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# Underwater Post irradiation Examination at KAERI

Y.J. Son, E.K. Kim, D.K. Min, E.P. Lee, H.K. Lee, D.S. Koo, H.S. Shin, and Y.B. Chun

Korea atomic Energy Research Institute
P.O.Box 105, Yusong, Taejon, Korea, 305-600

J.Y. Park
Korea Nuclear Fuel Co., Ltd.

## ABSTRACT

A wide range of post irradiation examination (PIE) to evaluate the performances of spent nuclear fuel assemblies and rods has been conducted at KAERI. Visual inspection and dimensional measurement device equipped with underwater camera, eddy current testing probe, ultrasonic sensor, image processing system and encoder system provide geometrical changes of the fuel assembly as well as the periphery fuel rods. Image processing technologies are introduced in measuring fuel rod length, diameter, rod to rod gap and assembly length. Nearby gamma scanning device provides burnup profiles for the fuel assembly and rods. There are two gamma scanning systems, wall mounted stationary system and comprehensive movable system, are in operation at KAERI. After underwater NDT examinations, fuel assembly is dismantled and fuel rods are extracted selectively for more precise PIEs. The extracted fuel rods are inspected by UT/ECT probes to check the integrities of the cladding tubes. The dismantled fuel assemblies could be reassembled according to the dismantled status. Double concentric tubes to put together the top end piece and the guide thimble tubes are fastened by the tapered screws to reconstitute the dismantled fuel assemblies. For more intensive and detailed examinations, the selectively extracted fuel rods are transferred to hot cell and examined.

## 1. Introduction

Nuclear power has been one of the major sources of energy demands in Korea since the first commercial nuclear power operation in 1978. As of May

2003, 14 PWR type nuclear power plants and 4 PHWR are providing around 40 % of the national electricity demand with total capacity of 15,720 MWe. 14x14, 16x16 and 17x17 type fuels are used in PWR type reactors. Two more PWRs are now under construction and according to the national energy program and eight more PWRs are scheduled to be constructed by 2016. Table 1 and 2 show the electrical energy share as of 2001 and the present status of nuclear power plants in Korea, respectively.

**Table 1. Electric Energy Production Share of Korea as of 2001**

| | Nuclear | Hydraulic | Coal | Oil | LNG | Total |
|---|---|---|---|---|---|---|
| Energy (GWD) | 4,669 | 173 | 4,597 | 1,171 | 1,269 | 11,879 |
| Percentage (%) | 39.3 | 1.5 | 38.7 | 9.8 | 10.7 | 100 |

Nowadays, the fuel design groups and the utility groups put great efforts on getting higher burnup, higher power and high integrities of the fuels under those severe conditions. To assure the nuclear safety of the plant, many activities to improve fuel performances as well as the fuel safeties have been conducted, so far. Fuel inspection technologies, in this context, have been playing a great role in improving fuel performances and operation safety of the plants.

KAERI as a government sponsored research establishment, endeavored to develop fuel inspection technologies to support utilities as well as research activities by providing nuclear fuel performance data adequately. Table 3 shows the in-pool activities conducted in underwater PIE for the spent nuclear fuels at KAERI. Three large pools of KAERI enable full scale of underwater examinations for the PWR type of irradiated nuclear fuels. Figure 1 shows the plane drawing of post-irradiation examination (PIE) facility at KAERI. Three pools for CASK receiving & unloading, fuel storage, and inspection & dismantling of the fuel assembly have been run since 1985 to evaluate the fuel performances as well as to develop series of underwater fuel examination technologies. Underwater inspection for the fuel assembly covers various examination items physically and/or mechanically, such as gamma spectroscopy for the fuel assembly and rod, visual inspection, dimensional measurement, geometrical change inspection, and hold-down spring force measurement, etc as well as the technology for the fuel rods covers the examination items such as oxide layer

**Table 2. Status of Nuclear Power Plants in Korea**

| NPP | Power (MWe) | Type | Supplier | | Startup |
|---|---|---|---|---|---|
| | | | Reactor | Turbine | |
| Kori-1 | 587 | PWR | W | G.E.C | ’78.4 |
| Kori-2 | 650 | PWR | W | G.E.C | ’83.7 |
| Kori-3 | 950 | PWR | W | G.E.C | ’85.9 |
| Kori-4 | 950 | PWR | W | G.E.C | ’86.4 |
| Wolsung-1 | 680 | PHWR | AECL | Parson | ’83.4 |
| Wolsung-2 | 700 | PHWR | HANJOONG /AECL | HANJUNG (GE) | ’97.6 |
| Wolsung-3 | 700 | PHWR | HANJOONG /AECL | HANJUNG (GE) | ’98.7 |
| Wolsung-4 | 700 | PHWR | HANJOONG /AECL | HANJUNG (GE) | ’99.6 |
| YGN-1 | 950 | PWR | W | W | ’86.8 |
| YGN-2 | 950 | PWR | W | W | ’87.6 |
| YGN-3 | 1000 | PWR | HANJOONG /KAERI(GE) | HANJUNG (GE) | ’95.3 |
| YGN-4 | 1000 | PWR | HANJOONG /KAERI(GE) | HANJUNG (GE) | ’96.1 |
| YGN-5 | 1000 | PWR | HANJOONG /KAERI/KOPEC | HANJUNG (GE) | ’01.12 |
| YGN-6 | 1000 | PWR | HANJOONG /KAERI/KOPEC | HANJUNG (GE) | ’02.12 |
| Ulchin-1 | 950 | PWR | FRAMATOME | ALSTOM | ’89.9 |
| Ulchin-2 | 950 | PWR | FRAMATOME | ALSTOM | ’88.9 |
| Ulchin-3 | 1000 | PWR | HANJOONG /KAERI(CE) | HANJUNG (GE) | ’98.6 |
| Ulchin-4 | 1000 | PWR | HANJOONG /KAERI(CE) | HANJUNG (GE) | ’99.6 |
| Ulchin-5 | 1000 | PWR | HANJOONG /KAERI(CE) | HANJUNG (GE) | ’04.6 |
| Ulchin-6 | 1000 | PWR | HANJOONG /KAERI(CE) | HANJUNG (GE) | ’05.6 |
| Total | 17,717 | | | | |

**Table 3, Underwater PIE Items of PIEF**

| Items | |
|---|---|
| Visual inspection | Underwater Camera |
| Dimensional Measurement | Encoder/XY table/ Image processing |
| Underwater Fuel Rod Verification | Gamma radiation collimation |
| Hold-down Spring Force Measurement | Load Cell/Encoder |
| Underwater Gamma Spectroscopy | |
| Exponential Experiment | |

thickness measurement, wear depth measurement, rod diameter and ovality, growth, and fuel defect identification, etc. Under the in-pool PIE technique development program, under water dismantling and reconstitution technology were also developed. For dismantling of the assembly, various kinds of dismantling methods were developed and applied in the PIEF pool according to the design and fabrication types of the fuel. For the first generation nuclear fuels which was supplied for the beginning periods of NPPs of Korea, the fuel dismantling was carried out by cutting the guide thimble tubes with a band saw or by milling out the welds between the tubes and top end piece (TEP). But now,

**Figure 1. Plane Drawing of PIE facility at KAERI**

reconstitutably designed fuels facilitate dismantling as well as maintenances. With very simple remote handling tools to remove the screws or lock tubes which assembles the guide tubes and TEP allows to access to the fuel rods to be extracted. For the selective extraction of fuel rods, fuel rod index is used in aligning the fuel extraction tool to the fuels to be extracted.

## 2. Status of fuel services

PIE facility was constructed and started its hot operation from 1985. The main activities of PIEF are to examine the irradiated nuclear fuels and evaluate the fuel performances. And, many efforts were put on the examinations to find the root causes of the defective fuels and preparing the remedies to assure the safety of the fuels. All type of indigenous irradiated PWR fuel assemblies were transferred to PIEF and examined. The fuel assemblies received full scale of underwater examinations and dismantled fuel rods were extracted selectively for furthermore in-pool and hot cell PIEs. For the underwater fuel inspection and examination, KAERI developed comprehensive transportable fuel inspection equipment with the start of the indigenous nuclear fuel development program of Korea. The equipment was developed for use at NPP site to verify fuel performances and integrities. This equipment has been used in fuel inspection during refueling outages to get the information of irradiation performance and reload flexibility of the fuels to be reloaded. Figure 2 and 3 shows the fuel inspection equipment developed by KAERI.

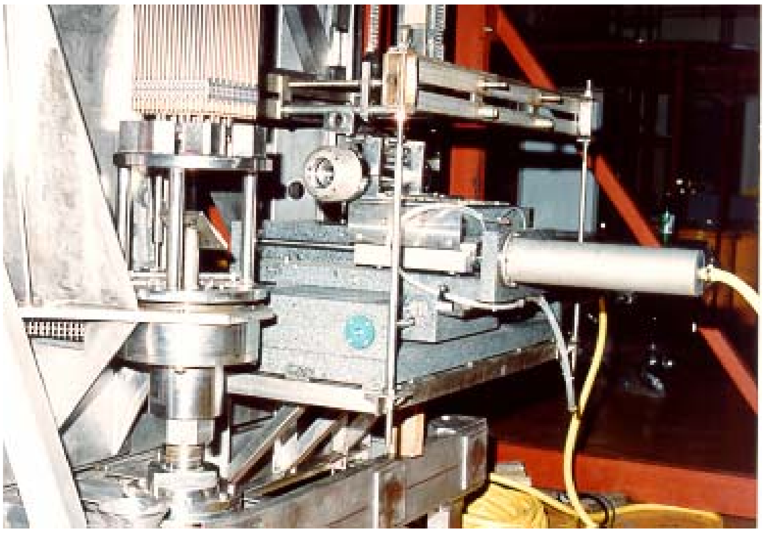

**Figure 2. Measuring System mounted on the XY Table**

Most of developed technologies were transferred to the utility service groups to apply for the on-site fuel inspections at Nuclear Power Plants. On the other hand, KEPCO Nuclear Fuel Co., Ltd (KNFC) has been extending the fuel fabrication capabilities and now supplying all the type of nuclear fuels to NPPs in Korea. The nuclear fuel production capacity of KNFC is 400 MTU/yr for PWR fuels and 400 MTU/yr for CANDU fuels. As a major nuclear fuel provider, and to cope with the growing needs of fuel services, KNFC runs nuclear fuel service

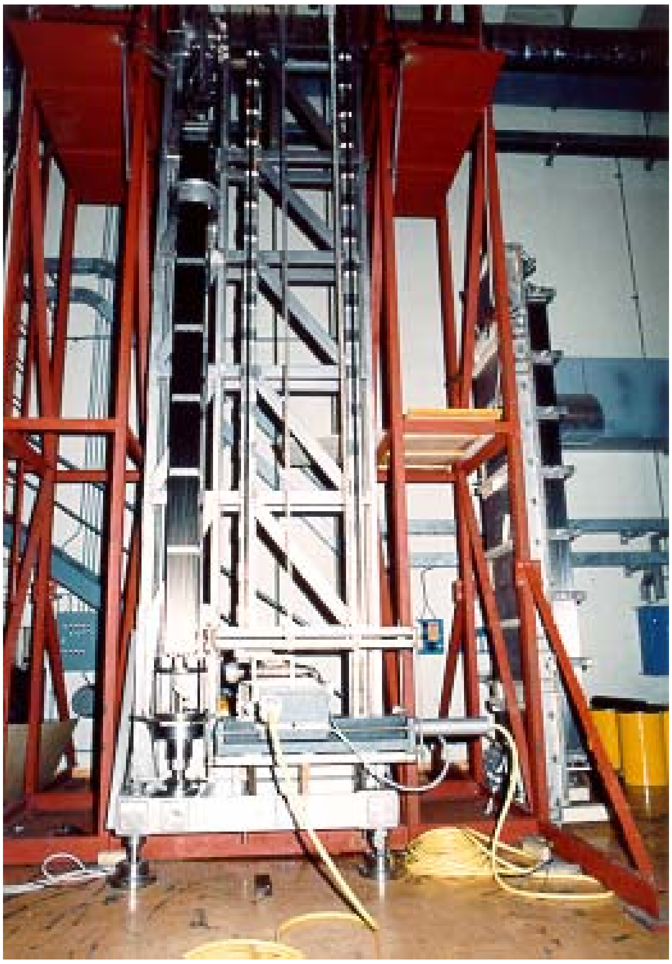

**Figure 3. A Comprehensive Transportable On-site Fuel Inspection System**

team to guarantee the safety of the nuclear fuels. KNFC set forth three years fuel repair technology development program to investigate fuel integrities. For the first step, KNFC developed fuel repair equipment for <u>W</u> 17x17 type fuels with assistances of <u>W</u>-Atom. This equipment was put in the fuel repair campaign for the damaged fuels at YGN 1 & 2. Subsequently, <u>W</u> 14x14 type fuel and <u>W</u> 16x16 type fuel repair equipment were developed and put in the fuel repair campaign.

The major equipment and items are as follows:

- Top nozzle disjoint/fixing tools
- Rod removal/insertion equipment
- Fuel assembly rotating equipment
- Work platform for fuel repair installations
- Visual inspection equipment

In this period, single rod inspection technology for visual inspection, rod diameter, fretting wear depth, oxide layer thickness and general defect measurement has been developed.

# 3. Fuel service activities

Since the first nuclear power plant, Kori unit-1, started its commercial power operation in 1978, various kinds of fuel failure and damage occurred. The first reported fuel failure events were due to baffle jet flow damages on the peripheral fuels in the vicinity of baffle joint of reactor vessels. Since then, various kinds of fuel damages, such as design oriented failures, debris induced defects, flow induced vibration-oriented fretting/wear, etc were occurred. Since the first big fuel repair campaign conducted by W fuel service team for the Kori unit-1 fuels damaged from baffle jet flow, Westinghouse, CE fuel service teams conducted fuel service activities in 1980's. Now, most of fuel service activities are carried out by KNFC fuel service team. With the single rod inspection technologies described in the previous section, irradiation performance examination campaign against the fuel rod irradiated at YGN#4 was conducted successfully in 2002.

For the second step, fuel assembly irradiation performance examination technologies including peripheral rod and grid oxide layer thickness and geometrical measurement have been developing. For the last step, fuel component function test technology including rod dragging force from fuel assembly, grid cell dimension, top piece dragging force from fuel assembly and guide tube oxide layer thickness measurement technology will be developed.

On the other hand, the fuel service technologies development program for the fuel Plus-7 of the Korea standard nuclear power plants and next generation fuels (NGF) of the W type NPPs to upgrade safety, reliability and economy of the nuclear fuel by improving the fuel components and fuel designs are continued.

# 4. Underwater Post Irradiation Examination

## 4.1. Visual Inspection

A radiation resistant underwater camera mounted on the XY table is used for the visual inspection of the fuel assembly. Fuel assembly standing on rotary base plate of the visual and dimensional inspection stand is inspected as the rotary plate rotates the fuel assembly to expose all faces to a camera. The camera is raised and lowered along the fuel assembly. Figure 4 shows the visual and dimensional inspection stand installed in the third pool of PIEF at KAERI.

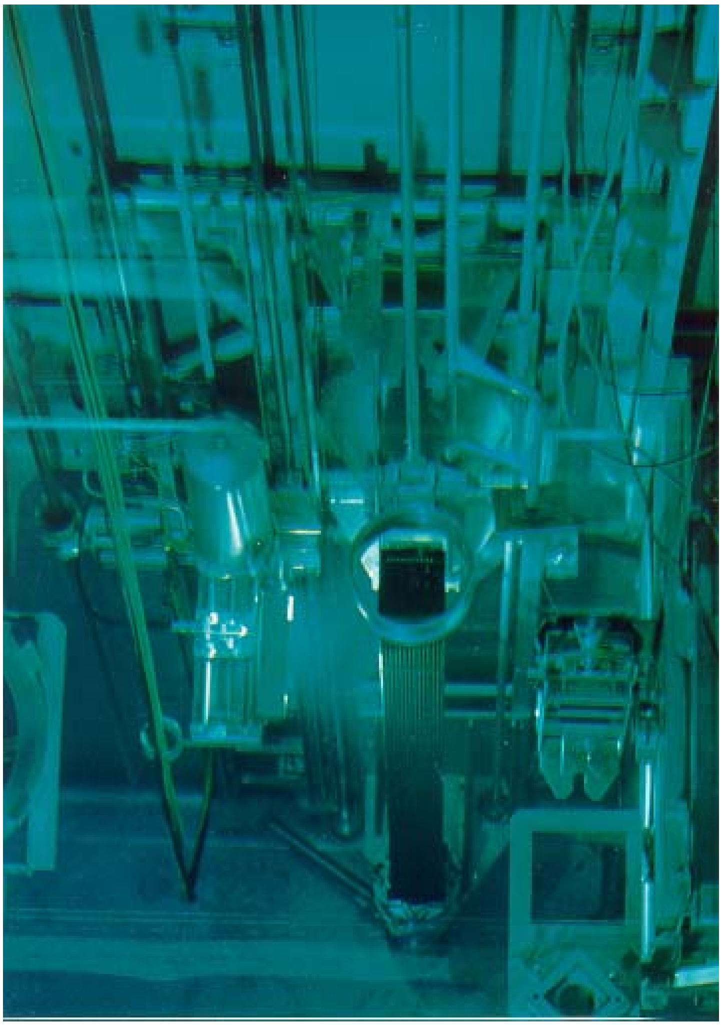

**Figure 4. Visual and Dimensional Inspection Stand in PIEF Pool of KAERI**

### 4.2. Dimensional Measurement

Fuel rod length, rod diameter, rod to rod gap, shoulder gap, assembly length, twist, bowing, grid location, etc are measured by VDIS system. Two ways of measurement are carried out. The first one is the original way of dimensional measurement in which the readings are taken using an underwater camera system by aligning the prescribed surfaces with cross hairs superimposed on the monitor. Figure 5 shows the conventional dimensional measurement system panel. Another way of measurement is using image-processing methods in measuring. Figure 5 and 6 shows the image processing system incorporated with the VDIS and the images before and after image processing by this system.


**Fig. 5. Control Panel, Display Monitor & Data Acquisition System of VDIS**

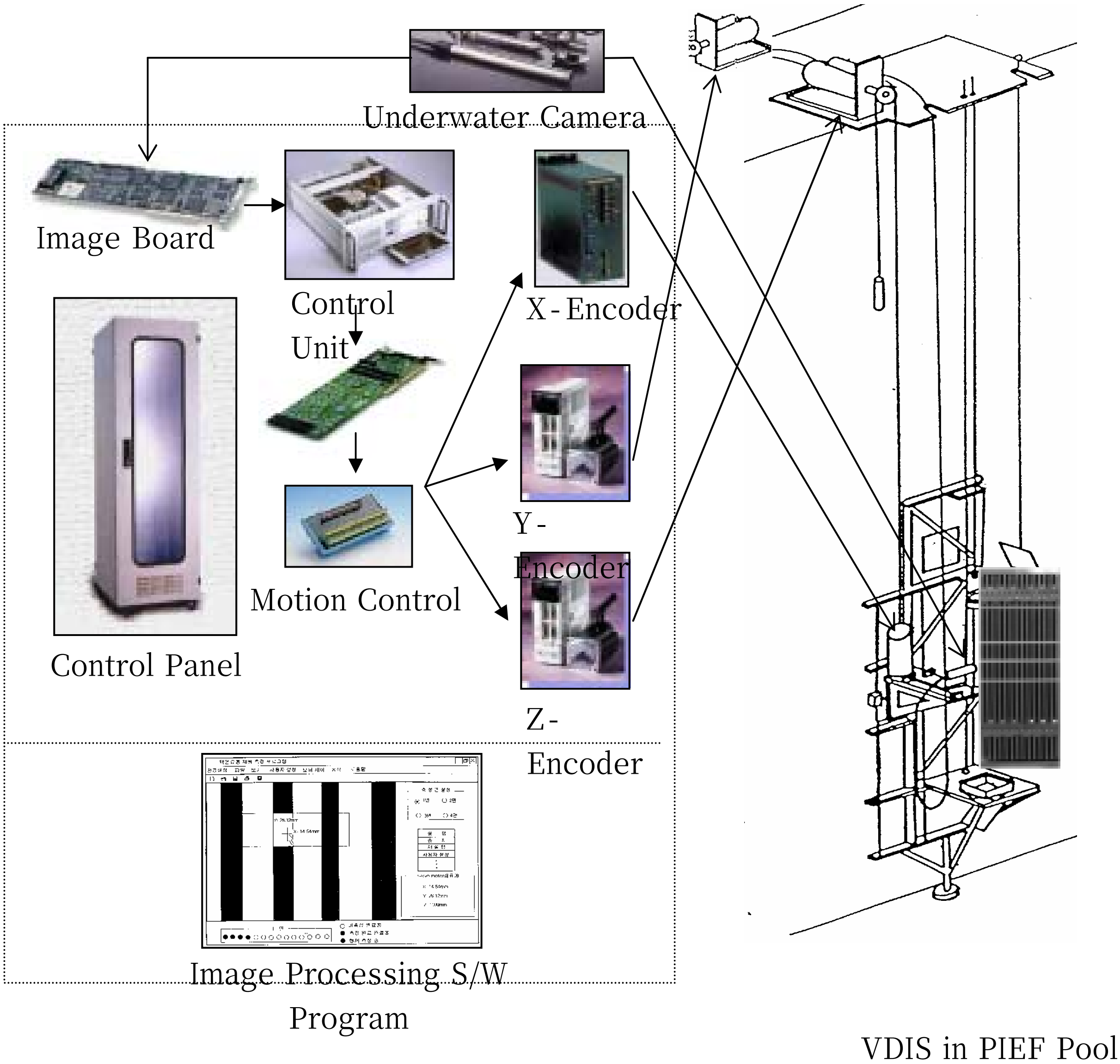


**Fig. 6. Schematic View of Image Processing System Incorporated with VDIS**

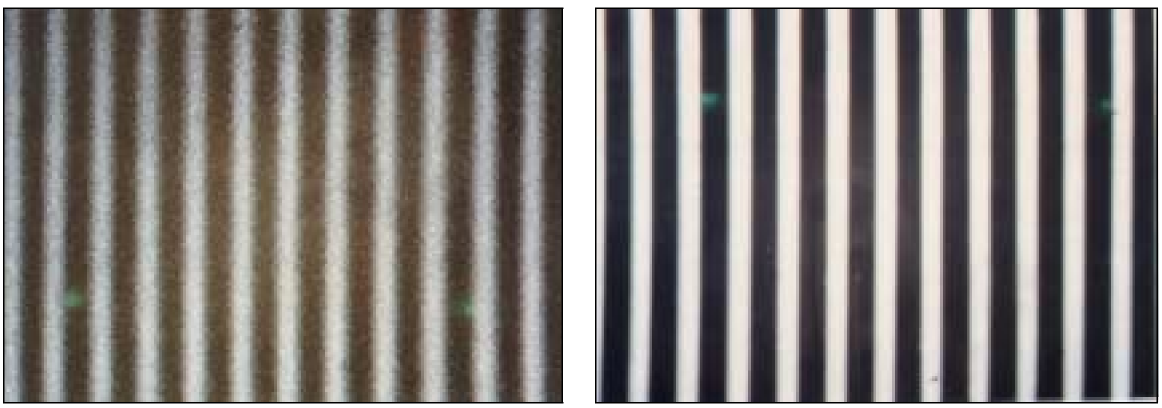

**Figure 7.    Fuel Rod Image before and after image processing**

### 4.3. Fuel Rod Verification Examination

This is to support IAEA inspection for the item counting and in verifying fuel rods in the dismantled fuel assembly. After dismantling a fuel assembly, several fuel rods are extracted for furthermore specified PIE. The remaining fuel rods are to be inspected regularly by IAEA. To avoid unnecessary rod extraction, which is not supposed to be examined but designated for the verification, KAERI developed fuel rod verification system. The idea of this equipment is to use gamma spectrometry system in collecting gamma spectra emit from fuel rod pellets by collimating them with special alignment system. Fuel rod index were designed to align fuel rods selectively along with the collimator tube, which was incorporated with the HPGe detector. The gamma radiation come through this collimator tube is collected and analyzed. By comparing the collected data with the background around the system and the radiation intensities around the empty holes that was made by rod extraction, the designated fuel rod is verified. Figure 8 shows the in-pool fuel rod verification system installed in the fuel storage pool of PIEF at KAERI.

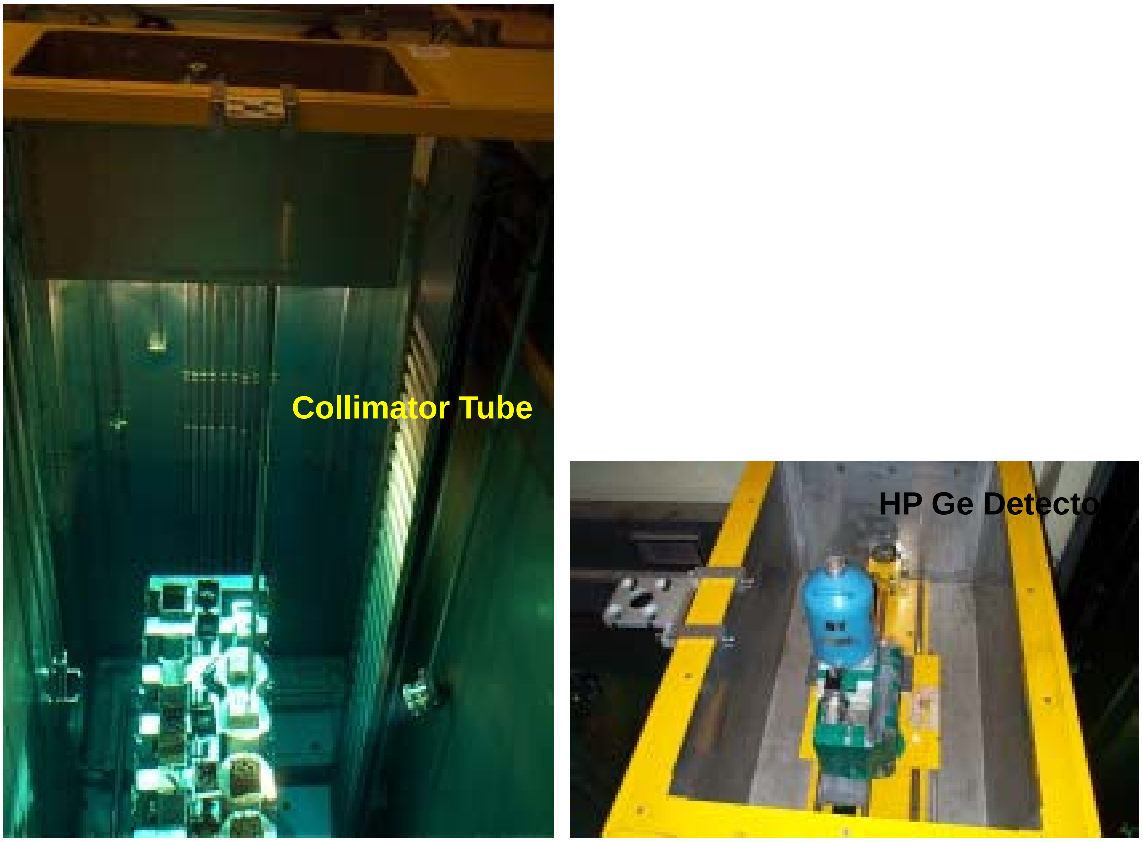


**Figure 8. In-pool fuel rod verification system at KAERI**

### 4.4. Hold-down Spring Force Measurement

The hold down spring is to suppress the fuel assembly against very strong and high speed of upstream coolant flows during the irradiation in the reactor cores. The proper hold-down spring force should be sustained during the irradiation. The spring should have enough strength to suppress the fuel assembly and should not exceed the design strength during irradiation so as not to make any deflection or damage of the fuel assembly structures due to the thermal and irradiation growth of the assembly. To measure the hold-down spring forces of the PWR type nuclear fuels, a simple and transportable hold-down spring force measuring equipment was developed. The leaf spring of TEP of fuel assembly is pressed down and the load-displacement curve is obtained which reveals the spring characteristics after irradiation. This system was designed to avoid any excessive load put on the fuel structures during the suppression of the leaf spring, Figure 9 shows the hold-down spring force measuring devices.

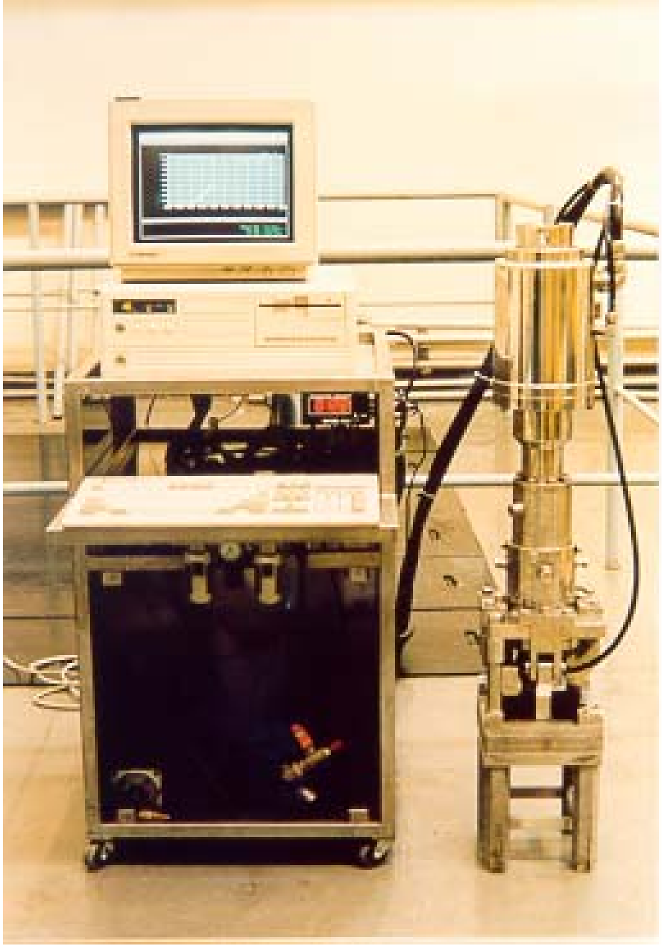

**Figure 9. In-pool Hold-down Spring Force Measuring Equipment**

### 4.5. Underwater Gamma Scanning

With the result obtained by measuring and collecting the gamma rays spectra emit from the fuel assembly, average burnup, cooling time, and initial enrichment are evaluated. And by introducing and applying a burnup credit concept in the spent fuel management system, it is expected to improve the fuel criticality safety and spent fuel management cost down. The maximum activity of spent fuel assembly is about 1 MCi with the uncertainty in determining the gamma activity ratio of burnup monitors is ~5%. This system can be applied in obtaining an axial burnup profile as well as a horizontal burnup gradient for the fuel assembly.

**Figure 10. Underwater Gamma Scanning System for Burnup Measurement**

### 4.6. Exponential experiment

Exponential experiment is introduced to predict the critical buckling by extrapolating the buckling of a small system, which is in extremely sub-critical state. The experiment was applied to the sub-criticality estimation for LWR spent fuel and confirmed that the experiment can be used to obtain the neutron effective multiplication factor for the sub-critical system in order to validate criticality calculations. The exponential experiment system is installed in PIEF pool at KAERI in order to determine the neutron multiplication factor for the PWR spent fuel stored in pool. The objectives of this experiment are to validate criticality calculation code and finally contribute to the implementation of the actinide plus fission product burnup credit. The exponential experiment system was installed in PIEF storage pool as shown in Fig. 11-13.   The system, which is

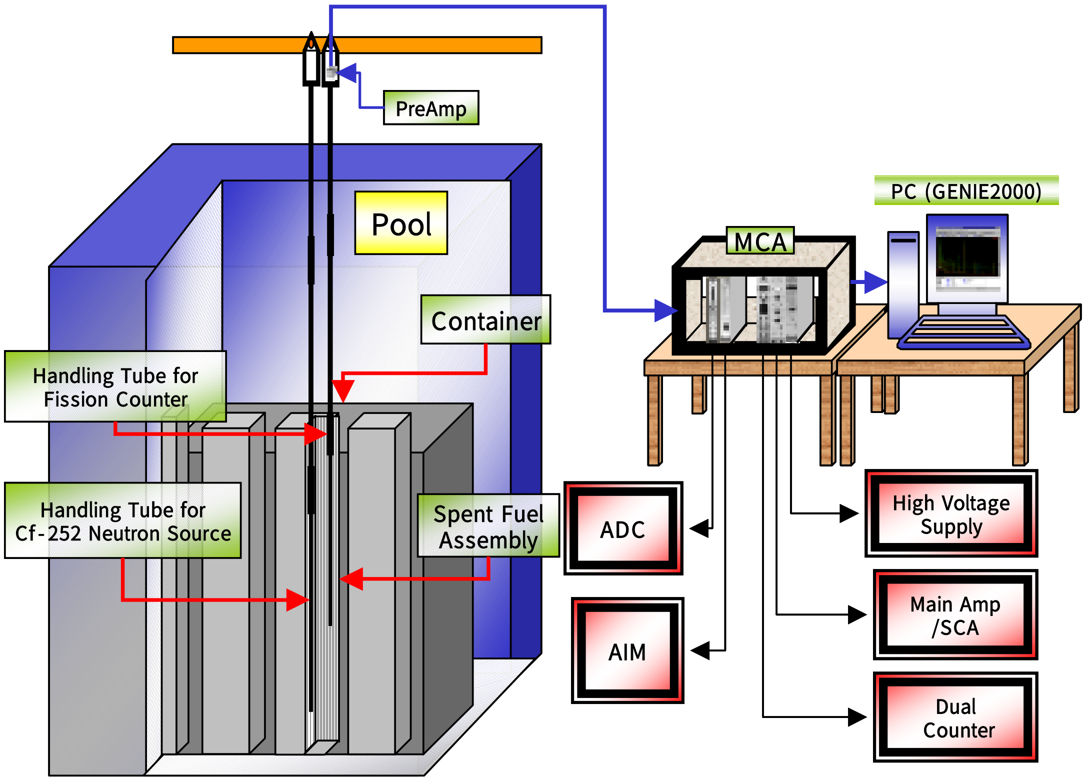


**Figure 11.   Exponential Experiment System Installed in the PIEF Pool**.

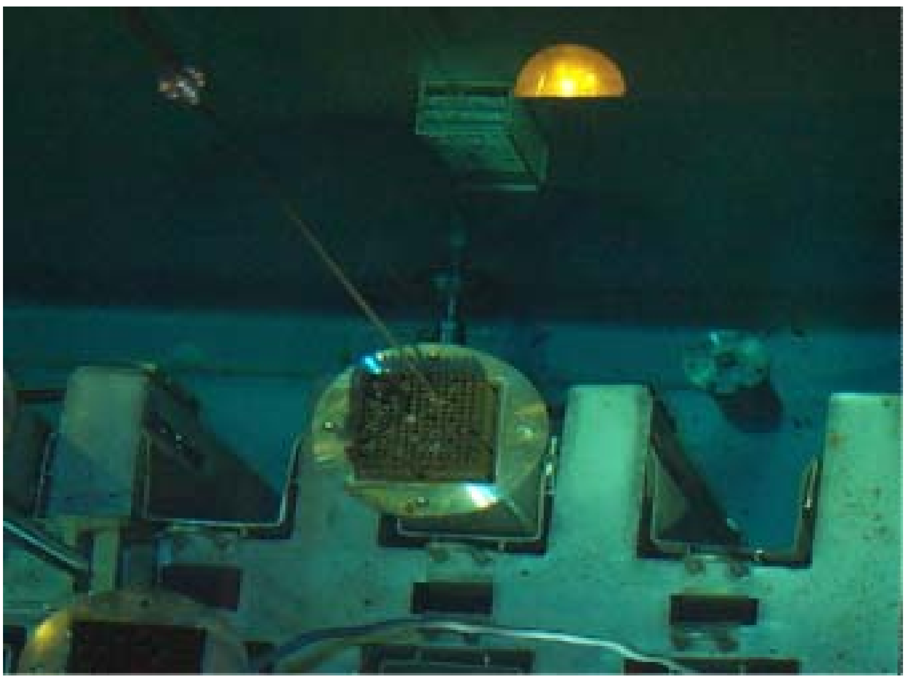

**Figure 12.   Exponential Experiment for Spent Fuel Assembly in PIEF Pool**

composed of neutron detector, signal analysis system and neutron source, 10 mCi Cf-252 has been installed in the storage pool of PIEF at KAERI in order to experimentally determining neutron effective multiplication factors of PWR spent fuel assemblies.

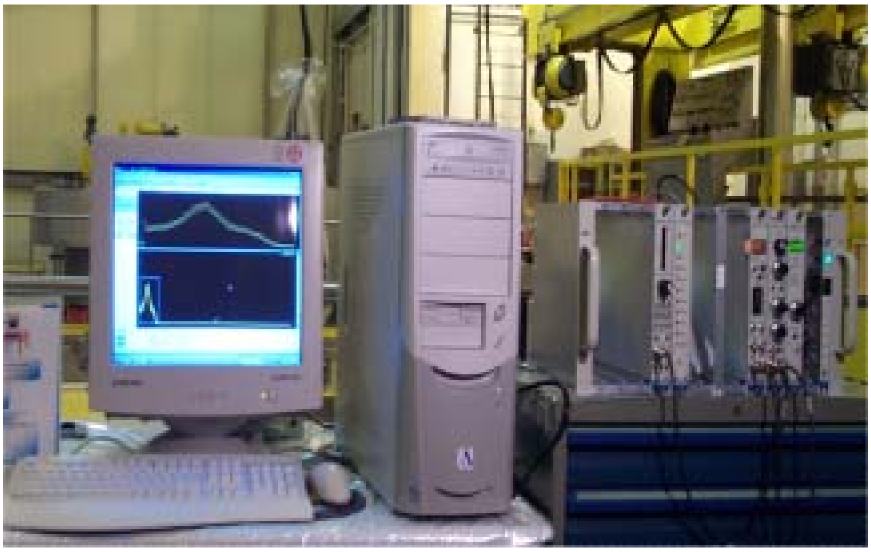

**Figure 13. Exponential Experiment System**

## 5. Conclusion

Underwater post irradiation examination technologies were developed and adopted to assure and improve the safety of nuclear fuels as well as nuclear power plants. Many of the developed technologies were put together with the fuel service technologies of the utility groups to provide proper fuel service activities. KNFC has been running a series of underwater fuel service technologies and now shows good capabilities in fuel service fields in Korea. KAERI put many efforts on the development of in-pool PIE for the LWR fuels. In order to provide appropriate underwater fuel examination technologies for the safeguard inspections, spent fuel management and fuel service activities, and in order to support nuclear R & D program in Korea, various kinds of underwater fuel examination technologies, such as fuel rod verification technology, exponential experiment, hold-down spring force measurement technology, image processing applied dimensional measurement methods, and burnup determination technology by underwater gamma spectroscopy were developed.

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