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Ageing Management Program for Reactor Components in HANARO

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Abstract

The HANARO, an open-tank-in-pool type research reactor of 30MWth power in Korea, has operated for 8 years since its initial criticality in February of 1995. The reactor power has been gradually increased to 24 MWth through the service period. Therefore the reactor age is very young from the viewpoint of the ageing effect on the reactor structure and components by neutron irradiation considering the expected reactor lifetime. But, we have a few programs to manage the ageing from the aspect of design lifetime of reactor components. This paper summarizes the overall progress and plan for the ageing management for the reactor components including lifetime extension and design improvement, remote measurements and in-service inspections.

The shutoff units and control absorber units have aged more rapidly than other structures or components because the number of rod drop cycles was higher than expected at the design stage. The system commissioning tests, periodic performance tests, and weekly operation for the stable supply of medical radioisotopes overriding the normal cycle operation have contributed to the high frequency of rod drop. Therefore, we have instituted a program to extend the lifetime of the shutoff units and the control absorber units. This program includes an endurance test to verify the performance for the extended number of drops and the management of shutdown methods to minimize the drop cycles for both the shutoff units and the control absorber units. The program also includes the design improvement of the damper mechanism of the control absorber units to reduce the impact force caused by rod drop.

The inner shell of the reflector vessel surrounding the core is the most critical part from the viewpoint of neutron irradiation. The periodic measurement of the dimensional change in the vertical straightness of the inner shell is considered as one of the in-service inspections. We developed a few tools and verified the performance to measure the straightness of the inner shell. We are developing more remote tools for the removal of the reactor components that interfere with the measurement work.

The wear of fuel channels is also one of the interesting components being monitored regarding

flow-induced vibration of the fuel assemblies.

1. Introduction

1.1 Descriptions of Reactor Components in Hanaro

The reactor is installed vertically in a pool of demineralized light water. The reactor structure is composed of a stainless steel plenum and grid plate, a zircaloy reflector vessel, an aluminum chimney, and zircaloy flow tubes. The reflector vessel is a toroidal tank whose central channel encloses the array of flow tubes. It is also penetrated vertically by many irradiation sites and experimental sites and horizontally by the beam tubes. The chimney is a hexagonal duct extending above the core, with two large inclined pipes for primary cooling system outlets on its sides. The flow tubes are secured to the grid plate. There are 23 hexagonal flow tubes and 8 cylindrical ones. Figure 1 shows in-pool structures including the reactor, shutoff rods, control rods, and beam tubes of HANARO.

On each cylindrical flow tube, a tubular hafnium neutron-absorber "rod" slides up and down, inside the space enclosed by the adjacent hexagonal tubes. A shroud tube extends above the flow tube to enclose and guide the rod. It also shields the absorber rod from the PCS flow exiting the core through the outlet nozzles. Four rods are Control Absorber Rods (CAR), and four are Shutoff Rods (SOR). Each absorber rod is suspended from an offset, track-guided carriage via a perforated support tube which has a hollow swivel joint called a ‘gimbal joint’ at each end. The absorber rods are identical for SOR and CAR and surround a circular flow tube, which in turn encloses an 18-element fuel bundle. The track is mounted inside the chimney wall. Generous mechanical clearances of 0.5 mm were set on all sliding surfaces to preclude jamming due to floating particles, or absorber and flow tube warp due to irradiation.

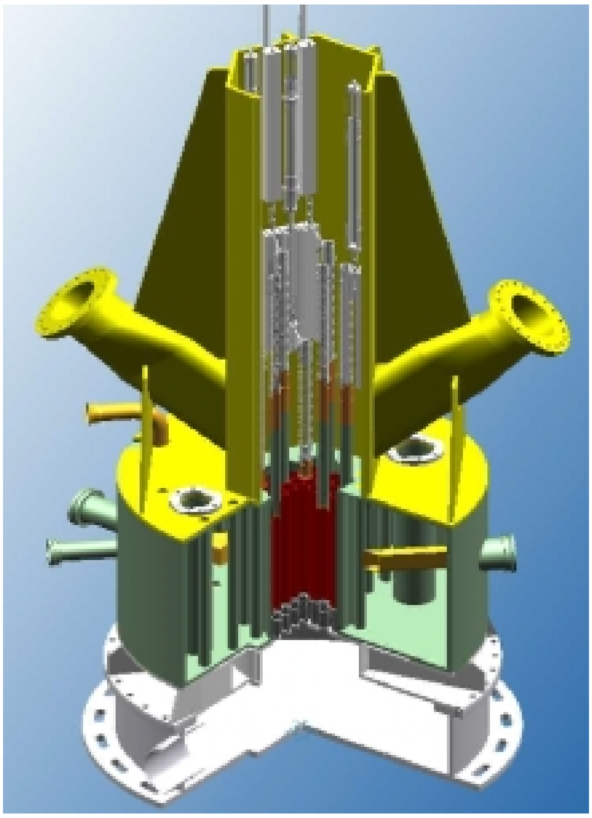

Figure 1. Reactor structure and internals of HANARO

Each SOR is actuated by a directly linked hydraulic cylinder on the chimney, which is pressurized by a hydraulic pump. The rod is released to drop by gravity, when triplicate solenoid valves ("dump valves") are opened to vent the cylinder. Pressure switches connected to the cylinder body tapings indicate up and down positions. The valves, switches and electric motor-powered pump are mounted at the pool top.

CARs are actuated by electric stepping motor-powered ball-screw drives at the pool top. The rod's lower carriage is linked to a middle carriage at the chimney top (i.e., in place of the SOR's cylinder), which is linked in turn to the drive through a long, angled tie-rod. For emergencies, an electro-magnet coupling can release the rod and carriages from the ball nut and they drop into the core. The ball screw and electro-magnet are enclosed in a dry-well which travels with the carriage.

1.2 Ageing Management of Reactor Components

HANARO has served for 9 years including the system-commissioning period of about one year after installation in 1993. The HANARO is rather young, but a program to guarantee its long-term performance is ongoing in addition to the preventive maintenance and inspections. Among them, the overall program of ageing management and relevant experience for the reactor components is summarized in this paper. Followings are the key items being managed from the ageing point of view based on the operation experience.

(1) Lifetime of shutoff units and control absorber units
(2) Dimensional change of inner shell of reactor core by irradiation effect
(3) Wear of fuel channels

2. Lifetime of Shutoff Units and Control Absorber Units

2.1 History of Operation and Maintenance

The performance of the shutoff units and control absorber units has been monitored through the commissioning and periodic performance tests. Wear, alignment change and deformation of the components cause the change of drop and withdrawal times of shutoff rods and control rods. No considerable deterioration has been found so far in the performance of shutoff units and control absorber units. There were a few replacements of off-the-self items such as a stepping motor and switches. One bearing of the ball screw drive in the dry-well of the control absorber drive mechanism was replaced because of a break of the ball seal. For 9 years operation, the mechanical items such as the absorber rods and components of driving mechanism that are located under water, have never been replaced or repaired.

There is one pair of track/carriage on each shutoff unit, and three pairs of track/carriage on each control absorber unit. The configurations of those tracks/carriages are the same or similar to each other. There is no detectable wear marks so far on such components being checked by visual inspection of the upper track/carriage on the CAR drive assembly, which can be easily removed from the reactor pool for dismantling. The biggest concern regarding ageing is the high number of drop cycles of SOR and CAR for a short period (9 years) of operation. During the design stage, the endurance of the current shutoff units and control absorber units was verified for drop cycles of 1,500 and 1400, respectively, assuming these to be high enough numbers for the life-time of the reactor. The experienced number of drops, however, as of the end of 2002 reached about 1000 (67% of lifetime) and 500(36% of lifetime), respectively, which are much higher than the expected numbers in the design stage. The high frequency of drop was caused by the drop tests for the system calibration during the commissioning stage and periodic performance tests including reactivity worth measurements. The weekly operation for the stable supply of medical radioisotopes overriding the normal cycle operation has partly contributed to the high frequency. It is certain that the actual number of drops will reach the verified numbers far before the end of the reactor life. Figure 2 shows the operation history as a percentage of the lifetime of the shutoff units and control absorber units to compare it with the reactor lifetime from the viewpoint of ageing by neutron irradiation. It is thought that the high cycles of impact loads by the drop of the shutoff rods and control absorber rods are of more concern from the safety point of view rather than by the wear of the moving system which can be detected by the change of the drop performance.

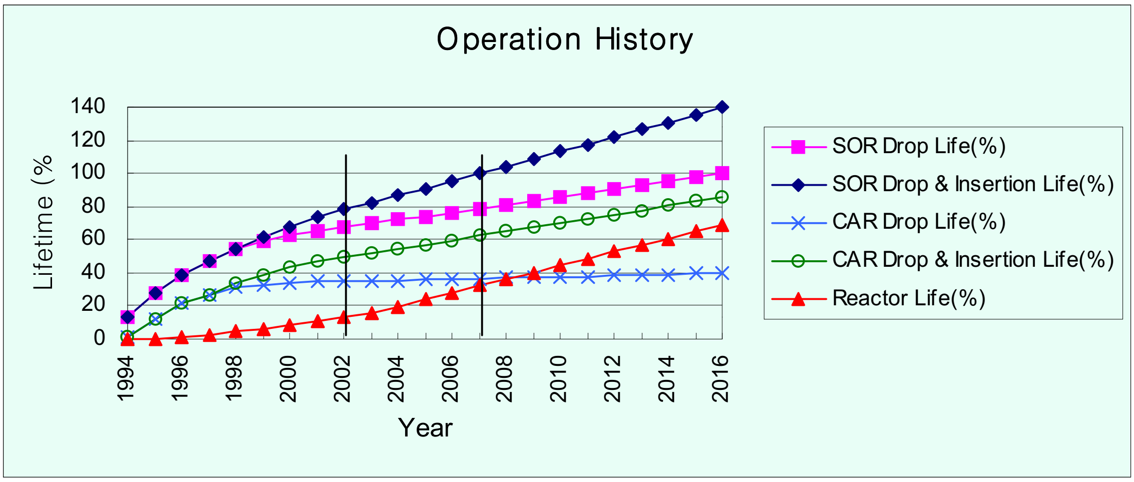

Figure 2. Operation History of Shutoff and Control Absorber Units

2.2 Program for Lifetime Extension

The shutoff rods(SOR) and control absorber rods(CAR) drop by gravity within 1.5 seconds and 0.8 seconds respectively in the case of a reactor trip in HANARO. The drops for the short times cause high impact loads on the system even though the loads are under the allowable limits. From 1998, therefore, we have been operating the shutoff units and control absorber units to minimize the increase of drop cycles of the absorber rods. During the scheduled shutdown we turn the actuating pumps off for slow insertion of the SOR instead of the drop by gravity. Slow insertion of a SOR takes about 7 seconds, which induces much less impact force than the case of drop by gravity. The CAR is inserted to the core by motor drive instead of gravity drop. Figure 1 shows how much we are retarding the increase of the drop cycles by the slow insertion instead of unnecessary rapid drop.

Even though we control the drop cycles by the change of shutdown method, it is certain that the number of drops will reach the verified numbers far before the end of the reactor life. HANARO is keeping each spare assembly for the shutoff unit and the control absorber unit that was used for the endurance test during the design verification stage. These will be tested again to verify the integrity and performance for an extended number of drops, about 4000 cycles. For the test we have constructed a test facility which has a half core configuration with full scale dimensions consisting of 13 hexagonal flow tubes, 4 cylindrical flow tubes and 3 outer-core flow tubes as shown in figure 3. The cross sections of the inlet plenum, core and outlet chimney is a half-shape(left-half in figure 3) to acquire a flow pattern similar to that in the reactor. We are performing a system-commissioning test of the primary flow system constructed in 2002.

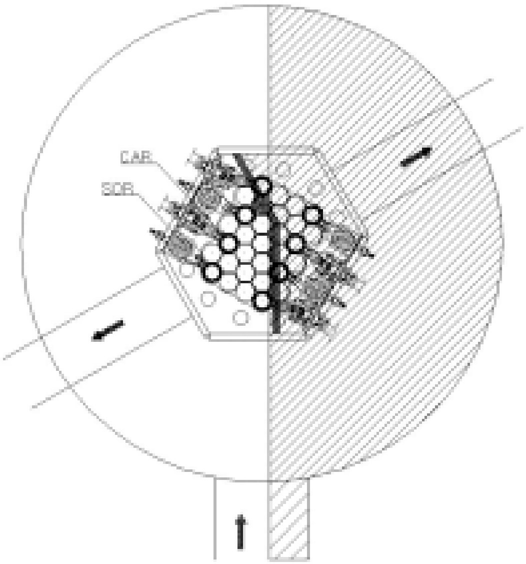

Figure 3. Concept of Half-core Test Facility

The test facility will be used not only for the endurance tests of the shutoff and control absorber units but also for a performance test, before application to the reactor, of new production units for shutoff and control absorber units, irradiation facilities, reactor control computer with design change, or experimental equipment, and for vibration and endurance tests for the design-changed fuel assemblies. The facility will also be useful for performance tests of newly developed tools for inspection and maintenance of the reactor, rehearsal of remote works, training of operators accessing the core, etc.

The CAR drops faster than the SOR. Even though there is no considerable change of drop time, we are interested in the impact load during the drop for the short period. We are checking the damping performance of the CAR drive assembly from 2001 by measuring the acceleration amplitudes during the CAR drop. This will help us to learn what is changing in the control absorber units from the viewpoint of wear or deformation of the components that affect the damping and impact force on the components. The 2nd measurement will be done in 2003 to compare the results with the first measurement. Regardless of the measurement results for the impact loads, we are performing various tests to improve the shock-absorbing damper. This test is on going using the spare unit installed at a test bracket in the service pool.

3. In-service Inspections

3.1 Visual Inspection of In-pool Structure

The visual inspection is carried out every five years with an underwater camera for all surfaces of the reactor structure, reactivity control units, beam tubes to examine the surface condition of the components for corrosion, erosion, wear, crack, and fastening status of wire-locking on large sized bolts. The first visual inspection was successfully completed in October 2000 without any abnormal findings. All inspections could be done at the top of reactor pool, with the normal level of the pool water, using an underwater camera and manipulator. It is possible, with the camera & manipulator assembly developed, to access in any direction by rotating of manipulator shaft and adjusting of head-angle up to +/-180 degrees, in addition to focus control.

3.2 Dimensional Inspection of Inner Shell of Reactor Core

Through a preliminary review, it was found that the inner shell of the reflector vessel surrounding the core is the most critical part from the viewpoint of neutron irradiation. The inner shell serves as a boundary separating the heavy water reflector from the core region, and should maintain necessary clearance with the adjacent core components such as flow tubes and absorber rods. According to creep and growth analysis results the inner shell is supposed to be deformed inward as shown in figure 4, at the middle of the wide side of the shell, due to the combined effect of neutron irradiation and stress.

Figure 4. Deformation of Inner Shell

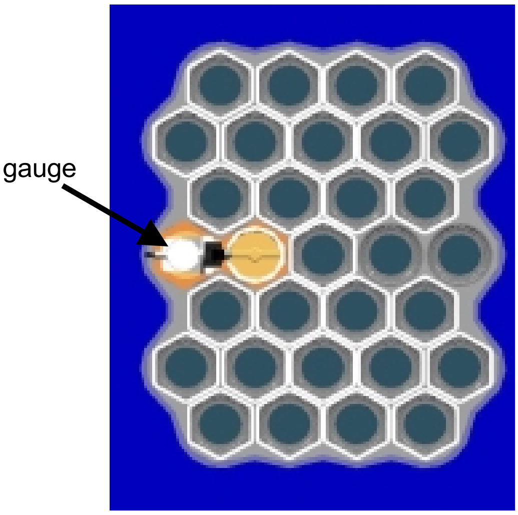

Figure 5. Measurement of Inner Shell

The original safety analysis report shows that its safety margin is large enough but reconfirmation is needed. As a possible way of evaluating the ageing effect, a reassessment of the irradiation creep and growth combined with a physical follow-up for the dimensional change in its vertical straightness is considered as the first priority. To confirm the analysis validity and safe operation of the reactor, we developed technology and tools to remotely measure the straightness of the inner shell. Figure 5 shows the measurement concept of the inner shell with a special gauge. The performance and the accuracy of the measurement tools including the gauge have been verified through tests using a dummy inner shell. The accuracy of the measurement shows very good results with a maximum error of 0.02mm as shown in figure 6 and figure 7.

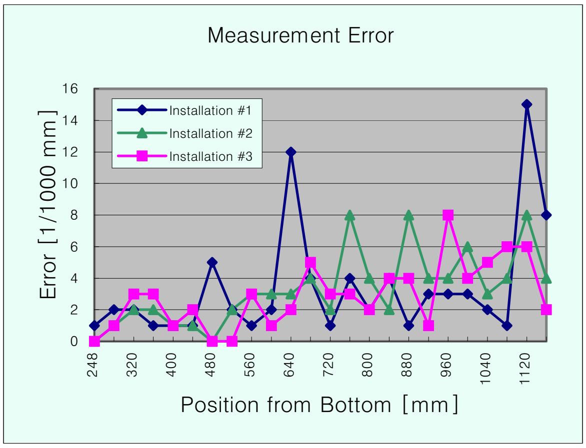

Figure 6. Measurement Error per Installation

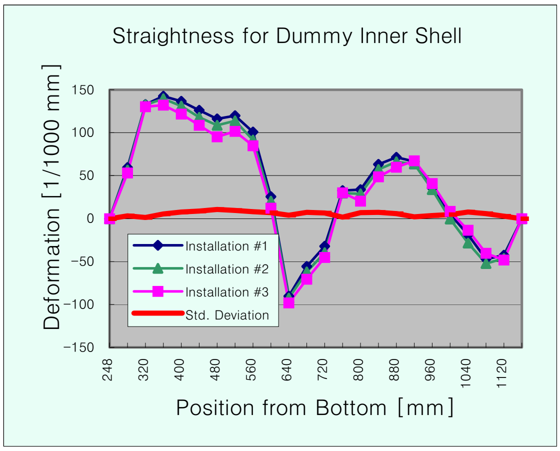

Figure 7. Measurement for Test Sample

To measure the inner shell dimension as shown in figure 5, a few flow tubes, absorber rods and guide tubes(called ‘shroud’) should be removed from the core to provide sufficient space for the gauge. In addition to the measuring tools, we have developed tools for the removal of flow tubes and shrouds. The tool for absorber rods is being developed. The straightness of the inner shell will be measured in the middle of 2003.

3.3 Dimensional Inspection of Reactor Components

The overall dimension and straightness of the flow tubes, which contain fuel assemblies and are replaceable, are being checked during refueling work. Regarding dimensional changes due to the irradiation effect on the components which are related to SOR/CAR movement, periodic inspections are required to check the functionality of the flow tubes, shrouds and absorber rods for the designated functions of SOR and CAR. The plan for dimensional inspection includes the measurement, every 10 years, of the diameter of the absorber rods (SOR/CAR), cylindrical flow tubes, and guide shrouds of SOR/CAR. In addition to the tools to remove the flow tubes and shrouds, an under-water storage rack was also developed and is ready for use for the storage and inspection of various components removed from the reactor. Various special tools such as dial gauges and calipers are being developed for the remote measurement of these dimensions.

4. Wear Inspection of Fuel Channel

It has been observed that fuel assemblies have mechanical damage on some components due to the flow-induced vibration in the fuel channels. The matching area on the fuel channel is concerned to be worn. Therefore, the inspection for the inner surfaces of the fuel channels is required from the lifetime point of view. It is very difficult and time-consuming work to remove and install the fuel channels because of their inherent characteristics and the physical interference of other components in the reactor. Thus we developed special tools for the inspection of the fuel channels by using an impression material without the removal of the reactor components. The impression material is a compound to replicate the damage of the fuel channels within a limited working time considering the hardening time as well as radiation effect of the impression material.

The wear inspection was successfully accomplished for a few fuel channels. The result shows visible wear marks on a hexagonal fuel channel at the positions corresponding to fuel components such as the bottom guide arms and top springs. The wear damage is slight, 0.2mm depth maximum, in comparison with the thickness (1.6mm) of the fuel channel. No visible wear mark has been found in the cylindrical flow tubes so far. The wear inspection is being continued for all the remaining fuel channels to get the valuable results for estimation of the lifetime of the fuel channels. Also, we have another plan to inspect the deformation and/or wear of the spider pin of the fuel channel by using the impression material and proper tools.

5. Conclusions

This paper summarized the program for the activities being or to be done, from the ageing management point of view, for the HANARO reactor components based on results of operation and maintenance experiences for 9 years.

The shutoff units and control absorber units have aged more rapidly than other structures or components because the number of rod drop cycles was higher than expected at the design stage. Therefore, a program for the lifetime extension of shutoff units and control absorber units is on going. This program includes an endurance test to verify the performance for the extended number of drops and the management of shutdown methods to minimize the drop cycles. The program also includes the design improvement of the damper mechanism of the control absorber units to reduce the impact force caused by the rod drop.

As one of in-service inspection, the first visual inspection of in-pool structures was successfully performed in October 2000 without observing any abnormal conditions. We developed various tools and verified their performance to measure the straightness of the inner shell in 2003 to confirm the creep/growth analysis results for the inner shell of the reflector vessel as well as for the functionality check of SOR/CAR.

The wear of fuel channels is also one of the interesting inspections on going. We have developed proper tools and methods to mold the shape of the wear on flow tubes induced by fuel vibration. The wear of fuel channels is negligible upon measurement so far.