Technical Issues Occurred during an Out-Pile Testing of HANARO Long-Term Irradiation Capsule

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1. Introduction

The High Flux Advanced Neutron Application Reactor (HANARO) has been operating as a platform for basic nuclear research in Korea, and the functions of its systems have been improved continuously since its first criticality in February 1995. Various neutron irradiation facilities such as rabbit irradiation facilities, loop facilities, and capsule irradiation facilities for irradiation tests of nuclear materials and fuels have been developed at HANARO. Among the irradiation facilities, the capsule is the most useful device for coping with the various test requirements at HANARO. Irradiation capsules have been developed and actively utilized for the irradiation tests requested by numerous users to support the national research and development programs on nuclear reactors and nuclear fuel cycle technology in Korea [1,2]. Capsule technology was initially developed for irradiation testing under a commercial reactor operation environment. Mainly, irradiation testing of the capsules has been performed at around 300℃ within four reactor operation cycles (equivalent to 1.5 dpa) at HANARO.

Based on the accumulated experience as well as the sophisticated requirements of users, HANARO has recently been required to support national R&D projects requiring a higher neutron fluence. To scope the user requirements for a higher neutron irradiation fluence up to 10 dpa, several efforts using an instrumented capsule have been conducted at HANARO [3,4].

In this paper, the progress of development of long-term testing capsule at HANARO is described and several technical issues occurred during an out-pile testing of the capsule are discussed.

2. Development of Long-Term Irradiation Capsule for a Higher dpa

As future nuclear systems are demanding higher neutron fluence irradiation than present nuclear power plants [5], it is necessary to develop a new irradiation capsule for a longer irradiation testing at HANARO. However, as the irradiation capsule is exposed to a very high pressure coolant flow during irradiation testing, it is known to be vulnerable to vibration-induced fatigue cracking [3]. Therefore, HANARO instrumented capsules had been limited to irradiation of four reactor operation cycles equivalent to 1.5 dpa. The long-term irradiation capsule technology has been developed stepwise. At first, a new capsule having several design improvements on material and welding method was suggested and successfully applied for the irradiation at HANARO at up to eight reactor operation cycles equivalent to 3 dpa [3].

Based on the stress analysis of the part during the irradiation testing, another optimized design of the rod tip of the capsule was made for 5 dpa irradiation, as shown in Fig. 1. The design of the capsule was optimized to suppress the applied stress on the vulnerable part of the capsule [4].

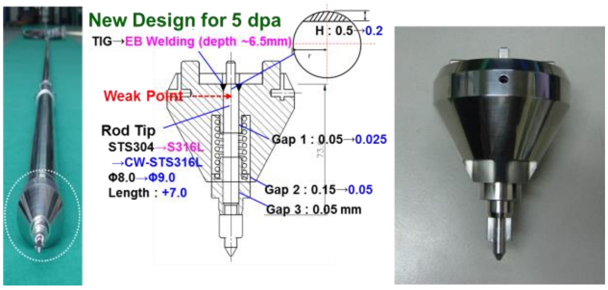

Fig. 1. The optimized design of the capsule bottom part for 5 dpa irradiation

The safety of the new capsule should be fully checked before irradiation testing. Out-pile performance and endurance testing was performed before HANARO irradiation testing. The new capsule was out-pile tested safely up to 450 days equivalent to 5 dpa irradiation in the reactor, as shown in Fig. 2. The design and out-pile testing results were submitted to the 'Reactor Safety Review Committee of HANARO' and approved for an irradiation testing at HANARO. The new capsule will be actively utilized for the irradiation of materials of future nuclear systems including small & medium power reactor requiring a harsh irradiation environment.

Fig. 2. Photo celebrating the development of HANARO long-term irradiation capsule (5 dpa)

The optimized design of the capsule is under testing to evaluate a possibility of irradiation up to 10 dpa. The capsule has been safely out-pile tested for 23 operation cycles (690 days) equivalent to 7.6 dpa irradiation in HANARO by this August, as shown in Fig. 3.

Fig. 3. New designed capsule out-pile tested for 23 cycles (690 days)

3. Technical Issues Occurred during an Out-Pile Testing

During the out-pile testing of the long-term irradiation capsule, several technical issues, such as 1) possibility of fatigue failure of the capsule, 2) possibility of damage of the HANARO system, 3) compatibility of the capsule control system were suggested, design-improved, and have been verified.

As the irradiation capsule is exposed to a very high pressure coolant flow of 19.6 kg/s during irradiation testing, the bottom rod tip of the capsule has been known to be vulnerable to vibration induced fatigue failure [3]. The vibration behavior of the capsule in the single channel out-pile test loop was measured using a laser vibrometer. The out-pile test loop was evaluated to be valid for verifying an integrity of the HANARO irradiation capsule [6]. The out-pile testing was conservatively performed under 110% accelerated conditions of the reactor coolant flow amount. Based on the obtained root mean square (RMS) of vibration amplitude of 120.42 μm at a point 1.42m above the rod tip was evaluated to have the highest stress of 124.6 MPa at a 15mm position from the end of the rod tip using the ANSYS code [4]. Considering the negligible stresses by the guide spring and welding residual stress, and the maximal stress of 102.9 MPa by the upward flowing coolant, the applied stress on the rod tip is much less than the fatigue strength of 348 MPa of the part. The fatigue strength of a material is known to be a near about half the value of strength of the material [7].

The magnitude of vibration of the capsule of 120.42 μm is satisfying the vibration displacement design criteria of 300μm of HANARO. Therefore, the only contacting point of the capsule with HANARO is the receptacle part of the reactor guide tube. The part was examined to be safe without any abnormal signs of fretting and fatigue after 15 operation cycles of out-pile testing.

During the out-pile testing, the failure of the top guide spring of the capsule was observed, as shown in Fig. 4. Based on the analysis of the failed parts, a new design of the top guide spring of the capsule was made for long-term irradiation testing of up to 10 dpa, as shown in Fig. 5. 10 dpa is equivalent to irradiation testing for 30 cycles at HANARO.

Fig. 4. The failure of the top guide spring during an out-pile testing of the long-term irradiation capsule

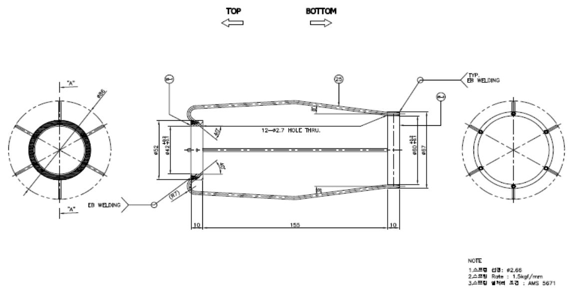

Fig. 5. The new design of the top guide spring of the long-term irradiation capsule

Because of an abnormal temperature variation of the specimens during long-term irradiation testing, a new capsule control system having two gas control lines instead of the previous single gas line was introduced at HANARO for a precise temperature control of the specimens during irradiation testing, as shown in Fig. 6 [8]. The compatibility of the system for the long-term irradiation testing up to 10 dpa still needs more qualifying irradiation testing at HANARO.

Fig. 6. A new capsule control system (VHC-M4) installed at HANARO for a long-term irradiation

4. Summary

Based on the user requirements of future nuclear systems demanding higher neutron fluence irradiation testing than present nuclear power systems, a new capsule for a long-term irradiation testing of up to 10 dpa in HANARO was prepared and out-pile tested. During the out-pile testing of the long-term irradiation capsule, several technical issues, such as 1) possibility of fatigue failure of the capsule, 2) possibility of damage of the HANARO system, 3) compatibility of the capsule control system, were suggested and design-improved. The new capsule should be strictly verified before an application in HANARO.

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