# Current Status and the Future of the Irradiation Services in the HANARO Reactor

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**SUMMARY**
As a central plant of the Korea Atomic Energy Research Institute, Hi-flux Advanced Neutron Application Reactor, the HANARO, has been playing an important role in nuclear technology development and the utilization of radiation technology. HANARO's reputation such as a stable operation, build up of various research results and the support of the government picks up more research needs. Major utilizations of the HANARO reactor in Korea have focused on its irradiation service. It offers various types of irradiation tests for fuel and materials, which provides us with very useful information for designing and evaluating reactor materials. A number of irradiation capsules have been developed and installed in HANARO. Necessary technologies regarding HANARO are still being developed. The on-going and future researches, especially, about fuel and material irradiation including university programs and the current utilization statistics of the HANARO research reactor, are described in this article.

## I. INTRODUCTION

In the early 1980s, the Korean government decided to construct a new research reactor to meet the rapidly increasing domestic demand to utilize nuclear technology. HANARO represents a multi-purpose research reactor, 30MWt open-tank-in-pool type, which achieved its first criticality in 1995 in Daejeon, Korea. Now, HANARO is one of the large national research facilities in Korea, devoted to neutron beam applications, safety and performance improvements of nuclear power plants, a stable supply of radioisotope, and many other applications of neutrons in science & technology, industry, medical welfare, etc[1]. The most important objective of HANARO at this moment in time is to increase the level of its utilization. Many experimental facilities are under utilization, development or planning for the nation-wide utilization of HANARO.

In Korea, 19 nuclear power reactors, 15 PWR plants and 4 PHWR plants, are under operation [2]. The nuclear share is above 40% of the total electric power generation. The national mid- and long-term atomic energy R&D program on nuclear reactors and nuclear fuel cycle technology was launched in the early 1992 which requires numerous in-pile tests in HANARO. Besides, extensive efforts have also been made to establish design and manufacturing technology for irradiation facilities. As a part of the national nuclear R&D programs, a series of in-pile tests are being carried out to examine the performance of the advanced fuel compared to the standard fuel and the advanced structural and core materials. To this extend, two types of irradiation tests were planned for HANARO: capsule tests and loop tests.

In this paper, we describe the status of the research reactor operation, fuel and materials irradiation as well as the utilization facilities. In addition, we describe the utilization statistics and the active plan to promote the utilization of HANARO further.

## II. OPERATION MODE CHANGE OF HANARO

Operation of HANARO has been flexibly adjusted to meet the reactor's demands. A two-week operation and a one-week shutdown was the basic operation mode in the beginning. From 1998, the operation mode was changed to a weekly operation – at least three operation days every week for the stable supply of medical radioisotopes to meet the request of a greater supply of radioisotopes from domestic hospitals. Annual operation time was about 160 days during 1998-2001, while the reactor power was gradually increased to meet the increasing demand as shown in Fig. 1[3]. From the middle of 2002, the operation mode was changed again to a two-week operation and a one-week shutdown so as to satisfy the rapidly increasing demand. Thereby, the reactor availability reached about 210 days. In 2003, we changed the operation mode to an 18-day operation and a 10-day shutdown. It is almost equivalent to a three-week operation and a one-week shutdown for the majority of reactor users, due to the reduction of the operation during weekends. The operation time in 2003 was about 215 days and a similar record is expected in 2004, but the reactor availability to users will be increased because of the operation at 30 MW from the middle of 2004. The cycle length will be increased further in the future as the demand increases. A summary of the total operation time and power generation for the HANARO reactor is given in Fig. 1.

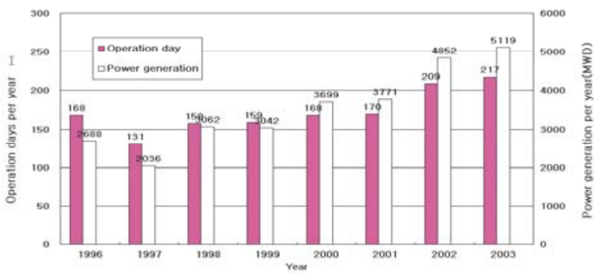


**Figure 1. Trend of the yearly power generation and operation time**

### III. FUEL AND MATERIAL IRRADIATION

The nuclear fuel and material irradiation test is one of the important missions of the HANARO reactor to support the national mid- and long-term nuclear R&D program and basic researches. HANARO has seven vertical holes of two different diameters (74.4 and 60 mm in diameter) for typical capsules to be used for material and fuel testing.  Five types of capsules and three types of I&C systems have been developed and offered to internal and external users; two non-instrumented and three instrumented capsules, and three I&C systems for material and fuel irradiation experiments, respectively.

#### A. Material Irradiation

Initial stage of the R&D program was concentrated on developing material capsules and the related facility such as a cutting device for 3 years from 1992. After an additional one year of field testing of the I&C system and the upgrades of the software for the material irradiation test, the capsule and related-devices have been installed and operated since 1997. For the material irradiation experiment, 67 capsules (54 non-instrumented and 13 instrumented capsules) have been designed, fabricated and successfully irradiated in HANARO since 1995. Small aluminum capsules are also used for the simple irradiation tests under a low temperature and a low neutron flux condition. This capsule was originally developed for isotope production. Dimensions of the capsule are 20mm in diameter and 30mm in length.

The instrumented capsule consists of a main body, a protection tube, a bottom guide assembly and a guide tube.  Most of the parts are made of SA-240 Type 304 stainless steel.  Fig. 2 shows the schematic view of the HANARO capsule. The main body with the test specimens is the cylindrical shell with a 60 mm external diameter and 870 mm in length which is placed in the in-core region of HANARO. The protection tube is a long pipe with 48.6 mm in diameter and 4,615 mm in length. It protects the instrumented cables from the coolant. One end of the tube is connected to the capsule main body. A role of the bottom guide assembly attached at the bottom end of the main body is to fix an instrumented capsule to the capsule-mounting spider of the HANARO reactor during an irradiation test. The instrumented capsule for the material test has the characteristic of 5 stages for an independent temperature control and maximum temperature control up to 500°C. It has 14 thermocouples, 5 neutron fluence monitors and 5 micro-heaters.

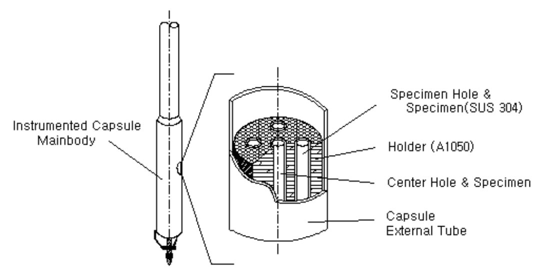


**Figure 2. Schematic view of the instrumented capsule main body**

They were designed for the irradiation of the reactor pressure vessel, reactor core, Zr-based fuel cladding, and pressure tube materials. They have produced valuable data for the life extension of nuclear power plants. Fig. 3 shows the typical instrumented capsule for the material irradiation tests.

The small capsules are also used to support the irradiation tests requested by external researchers from universities for the irradiation of nuclear, nano-, semi-conductor and magnetic materials[4].

**Figure 3. Instrumented Capsule for Material Irradiation Tests**

Development of the experimental in situ techniques for the in-pile creep test of nuclear materials has also been done since 1999[5]. This kind of capsule, called an advanced capsule, is a device to measure the changes of the nuclear material properties controlling the irradiation conditions during an irradiation test in HANARO. The first creep test in the HANARO reactor was performed in the out-core test hole of HANARO, at which the neutron flux and gamma heat are considerably low, in 2002. The purpose of this capsule was to confirm the integrity of the stress loading unit and LVDT equipped in the capsule and to evaluate the design parameters such as the temperature and pressure in the irradiation condition. Recently, the verification tests for the creep capsule development were performed in the in-core hole of HANARO. In this test, the environmental conditions such as the specimen temperature, capsule inside pressure and neutron flux are in accordance with the user's requirement. Based on the creep irradiation test data, the advanced creep capsule which can load multiple specimens has been designed and will be manufactured by the end of 2004.

The current application program of the capsules in the HANARO reactor is as follows:

(i) Reactor materials tests
   a. Reactor vessel materials: SA508 & weld m aterial, SA533 (KAERI-programs)
   b. Reactor pressure tube material: Zr-2.5Nb
   c. Structural materials: STS304, STS316, STS321, Cr-Mo alloy
   d. Reactor vessel materials: SA508, SA533 ( Industry-programs)

(ii) Fundamental research
   a. Zr-1Nb-1Sn-X Alloy, Zircaloy-4, STS350, STS 304, STS 309
   b. Semiconductor and magnetic materials
   c. Neutron dosimeter and so on.

**B. Fuel Irradiation**

Based on the considerable experiences of the material irradiation tests and the 3 years of development of the fuel capsule technology, a non-instrumented capsule with a total length of 960mm and an outside diameter of 56mm has been developed and is now being used. The capsule has been optimized and used for the irradiation test of new fuels such as the high burnup fuel, DUPIC, and the high performance metallic fuel since 1999 [6, 7]. From 2000, an instrumented capsule is being developed to measure the fuel characteristics, especially, the fuel temperature, internal pressure of fuel rod, fuel elongation, and neutron flux during an irradiation test of nuclear fuel in HANARO. In 2004, the centerline temperature of PWR $UO_2$ fuel pellets, the rod internal pressure and irradiation growth as well as the neutron flux were continuously measured and monitored during the design verification test of the instrumented capsule. The capsule geometry is similar to that of a non-instrumented capsule, which is, however, modified based on the user requirements. The instrumented capsule is about 5m in height and consists of a main body of 56mm in outer diameter and about 1 m in length, three test fuel pins of 11.7mm in outer diameter and about 20 cm in length, a bottom guide assembly, a guide tube and a protection tube made of STS 304 stainless steel tube. Fig. 4 is the photograph of an instrumented fuel capsule.

**Figure 4. Instrumented Capsule for Fuel Irradiation Tests**

In the case of controlling the fuel temperature, the design concept of the capsule is taken to apply a universal principle(double containment concept) for the experiments involving fissile in a research reactor[8]. The components of the capsule were designed for the specimen to be effectively cooled, monitored the indication of fuel failure and exposed in neutron environment during irradiation test.

In light of these growing fuel test needs, a new I&C system for the fuel irradiation tests has been designed and manufactured. The overall system consists of two sub-systems: a temperature control system and a fuel failure monitoring system[9]. The temperature control system controls the surface temperature of the specimens by adjusting the mixing ratio of the gas in an annular gas space. The fuel cladding failure monitoring system detects the fission products in the annulus gap due to a fuel cladding failure in each capsule separately mounted inside the basket. The I&C system also has several subsidiary functions, such as a data acquisition and storage function, a self-diagnosis function, and an alarm-indicating function. Fig. 5 shows the I&C system for the fuel irradiation tests. The I&C system has three operational modes: manual mode, auto mode, and computer-aided mode.

Prior to an application of the system to HANARO, it should be modified based on the out-pile performance test data. After the completion of a series of out-pile experiments, this system will be installed in HANARO and the in-pile performance test will be performed in 2005.

**Figure 5. I&C system for fuel tests**

The conceptual design of the 3-pin Fuel Test Loop started at the end of 2001 and will be completed by 2006. Both the basic and detailed design were finished by March 2004. At present, the safety analysis report for the license and the IPS mock-up test for the verification of the design concept have been prepared[10]. The FTL that can simulate the operating conditions (high temperature, high pressure and water chemistry) of commercial PWRs and CANDUs is being developed for the integral performance test of the nuclear fuel. The loop consists of the In-pile Test Section(IPS) and the Out-Pile System(OPS). The number of fuel rods to be tested at a time in the IPS is limited to three. The IPS will be installed in the IR1 test hole of HANARO.

The current application program of the capsules in the HANARO reactor is as follows:

(i) Fuel tests
  a. Advanced PWR fuel
  b. DUPIC fuel
  c. Burnable poison materials: $Gd_2O_3$-$TiO_2$, $Dy_2O_3$-$TiO_2$
  d. U-Zr alloy

(ii) Fundamental research
  a. $UO_2$ fuel

## C. Future of irradiation

Although fruitful experiences were obtained from various in-pile tests for about ten years, it is necessary for us to have leading-edge technology to satisfy the specific test requirements of the recent R&D activities such as the high-fluence- and high-burnup-related tests. To meet the demands for the high burnup test at HANARO, new capsule assembly technology and re-instrumentation technology are required in the HANARO reactor. In 2003, a mockup of the capsule assembly machine was designed and fabricated[18]. The mockup manufactured consists of a base plate, a capsule stand, a capsule guide pipe and a clamping device. Dimensions of the mockup are 1m in outer diameter, 1.8m in height and 136kg in weight. Pre-operational tests of the mockup were performed in 2004. From the pre-operation tests, the capsule assembly machine will be optimized soon and this remote assembly procedure can be used in the remote assembly of capsule components for the long time irradiation tests in HANARO. A capsule mockup will be designed and fabricated, which is more compatible to the HANARO operation conditions and well matched with the user requirements.

And in-situ measuring technology using sensors (such as a pressure transducer, LVDT etc.) was also developed at the same time with the fuel irradiation test program. In addition, the investigation for the technical demands of the advanced capsules for measuring the properties of the material in a real time during an irradiation was conducted in 2004. The investigation shows that users in Korea want to develop the advanced capsules for studying the behavior for creep, crack propagation and fatigue during an irradiation. On the other hand, development of the HTGR for the production of hydrogen as new energy source is planned to start in the near future in Korea. Therefore, for some forthcoming years, not only capsules for the measurement of the fatigue and crack propagation properties of materials but also a capsule for studying graphite properties at a high temperature will be developed according to the user's requirement in HANARO. For the research period of 2003-2006, we are planning to develop new technologies for the precise control of both the irradiation temperature and total neutron fluence of specimens during an irradiation. This technology will be effectively applied for the study of the effects of radiation on materials using an identical capsule.

## IV. UTILIZATION STATISTICS AND ACHIEVMENTS

The primary mission of HANARO includes education, basic and applied research in neutron-related science and engineering and the application of technology in areas of national concerns. KAERI is requested to establish a national mechanism to accelerate the nation-wide utilization of the HANARO reactor and also to support the fundamental research programs from university professors. In order to promote the HANARO utilization, the following have been achieved. First, HANARO Steering Committee, HANARO User's Association and 6 Peer Groups were organized and have been operated from the first Coordinator Meeting in December 1999[11]. It was agreed to periodically review the achievements and prepare a work plan of the activities. The HANARO Steering Committee, composed of government representatives, HANARO users, the regulatory body, KAERI, and a few relevant experts, makes important policies on HANARO management and utilization. HANARO User's Association, composed of representatives of Peer Groups, discusses issues raised from each group and recommends its opinion to the HANARO Steering Committee. Presently six active Peer Groups are in operation. Each group holds regular meetings to discuss issues and to exchange information among them.

Second, as a part of the information exchange, a HANARO workshop is held to promote the utilization of HANARO once every year. More than 200 research papers are presented in each year and the research activity and related works tend to be increasing [12].

Third, the utilization of the HANARO facilities can be categorized as R&D, education for university students, and service activities. Periodically, the R&D funding for the HANARO utilization program is mostly from MOST except for the bilateral contract case and open to universities and research institutes as well as industry. Since 1999, about 40 collaborations with outside users in the area of irradiation test were established involving 244 users from universities, research institutes, and industries. The total governmental funding from FY1999 to FY2004 was above $120M for the irradiation service activities. For FY2005, many users expressed interest in the possible usage of the HANARO reactor for a variety of R&D applications in the area of irradiation test and they are in the submittal stage of proposals to MOST.

For effective development planning of the required irradiation technology, policy formulation and monitoring of the progress is made, the yearly trend of the number of samples and irradiation time using capsules from FY 1997 to FY 2003 is as shown in the Figure 2.

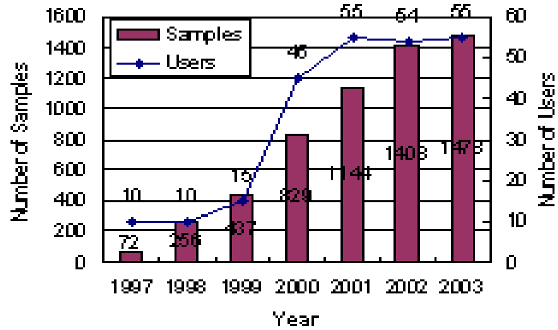


**Figure 6. Annual Trends of Irradiation Service**

More than 5,600 specimens, requested from universities, research institutes, and industries, were irradiated in HANARO for 53,000 hours using capsules.
The utilization statistics of the past will be greatly enhanced in the next decade for the next generation reactor programs along with the national R&D programs. From the information the burden on the irradiation services has gradually shifted from the internal users related to the national R&D projects to the outside users within Korea. As well, there are many choices for the utilization of devices and services.


**ACKNOWLEDGEMENTS**
This study was supported by Korea Institute of Science & Technology Evaluation and Planning (KISTEP) and Ministry of Science & Technology (MOST), Korean government, through its National Nuclear Technology Program.


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**Terminology**

HANARO: High-flux Advanced Neutron Application Reactor
DUPIC: Direct Use of Spent PWR Fuel in CANDU Reactor
FTL: Fuel Test Loop,
CT: Central Trap
I&C: Instruments and Control
LVDT: Linear Variable Displacement Transducers
IPS: In-pile Test Section
OPS: Out-Pile System
MOST: Ministry of Science and Technology