THE CONTRIBUTION OF HANARO TO THE R&D RELEVANT TO THE SMART AND VHTR SYSTEM

K.N. CHOO, M.S. CHO, J.S. PARK, W.J. LEE, I.C. LIM, J.J. HA
Korea Atomic Energy Research Institute,
Daejeon,
Republic of Korea
knchoo@kaeri.re.kr

1. INTRODUCTION

The High Flux Advanced Neutron Application Reactor (HANARO) is an open pool type multipurpose research reactor located at the Korea Atomic Energy Research Institute (KAERI) in Korea. HANARO has been operated, and the functions of its systems have been improved continuously, since its first criticality in February 1995; and it is now being successfully utilized in such areas as neutron beam research, fuel and materials irradiation tests, radioisotope production, neutron activation analysis and neutron transmutation doping. A significant number of experimental facilities have been developed and installed since the beginning of the reactor's operation, and continued efforts to develop more facilities are in progress. Various neutron irradiation facilities for irradiation tests of nuclear materials and fuels have been developed at HANARO. The irradiation facilities have been actively utilized for various material irradiation tests requested by numerous users.

In this paper, not only the status of HANARO irradiation facilities, but also the support of R&D relevant to present and future nuclear systems of HANARO is described.

2. STATUS OF HANARO AND IRRADIATION FACILITIES

2.1. HANARO reactor

In April 1995, KAERI completed the construction of a high performance multipurpose research reactor named HANARO which means, in Korean, "uniqueness". The core features a combination of a light water cooled and moderated inner core and a light water cooled but heavy water moderated outer core. The inner core has 28 fuel sites and 3 test sites. Three test sites are hexagonal shaped and used for capsules, fuel test loop (FTL), and radioisotope (RI) production. The outer core consists of 4 fuel sites and 4 test sites, which are embedded in the reflector tank. There are several vertical test holes such as CT, IR1, IR2 (hexagonal type) and OR (cylindrical type) in the core of HANARO, and additionally, Large Hole (LH), Hydraulic Transfer System (HTS), Neutron Transmutation Doping (NTD) and Irradiation Position (IP) positions in the reflector region of the reactor for nuclear fuels and materials irradiation testing, RI production and Si doping, as shown in Figure 1. The neutron flux of the IP hole varies markedly depending upon the location in the reactor core. The seven horizontal beam ports such as ST1, ST2, ST3, ST4, NR, CN and IR in the reflector region of the reactor are being actively applied for scattering and diffraction of neutrons, neutron radiography, and the out-of-core neutron irradiation facilities Cold Neutron Reflection Facilities (CNRF), Boron Neutron Capture Therapy (BNCT) and dynamic Neutron Radiation (NR).

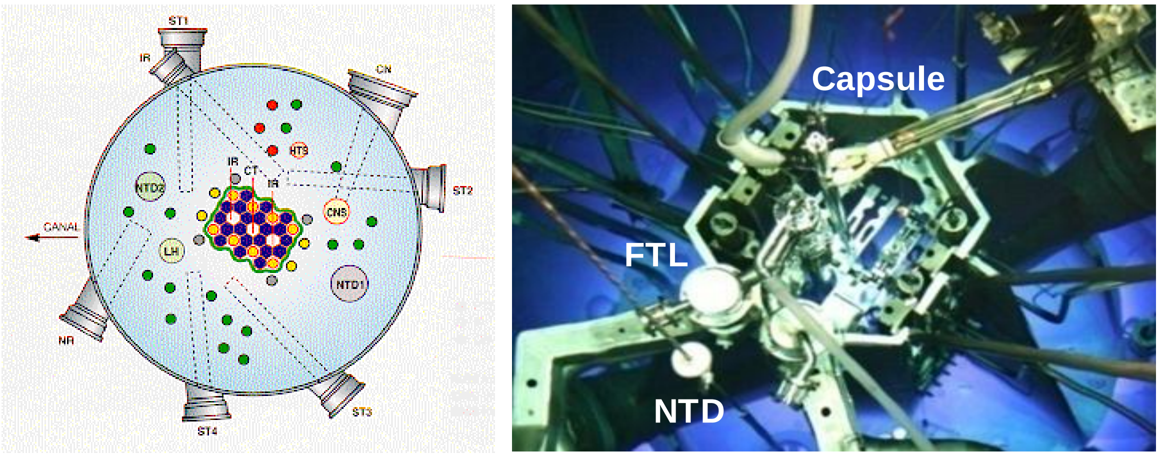

Fig. 1. Configuration and photograph of the HANARO core.

2.2. Irradiation facilities at HANARO

Various neutron irradiation facilities such as the rabbit irradiation facilities, the loop facilities and the capsule irradiation facilities for irradiation tests of nuclear materials, fuels and radioisotope products have been developed at HANARO [1]. Among the irradiation facilities in HANARO, the capsule and rabbit systems have been used for the irradiation of nuclear materials, and the FTL was installed in IR1 by the end of 2008.

The rabbit was originally designed for isotope production, but it can be used for the irradiation test of fuel and materials. Figure 2 shows the typical rabbit (20 mm in diameter and 30 mm in length for specimen) inserted into the HTS hole. It is very useful for numerous irradiation tests of small specimens at a low temperature, below 200^{o}C, and neutron flux conditions.

The instrumented and non-instrumented capsules have been developed at HANARO for new alloy and fuel developments and the lifetime estimation of nuclear power plants (NPPs). For the development of an instrumented capsule system, the capsule related systems such as a supporting, connecting and controlling system were also developed. After locking the capsule in a test hole, the instrumented capsule is fixed by a chimney bracket and robotic arm supporting systems. Two sets of cantilever type robotic arm systems for the CT and IR2 test holes were installed at the location of the platform level of the reactor, which is 5.5 m in height from the bottom of the capsule, but the in-chimney bracket is temporarily installed on the top of the reactor chimney for capsule irradiation tests. At the junction box system, heaters and thermocouples can be easily connected to and separated from the capsule controlling system before or after an irradiation test. The capsule temperature control system consists of three subsystems: a vacuum control system, a multi-stage heater control system and a man-machine interface system. After an irradiation test, the main body of the instrumented capsule is cut off at the bottom of the protection tube with the cutting system, and it is transported to the Irradiated Materials Examination Facility (IMEF) by using a HANARO fuel cask.

The FTL is a facility that can conduct fuel and material irradiation tests at HANARO (Figure 3). It is composed of an in-pile test section (IPS) and an out-of-pile system (OPS). The IPS in the IR1 irradiation hole can accommodate up to three pins of PWR or CANDU type fuels and has instruments such as a thermocouple, LVDT and SPND to measure a fuel's performance during a test. The environment around the IPS is subjected to a high neutron flux (Thermal flux: 1.2×10^{14} cm^{-2}s^{-1}, fast flux: 1.6×10^{14} cm^{-2}s^{-1}). The FTL simulates commercial

NPP operating conditions such as its pressure, temperature, flow and neutron flux to conduct irradiation tests. The application fields of the FTL are nuclear fuel and material irradiation tests at the operating conditions of a commercial power plant, fuel burn up and mechanical integrity verification tests, irradiation data generation for a performance analysis model (PWR fuel, CANDU fuel and metallic fuel), technical improvement of a design and fabrication process for advanced fuel development, fuel rod irradiation testing for performance verification and more. The typical design pressure and temperature of the in-pile section of the FTL is 17.5 MPa and 350^{o}C, respectively. Since test operation in mid-2009, the FTL has been utilized for the irradiation test of PWR type fuels.

HANARO has two irradiation holes for neutron transmutation doping to manufacture high quality n-type semiconductors. A semiconductor doped with neutrons has much better dopant distribution as compared to others made by conventional chemical doping methods and is especially required for the effective use of high power operating devices such as insulated gate bipolar transistor (IGBTs), integrated gate commutated thyristors (IGCTs) and gate turn off thyristors (GTOs). The demand for NTD silicon is increasing rapidly with the increase of wind, solar and fuel cell energy systems; hybrid cars and hydrogen fuel cell engines and devices to reduce electricity loss. A commercial NTD service for 5, 6 and 8 inch silicon ingots is being performed at NTD1 and NTD2 where the world's best quality products takes more than 10% of the world market share.

Fig. 2. Irradiation rabbit, non-instrumented capsule and an instrumented capsule.

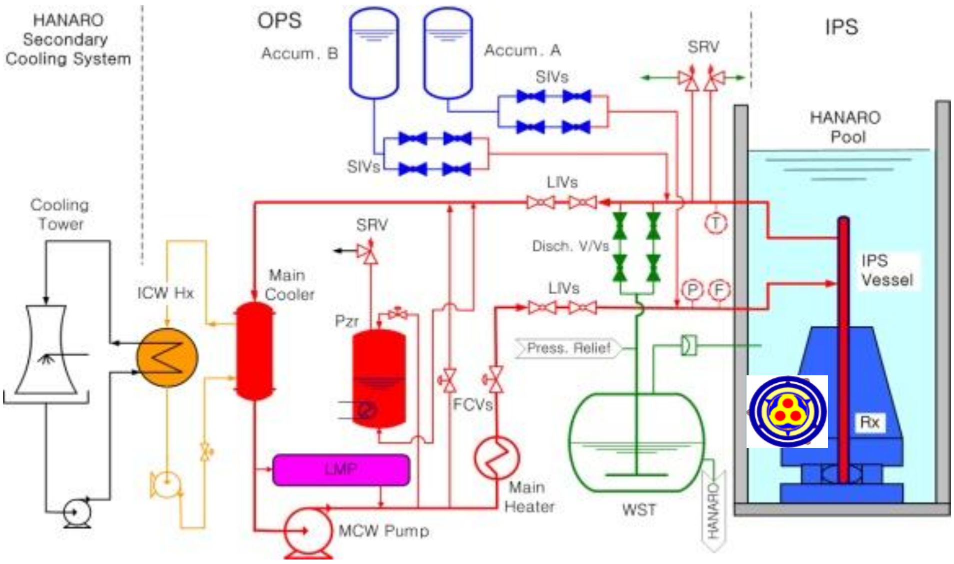

Fig. 3. Schematic Diagram of the FTL.

2.3. Capsule irradiation in HANARO

Instrumented and non-instrumented capsules have been developed at HANARO for new alloy and fuel development and the lifetime estimation of NPPs. Extensive efforts have been made to establish design and manufacturing technology for a capsule and temperature control system, which should be compatible with HANARO's characteristics [2, 3]. Up to now, material and fuel capsules have been developed and are being utilized for irradiation testing of materials and nuclear fuel at HANARO, and creep and fatigue capsules are being developed to study the creep and fatigue behaviour of materials under irradiation.

The material capsule is one of the irradiation devices which can evaluate the irradiation performance of nuclear and high technology materials at HANARO. The capsule has an important role for the integrity evaluation of reactor core materials and the development of new materials through precise irradiation tests of specimens such as a reactor pressure vessel, reactor core structural materials, parts of a fuel assembly and high technology materials.

The fuel capsule is applicable to research into the irradiation characteristics of fuel pellets and to obtain the in-core performance and the design data of nuclear fuel at HANARO. The fuel capsule has also been utilized for the irradiation characteristics test of Direct Use of Spent PWR Fuel in CANDU Reactors (DUPIC) fuel and advanced PWR fuel pellets. The instrumented fuel capsule can be used to measure fuel temperature, internal pressure of a fuel rod, fuel deformation and neutron flux during a fuel irradiation test.

The creep and fatigue capsules were developed to obtain the creep and fatigue characteristics of nuclear materials during irradiation test. The loading stress needed for a test is applied on a specimen by a bellows system controlled by an external He gas pressure.

A typical HANARO irradiation material capsule consists of three main parts that are connected to each other: a protection tube (5 m), guide tube (9.5 m) and a capsule's main body. The main body including the specimens and instruments is a cylindrical shape tube of 60 mm in diameter and 1170 mm in length. The main body has five stages with independent micro-electric heaters, thermocouples and neutron fluence monitors to measure the temperature and the neutron fluences of the specimens, respectively. Heaters and thermocouples are connected to a capsule temperature controlling system through a guide tube and connection box system. A friction welded tube using STS304 and Al1050 alloys is introduced to prevent coolant leakage into a capsule during the capsule cutting process after an irradiation.

Based on a specimen's configuration and the basic design of a capsule, the reactivity effect, neutron flux, and gamma heating of specimens are calculated by MCNP code [4]. To compare the neutron flux of the specimens that are calculated by using the MCNP computer program before an irradiation test, two kinds of fluence monitors (F/Ms) are installed in the Al thermal media near a specimen (one F/M per stage) in a capsule. Monitoring wires of Fe, Ni, Ti, Nb or Ag are inserted in an Al tube. Nb-Ag and Fe-Ni-Ti wires are inserted for the measurement of the thermal and fast neutron fluences of the specimens, respectively. After an irradiation, the F/Ms are dismantled in a hot cell and the weight changes and gamma ray spectrum of the wires are measured to obtain a neutron spectrum. The obtained fast neutrons ($E>1.0$ MeV) by using the SANDII code are known to be located within about a 20% error range of the theoretical values calculated by the MCNP code. The temperature of the specimens during an irradiation is initially increased by the gamma heating and then roughly adjusted to an optimum condition by a gas control system and then finally adjusted to a desired value by a micro-electric heater. After the irradiation tests, the displacement per atom (DPA) and activation of the irradiated specimens are also evaluated by using the SPECTOR [5] and ORIGEN2 codes [6], respectively.

The irradiation temperature of the specimens is preliminary analyzed by using the GENGTC [7] and ANSYS codes [8]. Because the gamma heating rate varies along the vertical position of the reactor core, a gap adjustment between the capsule parts is very important to maintain a uniform temperature of the specimens over the region. Because of the complicated configuration of a specimen, a gap adjustment between the capsule parts is performed based on the expected temperatures obtained by the GENGTC code.

3. UTILIZATION OF HANARO TO THE NUCLEAR R&D

As HANARO represents multipurpose research reactors, it plays a major role in nuclear technology development and the utilization of radiation technology in Korea. Owing to its stable operation and the buildup of various research results as well as the support of the government for the reactor, more research demands for the utilization of HANARO are arriving. One of the major uses of the HANARO reactor focuses on its irradiation service. The irradiation facilities of HANARO have been actively utilized for various nuclear fuel and material irradiation tests requested by users from research institutes, universities and industries. Most irradiation tests have been related to R&D relevant to commercial nuclear power reactor ageing management and the safety evaluation of its components. Figure 4 shows the trends of the irradiation specimens and the time requested by users. The increasing trends of the irradiation tests were recently disturbed by the installation of the CNRF and FTL.

Based on the accumulated experience and the users' sophisticated requirements, HANARO has recently started new support of R&D relevant to future nuclear systems including the SMART and VHTR. The development of future nuclear systems is one of the most important projects planned by the Korean government. To effectively support R&D relevant to future nuclear systems, the development of advanced irradiation technologies concerning high temperature irradiation tests is being preferentially developed in HANARO. At present, another research reactor that will specialize in radioisotope production and the demonstration of reactor design is being planned in Korea. Therefore, HANARO will concentrate on irradiation and neutron beam research.

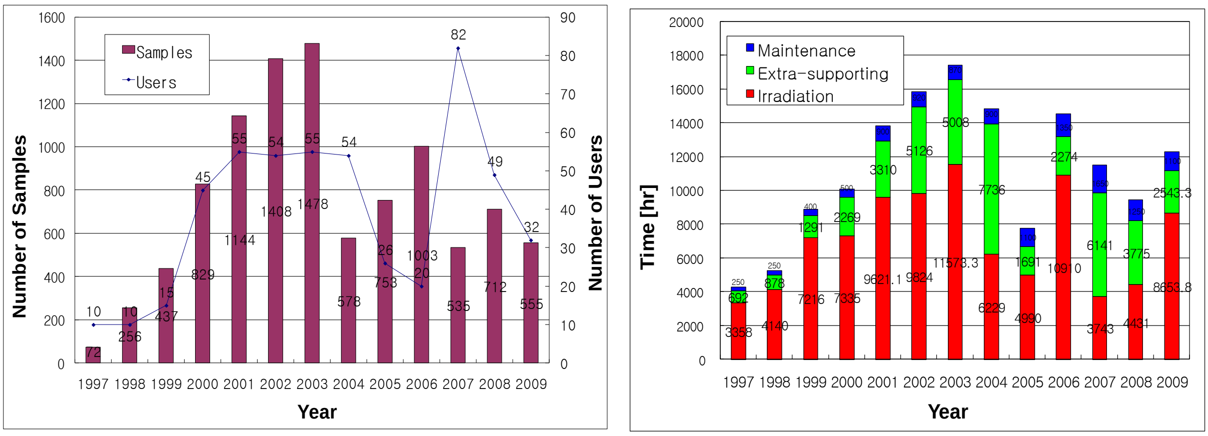

Fig. 4. Annual trends of HANARO users, samples, irradiation times.

3.1. Contribution of HANARO to the R&D of commercial reactors

The national R&D programme on nuclear reactors and nuclear fuel cycle technology in Korea requires numerous in-pile tests at HANARO. The main activities of capsule development and utilization programmes are focused on in-reactor material tests, safety related R&D for nuclear reactor materials and the components of commercial reactors, and basic research. Since 1995, 10 000 specimens from research institutes, nuclear industry companies and universities have been irradiated at HANARO for 92 000 cumulative hours using the developed capsule and rabbit irradiation systems. The capsules were mainly designed for the irradiation of a reactor pressure vessel, reactor core materials and Zr-based alloys. Most capsules were made for KAERI material research projects, but some capsules were made as part of national projects for the promotion of HANARO utilization at universities and for the irradiation tests requested by international research projects.

The facilities at HANARO have also been applied to several commercial based irradiation tests relevant to the extension of lifetime of the current nuclear power reactor Kori-1, new alloy and fuel developments with Doosan Heavy Industry Company (DHI) and Korea Nuclear Fuel Company (KNF), and control rod material evaluation in cooperation with Westinghouse Electric Company of the US. The archive material of the reactor pressure vessel of the Kori-1 reactor, which is the first NPP in Korea, was irradiated and evaluated to support the extension of the lifetime of the reactor, and the neutron irradiation performance of the Korean-made commercial RPV materials was also evaluated in HANARO. Several capsules were irradiated for the evaluation of the neutron irradiation properties of the parts of the nuclear fuel assemblies fabricated by KNF.

3.2. Contribution to VHTR projects

The Generation IV (GEN-IV) International Forum, or GIF, was chartered in July 2001 to lead the collaborative efforts of the world's leading nuclear technology nations to develop next generation nuclear energy systems to meet the world's future energy needs. Among the six GEN-IV systems, Korea has participated in the VHTR and sodium cooled fast reactor system (SFR) R&D programs and provisionally participated in the supercritical water reactor (SCWR) programme.

These new advanced nuclear reactor systems inevitably require higher irradiation test parameters than the conventional irradiation tests. Therefore, a strategic irradiation programme at HANARO has placed more emphasis on a special purpose capsule system by focusing on the specific material or fuels for a next generation power reactor.

The VHTR is one of the leading reactor designs, with participation between Korea and the US. The VHTR is the next step in the evolutionary development of high temperature reactors. VHTR technology addresses the advanced concepts for a helium gas cooled, graphite moderated, thermal neutron spectrum reactor with a core outlet temperature greater than 900 °C. The VHTR environment is unique, and little data exists on the behaviour of materials under irradiation and in the temperature and pressure ranges of interest. At present, no candidate alloy has been confirmed for use as either the cladding or structural material in VHTRs. To meet these challenges, a Gen-IV R&D plan for the structural materials in VHTRs was initiated as an I-NERI Project, which is a bilateral research agreement between the Ministry of Science and Technology (MOST) of Korea and the Department of Energy of the US [9].

To obtain the proposed test conditions by the joint U.S./Korea I-NERI Project of 'VHTR Environmental and Irradiation Effects on High-Temperature Materials,' the development of new instrumented capsule technologies for an IP/OR irradiation test and a high temperature irradiation test have been successfully performed in HANARO [10].

9Cr-1Mo and 9Cr-1Mo-1W steels were selected as candidate materials of a reactor pressure vessel of the VHTR, and the OR5 test hole in HANARO was selected as the irradiation test hole. Two HANARO irradiation capsules of the high temperature materials were successfully designed and irradiated in the OR5 test hole of HANARO at a 30 MW thermal power of 390±10°C up to a fast neutron fluence of 4.4×10^{19} cm^{-2} (E>1.0 MeV).

As a reactor pressure vessel material of the VHTR, modified 9Cr-1Mo steel manufactured by USINOR INDUSTEEL (Belgium) and forged 9Cr-1Mo-1W steel manufactured by DHI were procured. Various specimens such as standard and 1/2-size Charpy and plate tensile specimens of the matrix, welded, and heat affected zone parts made of the steels were prepared, as shown in Figure 5.

Fig. 5. The VHTR specimens stacked with spacers in the irradiation capsules.

HANARO irradiation capsules of 07M-21K and 08M-09K were designed and fabricated for an evaluation of the neutron irradiation properties of high temperature materials, as shown in Figure 5. These instrumented irradiation material capsules were newly designed to be irradiated in the OR5 test hole of HANARO for the first time. A capsule, with an outer diameter of 56 mm, is composed of five stages having many kinds of specimens and an independent electric heater at each stage. During the irradiation test, the temperature of the specimens and the fast neutron fluences were measured with 14 thermocouples and 5 sets of Ni-Ti-Fe neutron fluence monitors installed in the capsule.

The material capsule irradiation in the OR test hole is the first one done in HANARO. It might affect the safety of a reactor itself. Therefore, the irradiation of the 07M-21K capsule was examined to attain an admission of the 'Reactor Safety Review Committee of HANARO' based on the capsule design and safety analysis. In the examination, the neutron fluxes and gamma heating of the specimens located in the OR5 hole of HANARO were theoretically calculated to evaluate the thermal structural safety of the capsule, and the reactor reactivity change by the capsule was checked and proved to be negligible upon reactor safety [11].

Each irradiation capsule was irradiated for 1 cycle (about 24 days) in the OR5 test hole of HANARO with a 30 MW thermal output. During the entire irradiation, the measured temperatures of the specimens were consistently maintained in the range of 390±10°C.

The amount of neutron fluence of the specimens was calculated by MCNP code [4]. A fast neutron fluence of the specimens was obtained in the range of $1.1–4.4\times10^{19}$ cm^{-2} (E>1.0 MeV) depending on the irradiation time and specimen loading orientation in the reactor core. The DPA of the irradiated specimens was evaluated to be 0.03–0.07 by using the SPECTOR code [5].

After the irradiation test, the capsules were transported to the IMEF, and the irradiated specimens were mechanically tested. The high temperature materials for the VHTR were successfully irradiated in HANARO for an evaluation of the neutron irradiation properties for the joint US and Republic of Korea I-NERI Projects of 'VHTR Environmental and Irradiation Effects on High-Temperature Materials.

3.3. Contribution to the SMART project

The SMART is one of the most advanced SMRs [12]. There has also been a growing interest in small and medium sized reactors in developed countries that have deregulated their electricity market, under a call for flexibility in power generation. The Korean government decided recently to develop the system as one of its new growth engines and to obtain the standard design approval on SMART from the Korean licensing authority by 2011.

In order to fundamentally eliminate the possibility of a large break loss of coolant accident, major components of the reactor coolant system such as the pressurizer, the reactor coolant pump and steam generators are located inside the reactor vessel in the SMART system as shown in Figure 6 [13].

Alloy 690 was selected as the candidate material for the heat exchanger tube of the steam generator of SMART [13]. SMART R&D is now facing the stage of so-called “engineering verification and approval of standard design” toward application to the prototype DEMO fusion reactor. Therefore, evaluation of material performance under the relevant environment is required. One of the most important material performance issues is fracture toughness for which an engineering database is necessary to design a steam generator. Because the SMART steam generators are located inside the reactor vessel, the degradation of the fracture toughness of the Alloy 690 heat exchanger tube should be clearly determined for design lifetime neutron fluence. However, the neutron irradiation characteristics of the alloy are barely known. Therefore, an irradiation plan of the Alloy 690 materials to obtain the neutron irradiation characteristics of the alloy using HANARO irradiation capsules was planned [14].
The fast neutron fluence of Alloy 690 was required to be 1×10^{19} cm^{-2}, 1×10^{20} cm^{-2}, and 1×10^{21} cm^{-2} (E>1.0 MeV) [15], considering the lifetime neutron fluence (1.56×10^{19} cm^{-2}) of

the SMART steam generator. To obtain these neutron fluences, three different irradiation capsules were planned to be irradiated in the OR and CT test holes of HANARO.

Three different samples of heat Alloy 690 were prepared, and various specimens such as standard and sub-size plate tensile specimens, 0.4 T compact tension specimens, hardness and microstructure specimens (Optical and TEM) were prepared, as shown in Figure 7. Specimens were inserted into an Al thermal medium as a square bar shape with spacers of a same material to simplify the handling and thermal calculation of the capsule.

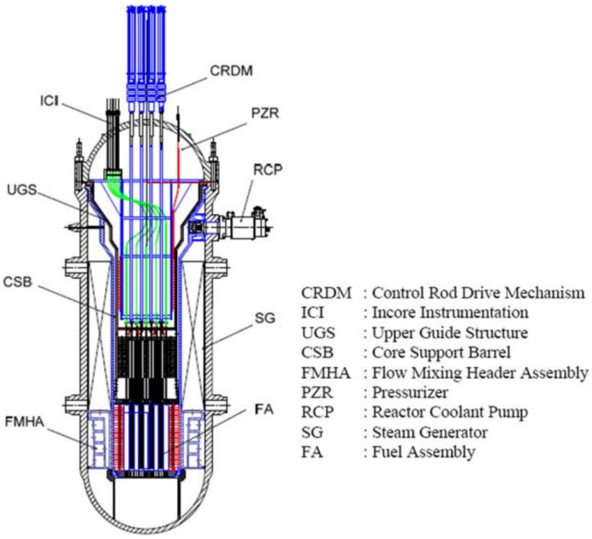

Fig. 6. SMART Reactor Assembly.

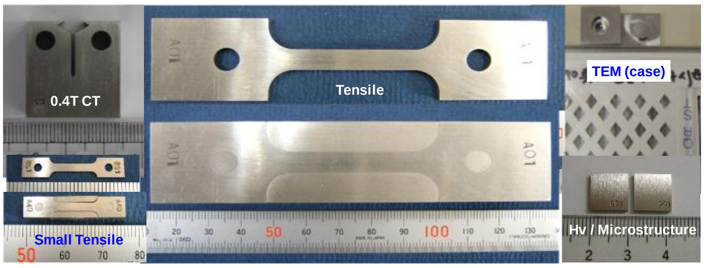

Fig. 7. The specimens stacked with spacers in the SMART irradiation capsule.

The first irradiation capsule of 09M-02K was designed, fabricated and irradiated for an evaluation of the neutron irradiation properties of Alloy 690. The capsule was designed to be irradiated at 250°C in the OR5 test hole according to a user's requirements [15]. In-reactor safety of the capsule was discussed, and it was proven to be safe for the irradiation tests of Alloy 690 in the OR5 test hole of HANARO [16]. The irradiation temperature of the specimens was preliminarily analyzed by using the GENGTC and ANSYS codes. The capsule was composed of five stages having many kinds of specimens and an independent electric heater at each stage. 14 thermocouples and 5 sets of Ni-Ti-Fe neutron fluence monitors were installed in the capsule to measure the irradiation test temperature and the fast neutron fluence of the specimens, respectively.

The first irradiation capsule of 09M-02K was successfully designed and safely irradiated in the OR5 test hole of the HANARO with a 30 MW reactor output for one cycle (about 25.5 days) as shown in Figure 8. During an irradiation test, the temperatures of the specimens were measured and monitored with thermocouples installed in the capsule. The irradiation temperature of the specimens was maintained in a range of 250±10°C. A fast neutron fluence of the specimens was obtained in the range of 1.77–3.76×10^{19} cm^{-2} (E>1.0 MeV). The amount of neutron fluence of the specimens was calculated by MCNP code and will be compared to the obtained value from the irradiated fluence monitors.

Based on the successful test of the first capsule, the second capsule of 10M-01K was designed, fabricated and irradiated for an evaluation of the neutron irradiation properties of Alloy 690. The capsule was designed to be irradiated at 250°C in the CT test hole for a higher neutron fluence than the first capsule. The second irradiation capsule of 10M-01K was successfully designed and safely irradiated in the CT test hole of the HANARO with a 30 MW reactor output for one cycle (about 25.5 days) as shown in Figure 8. The irradiation temperature of the specimens was maintained in a range of 250±10°C. A fast neutron fluence of the specimens was calculated to the range of 1.37–3.17×10^{20} cm^{-2} (E>1.0 MeV) by the MCNP code.

The irradiated capsule is currently being maintained in the reactor water pool for radioactivity cooling. After cooling, the main body of the capsule will be cut off at the bottom of the protection tube with a cutting system, and it will be transported to the IMEF. The irradiated specimens will be tested to evaluate the irradiation performance of the Alloy 690 in the IMEF hot cell. To obtain the neutron fluence of 1x10^{21} cm^{-2} (E>1.0 MeV), a third irradiation capsule is under preparation for an irradiation test in the CT test hole of HANARO. Irradiation tests will be performed by 2011 according to the SMART R&D schedule, which was decided by the Korean government.

The obtained material properties will be very valuable to acquire the standard design approval of SMART from the Korean licensing authority.

Fig. 8. Reactor cores during the irradiation tests of SMART Capsules.

3.4. Development of advanced irradiation technologies

Based on the accumulated experience and users' sophisticated requirements, several advances in material capsule technologies were made recently for more precise control and analysis of neutron irradiation effects at HANARO. New instrumented capsule technologies for more precise control of the irradiation temperature and fluence of a specimen, irrespective of reactor operation, have been developed. OR/IP capsule technologies for an irradiation test in the HANARO reactor, as well as the OR and IP test holes with a relatively lower neutron flux than the CT and IR test holes, have also been developed and successfully utilized.

At present, a strategic irradiation programme at HANARO will place more emphasis on a special purpose capsule system by focusing on specific materials or fuels for a next generation power reactor. These development programmes are closely connected with the national R&D program in Korea on nuclear reactors and nuclear fuel cycle technology such as the GEN-IV and fusion reactor programmes. Among the six GEN-IV systems, Korea has participated in the VHTR and SFR R&D programs and provisionally participated in the SCWR programme. These new advanced nuclear reactor systems inevitably require higher irradiation test parameters than the conventional irradiation tests. The development of a high temperature irradiation technology up to 1000°C is under development by introducing a double thermal media structure. A new capsule with a double thermal media structure such as Al-Ti and Al-graphite was tested, and the temperature of the specimens successfully reached 700°C. Precise instrumentation and welding technologies for a higher irradiation temperature are also under development. The schedule of these development programs is closely connected to the national research and development program in Korea on nuclear reactors and nuclear fuel cycle technology.

4. CONCLUSIONS

A HANARO irradiation capsule system has been developed and is actively being utilized for irradiation testing of fuels and materials of commercially operating nuclear reactors in Korea. Although HANARO has been applied on several commercially based irradiation tests, most irradiation tests have been related to national R&D projects relevant to present nuclear power reactors. Based on the accumulated experience and the users' sophisticated requirements, HANARO has recently started new support of R&D relevant to the future nuclear systems of SMART and VHTR. The SMART system that the Korean government recently decided to develop as one of its new growth engines is one of the most advanced SMRs in the world. The VHTR, with participation from Korea, is one of the leading reactor designs for the next generation of nuclear energy systems to meet the world's future energy needs. The development of future nuclear systems is one of the most important projects planned by the Korean government. To effectively support R&D relevant to future nuclear systems, the development of advanced irradiation technologies concerning high temperature irradiation test is being preferentially developed in HANARO. To extend the utilization of HANARO limited to the domestic applications, HANARO is considering international cooperation.

5. ACKNOWLEDGEMENT

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