination.

- Metallographic sample preparation
  - Sectioning, mounting, grinding, polishing and chemical etching are performed in the M3 cell, and/or at PIEF
- Metallography
  - Microstructural observations(optical/SEM) are performed in the M7 lead cell, and/or at PIEF.
- EPMA sample preparation
  - Sample preparation for EPMA is conducted in the M3 cell.
  - EPMA examination is carried out at the EPMA room of IMEF.
- TEM sample preparation
  - TEM sample preparation is performed in the M4 cell
  - Replica for TEM observation is prepared in the M4 cell.
- Density measurement
  - The density of the fuel samples is measured by using a precision balance installed in the M7 cell.
- Hardness measurement
  - The hardness of the fuel samples is measured by using a microhardness tester installed in the M7 cell.
- Burnup measurement
  - The burnup is determined by the measurement of ^{148}Nd separated chemically from the fuel sample by means of mass spectrometer.
  - Burnup measurement is performed in the Chemical Lab. of the PIEF.

- The samples to be analyzed will be transported by a small PADIRAC cask from the M4 cell of the IMEF to the Chemical Lab. of the PIEF.
- The expected amounts of the cumulative quantity of separated materials for the burnup measurements during this JD period are described in the summary of PIE program in the chapter II.

- Physical property measurement
  - Thermal expansion, thermal conductivity and creep tests on the fuel sample are performed in the M5a cell

(c) Maximum quantity estimated for PIE at KAERI

Table I-5. Maximum Quantity Estimated for PIE of DUPIC Program (April 2002～March 2007)

Fiscal year	Source of PIE	Quantity	Remarks
2002 (April 2002 ～March 2003)	3 mini-elements irradiated at HANARO in May 2001	3 mini-elements × 5 pellets/element × 10 g/pellet = 150 g	-Burnup: 8,000 MWd/tU
2003 (April 2003 ～March 2004)	3 mini-elements irradiated at HANARO in April 2002	3 mini-elements × 5 pellets/element × 10 g/pellet = 150 g	-Burnup: 12,000 MWd/tU -Some of irradiation pellets might be made either of SIMFUEL, UO2 or NU-Dy
2004 (April 2004 ～March 2005)	3 mini-elements irradiated at HANARO in April 2003	3 mini-elements × 5 pellets/element × 10 g/pellet = 150 g	-Burnup: 12,000 MWd/tU -Some of irradiation pellets might be made either of SIMFUEL, UO2 or NU-Dy
2005 (April 2005 ～March 2006)	3 mini-elements irradiated at HANARO in April 2004	3 mini-elements × 5 pellets/element × 10 g/pellet = 150 g	-Burnup: 20,000 MWd/tU -Some of irradiation pellets might be made either of SIMFUEL, UO2 or NU-Dy
2006 (April 2006 ～March 2007)	7 elements irradiated at HANARO in April 2005	7 elements × 50 large pellets/ element× 22.5 g/pellet = 7.9 kg	-Burnup: 10,000 MWd/tU
Total		8.5 kg	

* The PIE of the last irradiated bundle (7.9 kg) in March 2006 will be postponed to the next scope of Joint Determination.

4) Storage of Unexamined Fuel

The unexamined fuel elements and element-cuts are put into a stainless steel container and then sent to the hot cell and/or pool for temporary storage.

5) Radioactive waste treatment

Radioactive wastes are categorized into fuel specimen, solid waste and liquid waste, for which their treatment methods are described in the followings

- Fuel specimen
  - The fuel specimens examined are put in a container and then are stored in the hot cell and/or pool for temporary storage.

- Solid waste treatment
  - High level active wastes including the dismantled rig are put in 50 L stainless container which is water-tight, while low level active wastes are put in vinyl bags and in 200 L drum.
  - These are transferred to the RWTF for temporary storage.

- Liquid waste treatment
  - The liquid wastes come mainly from the pool water treatment unit, and are transferred to the low level active tanks located in the RIPF(Radio-Isotope Production Facility) and then to the RWTF.
  - A small quantity of liquid wastes produced during fuel cutting, grinding and polishing etc. in the hot cells is plastered in a can inside the cell and then treated like a high active solid waste.
  - The low active liquid wastes which come from intervention area and other contaminated areas are sent to the low level active waste tanks located in the RIPF and then to the RWTF.

I. SMART Fuel

1) Transportation

The cask for driver fuel will be used for transportation from HANARO to IMEF after irradiation test.

2) Fuel specification

Contents	Descriptions
- Irradiated fuel	U-Zr metallic fuel (6 rods)
- U^{235} enrichment	5~20 wt.% (to be decided depending on design)
- U^{235} content	2.3~9.2 g/rod
- Fuel core length in test fuel	~300 mm (depending on design)
- Clad thickness in test fuel	0.5 mm

3) Post-irradiation examination

(A) Scope of Work

- Nondestructive examination in hot cells
  - ○ Dismantling of fuel bundle
  - ○ Visual examination and photography
  - ○ Measurement of dimensional change
  - ○ Axial gamma scanning

- Destructive examination in hot cells
  - ○ Fuel rod cutting
  - ○ Grinding/Polishing/Chemical etching
  - ○ Measurement of dimensional change
  - ○ Fuel density measurement
  - ○ Chemical composition examinations

- ○ Metallography
- ○ Electron probe microanalysis
- ○ Bending test
- ○ Blistering test

(B) Method

- Cask receiving and unloading
  - ◦ Checking the dose rate close to the cask transport trailer.
  - ◦ Transfer of the cask to the decontamination room (IMEF), where the surface washing is performed.
  - ◦ Transfer of the cask to the unloading pool and remove of the cask lid by over-head crane.
  - ◦ Unloading of the fuel from the cask by handling tool

- Fuel transfer from pool to hot cell
  - ◦ The fuels are transferred to the M1 cell of the IMEF through the channel connected with the pool by the use of bucket elevator.

- Fuel bundle dismantling
  - ◦ Transfer to a dismantling machine by which the end plate of the fuel assembly is removed

- Nondestructive test
  - ○ Place the fuel rods on the rod examination multi-bench which is vertically positioned in the M1 cell
  - ○ Perform visual inspection and photography, profilometry, eddy current test, X-ray radiography, and axial gamma scanning

- Fuel rod cutting
  - The cutting of the fuel rod is carried out in the M2 cell.
    Maximum five rods are selected from a bundle and usually five samples of 2 cm in length are taken from each rod for destructive examination.

- Blistering test
  - Blistering test is carried out in the M2 cell

- Metallographic sample preparation
  - Sectioning, mounting, grinding, polishing and chemical etching are performed in the M3 cell

- Metallography
  - Microstructural observation is performed in the M7 lead cell.

- Density measurement
  - The density of fuel samples is measured by using a precision balance installed in the M4 cell.

- Reaction layer
- Corrosion product
- Bending test
- EPMA sample preparation
  - Au/C coating on specimen surface for EPMA analysis conducted in the M4 cell.

- Burnup measurement
  - The burnup is determined by the measurement of ^{148}Nd separated chemically from the fuel sample by means of mass spectrometry.
  - Burnup measurement is performed in the Chemical Lab. of the PIEF.

◦ The samples to be analyzed are transported by a small PADIRAC cask from the M4 cell of the IMEF to the Chemical Lab. of the PIEF.

(C) Schedule

□ transportation(to IMEF) ■ PIE

Fuels	Quantity	'02	'03	'04	'05	'06	remark
SMART Fuel	6 rods	□■	□■	□■	□■	□■ □■	1 rod/yr ('02～'05) 2 rods in '06

(D) Examination items

Irradiated Assembly	BU [at %]	Test Hole	Exam. Items
Capsule for SMART fuel irradiation	30～60	OR	NDA, Surface Exam., Density, Dimension, Swelling, Microstructure, Reaction Layer, Corrosion Product, Bending Test

4) Storage of unexamined fuels

The unexamined fuel bundles, fuel rods and rod cuts are put into a stainless steel container and then sent back to the HANARO storage pool. In general, the storage will follow the storage procedure of HANARO irradiated fuel

5) Radioactive waste treatment

Radioactive wastes are categorized into fuel specimen, liquid waste and solid waste for which their treatment methods are described in the followings;

- Solid waste

◦ High level active wastes are put in 50 liter stainless steel container which is water-tight, while low level active wastes are put in plastic bags and 200 liter drum.

◦ These are transferred to the RWTF for temporary storage.

- Liquid waste
  - ◦ A small quantity of liquid wastes produced during fuel cutting, grinding, and polishing etc. in the hot cells is plastered in a can inside the cell and then treated like a high level active solid waste.
  - ◦ The low active liquid wastes which come from intervention area and other contaminated areas are sent to the low level active waste tanks located in the RIPF and then to the RWTF.
  - ◦ In general, the radioactive waste treatment will be conducted by the procedures described in the section of 5) Radioactive Waste Treatment in the part A. PIE of PWR Irradiated Fuels.

J. Advanced LWR Fuel Pellet

1) Transportation

UO_2 and burnable absorber fuel pellets will be fabricated, loaded in cladding tubes and then seal welded in KAERI. Short fuel rod will be encapsuled, and then the capsule will be irradiated in HANARO. The capsule will be transported from the HANARO pool to the IMEF for examination.

2) Fuel specifications

Contents	Descriptions
1. UO_2 fuel pellet	30 pellets (5 pellets/rod x 6 rods)
- diameter	8 mm
- length	10 mm
- U^{235} enrichment	3~5 wt.%
- burnup	30,000 ~ 80,000 MWd/tU
- amount	less than 200 g
2. Burnable absorber	30 pellets (5 pellets/rod x 6 rods)
- diameter	8 mm
- length	10 mm
- composition	8~12 wt.% Gd_2O_3, 1~2 wt.% Er_2O_3, and 0~5 wt.% of Boride.
- U^{235} enrichment	0.7~5 wt.%
- burnup	15,000~60,000 MWD/tU
- amount	less than 200 g

3) Post irradiation examination

For each type of fuels, 30 pellets will be fabricated and encapsuled in 6 fuel rods to be irradiated at HANARO, respectively. For UO_2 fuel pellet fabrication, maximum 200 grams of UO_2 with 3~5 wt.% of U^{235} enrichment will be used while maximum 200 grams of UO_2 with 0.7~5 wt.% of U^{235} enrichment for the fabrication of burnable absorbers such as Gd_2O_3, Er_2O_3 and Borides will be used. PIE for the fuel performance test will be conducted from 2003 for 4 years. Maximum 30 pellets (15 UO_2 pellets and 15 burnable absorber) will be used for PIE during the period of this Joint Determination, and the PIE for the rest of them will be performed at the next scope of Joint Determination.

(A) scope of work

- Nondestructive examination in a hot-cell
  ◦ Dismantling of capsule
  ◦ Visual examination and photography
  ◦ Measurement of dimensional change
  ◦ X-ray radiography
  ◦ Axial gamma scanning

- Destructive examination
  ◦ Fuel rod cutting.
  ◦ Grinding/ polishing/ etching
  ◦ Fuel density measurement
  ◦ Metallography
  ◦ Chemical analysis for burnup determination

(B) Method

- Cask receiving and unloading
  ◦ Checking of the dose rate close to the cask transport trailer
  ◦ Transfer of the cask to the decontamination room (IMEF), where the surface washing is performed.
  ◦ Transfer of the cask to the unloading pool and remove of the cask lid by over-head crane.
  ◦ Unloading of the fuel rod/fuel bundle from the cask by handling tool.

- Fuel transfer from to hot cell
  - The fuel bundles are transferred to the M1 cell of the IMEF through the channel connected with the pool by the use of bucket elevator.

- Nondestructive test of rod
  - Place the fuel rods on the examination multi-bench which is vertically positioned in the M1 cell.
  - Perform visual inspection and photography, profilometry, measurement of dimensional change, and axial gamma scanning.

- Fuel rod cutting
  - The cutting of the fuel rod is carried out in the M2 cell. Maximum five (5) rods are selected from a bundle and usually five (5) samples of 2 cm in length are taken from each rod for destructive examination.

- Metallographic sample preparation
  - Sectioning, mounting, grinding, polishing and chemical etching are performed in the M3 cell.

- Metallography
  - Microstructural observation is performed in the M7 lead cell.

- Density measurement
  - The density of fuel samples is measured by using a precision balance installed in the M4 cell.

- EPMA sample preparation

◦ Au/C coating on specimen surface for EPMA analysis conducted in the M4 cell.

- Burnup measurement
  - ◦ The burnup is determined by the measurement of ^{148}Nd separated chemically from the fuel sample by means of mass spectrometry.
  - ◦ Burnup measurement is performed in the Chemical Lab. of the PIEF.
  - ◦ The samples to be analyzed are transported by a small cask from the M4 cell of the IMEF to the Chemical Lab. of the PIEF.

- TEM examination
  - ○ TEM sample preparation is performed in the M4 cell
  - ○ Replica for TEM observation is conducted in the M4 cell.

- Other PIE will follow the procedure described in Section 3

4) Storage of unexamined fuels

The unexamined fuel rods and rod-cuts are put in a stainless steel container and then sent back to the HANARO storage pool.

5) Radioactive waste treatment

The radioactive waste treatment will be conducted by the procedures described in the section of 5) Radioactive Waste Treatment in the part A. PIE of PWR Irradiated Fuels.

Chapter II.

Safeguards of Nuclear Fuel Materials

1. General Statement

The safeguards activities relevant to the '96 Joint Determination for Post-Irradiation Examination of Irradiated Nuclear Fuels described in KAERI/AR-417/95, April 1995 have been successfully carried out in terms of IAEA safeguards implementation as described in Facility Attachment and in compliance with ROK/US nuclear corporation agreement.

Activities of Post Irradiation Examination in KAERI have been directed to R&D on the improvement of nuclear fuel performance evaluation, fuel fabrication and design, as well as to support reactor operation safety as described in this report.

The general safeguards scheme will be sustained consistently to the next PIE safeguards activities.

So the important provisions described in the safeguards procedures of KAERI/AR-417/95 are still effective.

In consideration of demands and utilization efficiency of facilities, PIE activities will be carried out in PIEF and/or IMEF. Basically, PIE for the commercial nuclear fuels under 5 wt.% of U-235 enrichment will be conducted at PIEF. For the fuels over 5 wt.% of U-235 enrichment will be carried out at IMEF. According to the examination items, some fuel specimens are to be examined in PIEF and/or IMEF irrespective of its enrichment but those specimens will be returned to its designated places for storage. The storage conditions and locations for the fuel and specimens after examination are described in Chapter I.

These procedures allow safeguards office together with operator to discuss and analyze how to effectively resolve the problems which may arise in connection with domestic and international obligations related to the nuclear material safeguards. Any unplaned PIE activities out of the scope of works described in this report may not be carried out unless it is properly fit in the PIE plan described.

2. Safeguards Implementation Plan

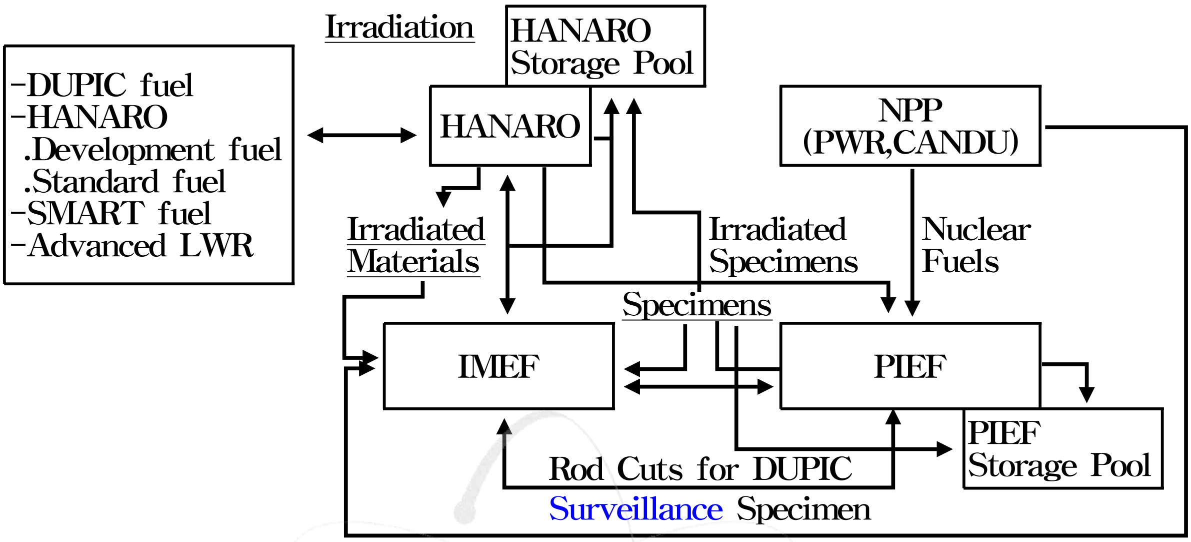

Fig. II-1. Nuclear Material Flow Relevant to PIE

2.1 Material Flow relevant to PIE

- Possible material flows relevant to PIE for irradiated materials including spent nuclear fuels are depicted in Fig. II-1.
- The spent nuclear fuels from commercial power plant including PWR and CANDU type plants are received at PIEF. The maximum number of nuclear fuels to be transferred are not exceed 3 assemblies in PWR and 3 bundles in CANDU type, respectively.
- For PIE, some specimens will be transferred to IMEF for examination and those specimens will be returned to PIEF after examination, and vice versa.
- HANARO irradiated fuels such as HANARO driver fuel, HANARO standard fuel, SMART fuel, DUPIC element, and Advanced LWR fuel pellets are basically examined at IMEF. And according to the examination items, some specimens will be transferred to PIEF and returned to IMEF after examination.
- PWR fuel rod cuts to be used for DUPIC fuel fabrication in IMEF will be transferred from PIEF to IMEF according to the examination plan described in Chapter I. 3. H. DUPIC fuels section.

- Nuclear power plant surveillance specimens are to be received and examined in IMEF.
- Generally, nuclear fuels over 5 wt.% of U-235 enrichment will be examined at IMEF and stored HANARO pool and fuels below 5 wt.% of U-235 enrichment except DUPIC fuels will be examined and stored at PIEF.
  The PIE for DUPIC fuels are described precisely in the report, DUPIC fuel fabrication using spent PWR fuel at KAERI, which is submitted with the updated JD materials for DUPIC to be adopted during 2002-2006.
- General radioactive wastes will be transferred to the RWTF and wastes including significant nuclear materials will be stored within each facility.

3. The status of DIQ's for nuclear facilities in KAERI

All related DIQ's(Design Information Questionnaires) were submitted to the IAEA and the revised DIQ's were submitted from time to time as needed.

Updated DIQs will be submitted to the IAEA as required to perform the R&D programs within the scope of this Joint Determination.

- PIEF
  Revised DIQ's were submitted to IAEA in Jan. 18, 2000 and September 3, 2001
- HANARO
  Final DIQ was submitted to IAEA in June 5, 1999
- IMEF
  Revised DIQ's were submitted to IAEA in May 20, 1998 and May 28, 2001
- DFDF
  Final DIQ was submitted to IAEA in Feb. 1, 1997

The major revised contents in PIEF DIQ are as follows;

1) The information on the DUPIC powder/pellet charaterization test in hot cell 9405 was deleted because it had been terminated at the end of September

2000. The DUPIC equipment such as OREOX furnace, sintering furnace, press, dial gage, tray, off-gas treatment device, fission gas treatment device and pipe at hot cell 9405 and 9406 were dismantled with presence of the IAEA inspector in November 2000 and removed to the radwaste storage building of KAERI.

2) Information on the post irradiation annealing experiment was added. The equipment such as a furnace to heat up fuel fragments, an electronic balance, a vacuum pump, a glove box to analyze the fission gas and a filter are included.

3) Enrichment range of PWR fuel was changed to less than 5 wt.% U_{235} from less than 4 wt.% U_{235} to include all kinds of enrichments of PWR fuel irradiated in NPPs of Korea.

4) The amount of spent fuel(rod, rod cuts and sample cuts) for PIE at operation areas was increased from 6.6 kg-U per year to 20 rods per year and the amount of PWR spent fuel rod cuts for DUPIC program is limited to 40 kg-U per year instead of total 50 kg-U to meet the scope and consistency of PIE activities. The in-force Facility Attachment seems to be affected by the amendments of PIEF DIQ because the equipment in hot cell 9405 were dismantled and removed, and enrichment range of PWR fuel was changed.

For the revised HANARO DIQ in June 5, 1999, the information on TRIGA MARK II&III fuel such as design specification of TRIGA fuel, TRIGA fuel handling and storage of TRIGA fuel etc. was deleted as a result of the transportation of all the TRIGA spent fuels to the USA. The information on dummy fuel of HANARO was added in order to reflect the IAEA inspector's request. We were informed from the IAEA on August 12, 1999 that the amendments of HANARO DIQ did not affect the in-force Facility Attachment.

With regard to the revised IMEF DIQ, a new activity was added in the IMEF. Before its revision, fuels irradiated in HANARO are transferred to the IMEF hot

cell via IMEF pool. But some of them are transferred to RIPA(Radio-Isotope Production Area) hot cell C10 for the removal of irradiation capsules and then transferred to IMEF Service Area for the study on 'measurement and modeling of diffusion coefficient of fission gases in single crystal fuel'. The amount of nuclear material is too small to have an effect on the inventory of the IMEF. The annual throughput of fresh fuel has the same as before(less than 20 kg) but includes DU, NU and LEU. For the flow sheet of nuclear materials in the IMEF, measured discards are not applicable and 4 inventory KMPs are reduced to 3 KMPs; KMP A: IMEF pool and RIPA hot cell C10, KMP B: hot cell, operation area, service area and EPMA laboratory, KMP C; other location of nuclear material.
We were informed on July 26, 2001 that the amendments of IMEF DIQ has been reviewed and it was found acceptable to the IAEA without affecting the in-force Facility Attachment.

DFDF DIQ has no change since the enforcement of its Facility Attachment.

The existing facility attachments of related facilities are attached in the appendices as a separated document.

4. Summary of PIE Program

4.1 Cumulative Quantity of Separated Materials for Burnup Measurements

Fuels			Result(mg)							Plan
			'95	'96	'97	'98	'99	'00	'01	'02-'06
No of fuel samples	PWR			4	6	-	7	3		54
	CANDU		-	-	-	-	-	-	-	54
	DUPIC					-		1		6
	HANARO					-	6			42
Fissile contents (mg)	PWR	Total-U		4.06	5.62		4.6	2.71		48.6
		Total-Pu		0.028	0.039		0.032	0.019		0.324
	CANDU CANFLEX	Total-U								48.6
		Total-Pu								0.486
	DUPIC	Total-U						1.91		5.4
		Total-Pu						0.013		0.036
	HANARO	Total-U					2.64			18.48
		Total-Pu					0.009			0.06
Total weight(mg)	Total-U			4.06	5.62		7.24	4.62		121.08
	Total-Pu			0.028	0.039		0.041	0.032		0.906

4.2 Summary of the PIE Program during this JD Period

□ Transportation ■ PIE

PIE Work scope	Quantity	Specifications	Fuel materials	Receiving (Transportation)					Remarks
				02	03	04	05	06	
PWR	Maximum 3 assemblies	PWR type 14x14,16x16 17x17	▪ Sintered UO_2 ▪ Zircaloy-4 clad ▪ <5 wt.% U-235 ▪ 5-70 GWd/tU	□■		□■		□■	PIEF IMEF for specimens exam.
CANDU	Maximum 3 bundles	CANFLEX CANDU	▪ Sintered UO_2 (NU or SEU)			□■	□■	□■	IMEF, PIEF for specimens exam.
Long-term dissolution behavior of spent fuel under repository condtion	3-5 PWR pellets/yr, (≤100g UO_2)	PWR type 14x14,16x16 17x17 pellets	▪ Sintered UO_2 ▪ <5 wt.% U-235 ▪ 5-70 GWd/tU	■	■	■	■	■	IMEF, PIEF for specimens exam.
Post-irradiation annealing experiment	150 g, total (50 g/each type fuel)	-PWR UO_2 -UO_2-Gd_2O_3 -UO_2 irradiated at HANARO	▪ 10-40 GWd/tU ▪ 20-40 GWd/tU ▪ 50-70 GWd/tU						PIEF for specimens exam.
HANARO Driver fuel	2 bundles/yr (≤10 bundles)	36 el./18 el. Al-U_3Si 19.75 w/o U-235	▪ 83 GWd/tU	□■ □■	□■ □■	□■ □■	□■ □■	□■ □■	IMEF PIEF for specimens exam.
HANARO Development fuel	U-Mo : 3 bundles	U-7 to 9 % Mo,	-40~70 wt.% (bundle)		□■	□■		□■	IMEF PIEF for specimens exam.
	U-Si : 1 bundle	USi (36 rod,25 vol%)	-60 wt.% (bundle)		□■				
	U-Mo : 4 mini-plates	U-Mo mini-plates	-60 wt.%		□■ □■		□■ □■		
HANARO Standard fuel	10 bundles 6 elements/bundle	Al-61% U_3Si 19.75 wt.% U-235 Alcan 6102 clad		□■	□■	□■	□■	□■	IMEF PIEF for specimens exam.
DUPIC fuel	-Max. 8.5 kg (HANARO irrad.)	CANFLEX type	▪ 8-20 GWd/tU	■	■	■	■	■	IMEF PIEF for specimens exam.
SMART fuel	6 rod 2.3-9.2 g/rod (U^{235})	U-Zr metallic fuel 5-20 wt.% U-235		□■	□■	□■	□■	□■ □■	IMEF PIEF for specimens exam.
Advanced LWR fuel pellet	< 100 g UO_2 (UO_2 fuel)	UO_2 3-5 wt.% U-235			□■	□■		□■	IMEF for specimens exam.
	< 100 g UO_2 (Burnable absorber fuel)	Burnable absorber 0.7-5 wt.% U-235	▪ Gd_2O_3, Er_2O_3			□■		□■	

서 지 정 보 양 식					
수행기관보고서번호	위탁기관 보고서번호	표준보고서번호	INIS 주제코드		
KAERI/AR-606/2001, KAERI/AR-583/2000 Rev. 1					
제목 / 부제	POST-IRRADIATION EXAMINATION AND R&D PROGRAMS USING IRRADIATED FUELS AT KAERI				
연구책임자 및 부서명	전용범				
연구자 및 부서명	소동섭, 이병두, 이성호, 민덕기				
발 행 지	대전	발행기관	한국원자력연구소	발행일	2000. 12
페 이 지		도 표	유(○), 무( )	크 기	26 ㎝
참고사항					
비밀여부	공개( ), 대외비(O), _급비밀		보고서 종류	기술현황보고서	
위탁연구기관			계약번호		
초록(300단어 내외)					

본 보고서는 조사 핵연료에 대한 조사후시험과 연구개발활동계획을 기술하였다. PWR 조사핵연료, CANDU 연료, 하나로 연료 및 시험 연료에 대한 조사후시험의 목적은 조사성능검사, 연료 integrity 검사 및 연료 성능에 대한 데이터베이스를 구축하는 것이다. 따라서 조사후시험시설, 하나로시설 및 조사재시험시설 등의 연구소내 시설들에 대한 포괄적 조사시험계획을 기술하였다.

주제명 키워드 (10단어 내외)
조사후시험과 연구개발 계획, 조사연료, 조사후시험시설, 조사재시험시설, 하나로시설

BIBLIOGRAPHIC INFORMATION SHEET			
Performing Org. Report No.	Sponsering Org. Report No.	Standard Report No.	INIS Subject Code
KAERI/AR-606/2001, KAERI/AR-583/2000 Rev. 1			
Title / Subtitle	POST-IRRADIATION EXAMINATION AND R&D PROGRAMS USING IRRADIATED FUELS AT KAERI		
Project Manager and Dept.	Yong-Bum CHUN		
Researcher and Dept.	Dong-Sup So, Byung-Doo Lee, Song-Ho Lee, and Duck-Kee Min		

Pub.Place	Taejon	Pub. Org.	KAERI	Pub.Date	2000. 12.
Page		Fig.and Tab.	Yes(○), No( )	Size	26 ㎝
Note					
Classified	Open( ),Outside(○),_Class	Report Type	State of Art Report		
Sponsoring Org.		Contract No.			

Abstract (About 300 Words)

This report describes the Post-Irradiation Examination(PIE) and R&D programs using irradiated fuels at KAERI. The objectives of post-irradiation examination (PIE) for the PWR irradiated fuels, CANDU fuels, HANARO fuels and test fuel materials are to verify the irradiation performance and their integrity as well as to construct a fuel performance data base. The comprehensive utilization program of the KAERI's post-irradiation examination related nuclear facilities such as Post-Irradiation Examination Facility (PIEF), Irradiated Materials Examination Facility (IMEF) and HANARO is described.

Subject Keywords (About 10 Words)

Post-Irradiation Examination(PIE) and R&D programs, Irradiated Fuels, Post-Irradiation Examination Facility (PIEF), Irradiated Materials Examination Facility (IMEF), HANARO