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The status and prospects of the irradiation tests at HANARO

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1. Introduction

The capsule is a device which can evaluate the irradiation effect of nuclear materials and fuels using a research reactor because it can reproduce the environment of nuclear power plants (NPP) and accelerate to reach the End-Of-Life (EOL) condition. Recently the integrity assessment of NPP and the extension of lifetime are being considered as important issue, and so the irradiation tests for the structural materials and fuels of NPP should necessarily be conducted. And, the capability of irradiation test is important because Korea participates in developing SFR and VHTR while the development of future nuclear systems is going on to obtain new energy sources all over the world. To effectively support the R&D for new nuclear systems at HANARO, the advanced irradiation technologies such as high-temperature irradiation, instrumentation, and long-term irradiation are being developed. In addition, the researches on the irradiation characteristics of super-conductor materials and new chemical materials are being progressed as a part of fundamental research.

2. Irradiation devices at HANARO

Irradiation tests of the materials at HANARO have been conducted usually using the standard capsule at temperaturas of about 300℃, at which the RPV materials of PWR are operating. As the reactors planned in the Gen-IV program will be operating under higher temperature and neutron flux, the temperature and flux at the requirement are gradually raising. The operating temperatures of the VHTR and SFR are expected to be about 1,000℃ and 550℃, respectively, which are much higher than the irradiation temperature of material capsules tested at HANARO up to recently. On the other hand, KAERI is participating in the development of new research reactors, i.e., the Ki-Jang of Korea and the JRTR of Jordan. Materials used for the reflectors are graphite, beryllium, and zircaloy. They are operating at the low temperature of less than 100℃, and thus the irradiation data at low temperature are necessary. In this way, the requirements for irradiation temperature have been variously changed according to the environments of specimens. The capsules at HANARO have been developed in the other forms according to the temperature requirements. They are classified as the standard capsule, the high-temperature capsule, and the low-temperature capsule, which are used respectively for irradiation at temperatures of 200~500℃, lower than 100℃, and higher than 700℃. In addition, the various irradiation facilities such as rabbit, small capsule, loop, and target are used according to volume of specimens, the required fluences. Analyses for the reactivity effect, neutron flux, and gamma heating necessary for capsule design are performed mainly by MCNP code. The irradiation temperature is analyzed using GENGTC and ANSYS codes.

The standard capsule shown in Figure 1 is mostly used for irradiation at temperatures of 200–500℃ at which PWR is operating.

Figure 1. Standard capsule

The concept of the low-temperature capsule is a direct contact with the coolant to lower the temperature of specimen. It is made that the reactor coolant pass through the bottom hole, as shown in Figure 2. It is used for irradiation of the reflector materials of the research reactor, such as graphite, beryllium, and zircaloy-4.

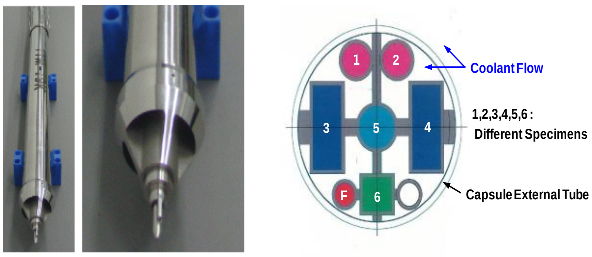

Figure 2. Low-temperature capsule

The high-temperature irradiation capsule has been developed as a concept with double thermal media, as shown in Figure 3. This is being developed to use for irradiation of VHTR material.

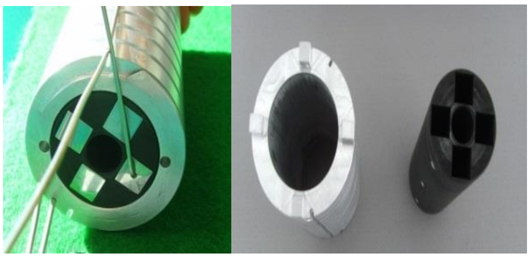

Figure 3. Structure of double thermal media

In addition, various types of small capsules such as rabbit, target have been developed as in Figure 4. These are used for non-instrumented irradiation of small amount of material and fuel as well as NAA and RI production.

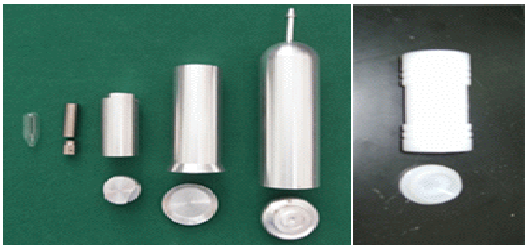

Figure 4. Small capsules

3. Recent Utilization of Irradiation Capsules

As the integrity assessment and lifetime extension of NPP are posing a big social issue around the world after Fukushima accident, the irradiation data for structural materials and nuclear fuels for NPP are indispensable and some are urgently required in Korea. Because the future nuclear energy systems are being developed as a method to get the new energy source worldwide and Korea participates in the development of SFR and VHTR, the irradiation capabilities are emerging as an important issue. Recently, the irradiation tests for research reactor materials and RPV materials of power plants have been finished at HANARO. And also, the irradiation tests for VHTR fuel and Zirlo fuel cladding material were conducted in the first half of the year. From the end of 2014, the fusion reactor materials, mortar concrete as well as Si and SiC etc. will be irradiated. U-Mo fuel and SFR fuel, the up-grade of PWR fuel are planned to be irradiated. In addition, the instruments such LVDT and SPND will be irradiated for long-running use at high temperature. The current status and the future plan of irradiation tests at HANARO are shown in the Figure 5.

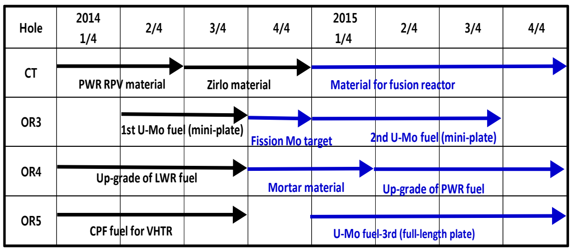

Figure 5. Plan of irradiation tests at HANARO

3.1 High-dose irradiation of PWR RPV steel

The continued utilization of nuclear energy systems for worldwide base load electricity offers a number of materials research challenges. One of the major degradation issues for reactor pressure vessel (RPV) steels is embrittlement associated with hardening from radiation induced solute-defect clusters. However, the effects of high-dose, long-term operation lifetimes and irradiation flux on hardening and embrittlement of RPV steel are now well-known worldwide. It is needed to obtain data from domestic RPV steel after high-dose irradiation for the potential extension of reactor operation licensing of nuclear power plants beyond their initial term. The specimens are the archive material of SA 508-Cr.3 RPV steel. 58 specimens for tension, fracture toughness and Charpy impact testing were inserted in the capsule and irradiated at fluence up to 5.51×10^{19} (n/cm^2) (E>1.0 MeV). The irradiation temperature was controlled at 290±10℃. The test results for irradiated RPV steel will be compared with the results for pre-irradiated RPV steel.

3.2 Irradiation of RR materials

Recently, Korea has much concern for development and export of RR because it succeeded to export a RR to Jordan and began to construct a new RR called KJRR. However, the irradiation data for structural materials such as graphite [1], beryllium and zircaloy-4 are very difficult to find, and so they are being the important issues for design and license of RR. Especially, it is very difficult to obtain the irradiation data at low temperature below 100℃ at which RR is operating. Accordingly, it is required to produce the irradiation data for RR materials for ourselves at this time. The irradiation tests were recently finished. Figure 6 shows the specimen temperatures during irradiation. The irradiation growth was observed and measured for Be, and Zr-4 in the hot cell.

3.3 Irradiation of reinforced concrete or mortar

Reinforced concrete (RC) is a composite material in which the relative low tensile strength and ductility is counteracted by steel bars as reinforcement in tensile regions. It is commonly used as a biological shield and as a load carrying support for a reactor vessel and, if any, changes in the mechanical properties can be particular significant for long-term irradiation. This study aims to investigate the response of a beam member in the RC design for long-term irradiation that RC supporting the reactor vessel may experience [2]. The RC structure close to the reactor vessel was considered as the most critical in estimating that the total fluence for 40 years becomes about 10^{14} to 10^{18} n/cm^2. The moment-curvature response of an RC beam was investigated with the maximum neutron fluence up to 10^{19} n/cm^2 and it shows twice the increase in ultimate strength, which is mainly contributed from the increased yield stress of mild steel. The RC beam response became so brittle that it may fail without large deformation as a warning. The same observation can be equally applied to other RC designs such as the column, slab, and foundation. Furthermore, the current investigation will be extended to a structural integrity evaluation of aging NPPs.

3.4 Irradiation the mini plate type U-7Mo fuel for research reactor

U–Mo particle dispersion in an aluminum matrix, termed as U–Mo/Al hereafter, has been under development for use at high power research reactors because of its potential for high U-density. Interaction layer growth and occasional porosity formation in the matrix, however, has hampered its qualification [3]. An excessive interaction layer growth and pore formation in the interaction layers were observed in this fuel. Performance of the plate type U–7wt.%Mo dispersed in an Al–5wt.%Si alloy matrix, is being investigated through irradiation tests. These tests will be performed three times as the burn-up rate of 45%, 65% and 85% respectively. Currently, the 1st mini-plate type of U-Mo fuel is being irradiated for 5 months. 2nd and 3rd irradiation will be conducted after the end of this year. Post-irradiation metallographic features and swelling etc. will be investigated after irradiation

3.5 Irradiation of coated particle fuel

TRISO (tri-structural isotropic) coated particle fuel has been studied extensively around the world. It consists of a microspheric UO_2 fuel kernel surrounded by four coated layers; buffer, IP_yC (inner pyrolytic carbon), SiC and OP_yC (outer pyrolytic carbon). Development of fuel is being progressed favorably for use in the VHTR which will be developed in Korea. The first irradiation test of the coated particle fuel has been recently finished. The capsule was loaded in OR5 hole, which has a nominal fast neutron flux of 1.2~1.5x10^{13} n/cm^2 s and a thermal neutron flux 2.0~2.5x10^{14} n/cm^2 s.

3.6 Irradiation of Si and SiC etc.

The basic researches for Si and Sic etc. are going on mainly at universities. The microwave losses of single crystalline Si and 4H-SiC are being studied because it is one of the most important physical parameters with regard to the applicability of microwave devices. The loss tangent (tangent δ) of 4H-SiC appeared to increase significantly when the specimen was irradiated with thermal neutrons [4]. On the other hand, SiC has attracted interests in radiation research due to the potential to be used at devices operating in high power and high temperature space application as well as neutron detectors. These applications may involve the integration of semiconductor devices into satellite systems in the earth orbit, so as to operate for several years in a radiation environment with widely varying temperatures. After neutron irradiation, a slight positive shift in the threshold voltage has been observed, which is attributed to the resistivity reduction.

3.7 Annual trend of utilization

The national research and development program on nuclear technology in Korea requires the irradiation tests of various materials at HANARO. The main activities of the capsule utilization programs are focused on the in-reactor material tests, safety-related research, and fundamental material research. 11,000 specimens from research institutes, nuclear industry companies, and universities have been irradiated for 122,000 hours using capsules and rabbit etc. since 1995. Figure 6 and 7 show the increasing trends of the irradiation works.

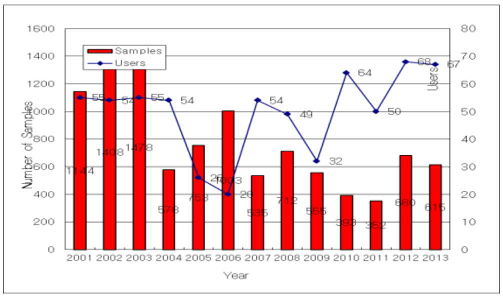

Figure 6. Irradiation samples and users at HANARO

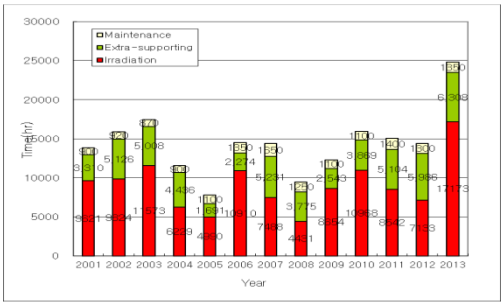

Figure 7. Time used for irradiation work at HANARO

4. Conclusion

Korea is conducting R&D programs relevant to new nuclear systems including research reactor, future nuclear system such as VHTR, SFR and fusion reactor system. In addition, research on the irradiation characteristics of super-conductor materials and new electronic materials is being conducted as a part of fundamental research. Irradiation tests in HANARO are mostly related to the R&D relevant to the ageing management and safety evaluation of NPP and development of the future nuclear system and production of design data of research reactor. The HANARO irradiation capsule system has been developed and actively utilized for the irradiation testing of fuels and materials. The irradiation tests of materials up to the present have been performed usually at temperatures below 300℃, at which the RPV of PWR materials is being operated. As the irradiation tests of the materials and fuels for a Gen-IV nuclear system are recently required and the development of new research reactors is going on, the capsules for high- and low-temperature irradiation are being developed at HANARO. The capsules are being developed to cover the overall range of irradiation conditions.

Acknowledgements

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REFERENCES

[1] Y.M.Lee, et. al., “A study on the irradiated strength and stress evaluation of nuclear graphite material”, Nuclear Engineering and Design 269, 193-199 (2014)

[2] K. William, et. al., “A review of the effects of radiation on microstructure and properties of concrete used in nuclear power plants”, U.S. NRC, NUREG/CR-7171, 2013

[3] G.L. Hofman, et. al., “Proceeding of the 2003 RERTR International Meeting” Chicago, IL, USA Oct. 5-10 (2003)

[4] H.S. Jung, et. al., “Microwave losses of undoped n-type Silicon and undoped 4H-SiC single crystals at cryogenic temperatures” Electron Mater. Lett. Col 0. pp 1-9 (2014)