Preliminary start-up the HANARO after the Long-term Shut-down

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1. Introduction

HANARO was shut down due to seismic rehabilitation project after the Fukushima Daiichi accident for 3 years from 10th July 2014 to September 2017. After reached the first criticality of the HANARO in 1995, it was the first long-term shut down experience. During the normal operation schedule, HANARO has the neutron sources such as photoneutrons and delayed neutrons from fission products. However, there is not enough neutron sources in the core at present because of the long term shut down. Radioactive fission products have been almost decayed. In order to restart the HANARO, it is required to test the performance of the 6 ex-core neutron detectors (fission chamber) that are used for power monitoring. In addition, behaviors of neutrons should be checked during withdrawal of the SORs (Shut-Off Rods) and CARs (Control Absorber Rods).

In this paper, sub-critical tests of the HANARO with or without the external neutron source are presented. HANARO was approached the criticality and it was confirmed by reactor analysis using HANAFMS (HANARO Fuel Management System) and experimental methods.

2. Theory

2.1 Without External Neutron Source

Since 10th July 2014, SORs and CARs have been inserted in the core except surveillance test period. Due to the long term shut-down, there are not enough neutron sources such as photoneutrons that are generated by the reaction of high energy photon with D_2O in the reflector tank of HANARO. Therefore it was suspected that the reactor could not reach the criticality. However, since the mass of the fissile material in the core exceeds the critical mass, it is tried to reach the criticality of the reactor with the small amount of photoneutrons and spontaneous fission as start-up sources. [1, 2]. Table 1 shows the production rates of neutrons by spontaneous fission of the main nuclides in the fuel of HANARO [3].

Table I: Neutron Production by Spontaneous Fission

Nuclide	$T_{1/2}$ (Years)	$T_{1/2}$ (α-decay)	neutrons/s/g
U-235	1.8E17	6.8E08	8.0E-4
U-238	8.0E15	4.5E09	1.6E-2
Pu-239	5.5E05	2.4E04	3.0E-2
Pu-240	1.2E11	6.6E03	1.0E03

2.2 With External Neutron source

The neutron source of Am-Be which was used for TRIGA-MARK2 in 1972 is considered as the external neutron source for start-up of HANARO. The specifications of the Am-Be external neutron source is shown in Table 2.

Table 2: Specifications of Am-Be external Neutron Source

Item	Description
Neutron production rate	7E6 n/s/-g(Am)
Average Energy	4 Mev
Activity of Am	3 Ci
Intensity	6.6E6 n/s

3. Methods and Results

3.1Fission Chamber and CIC test

For the performance test of the neutron detectors of HANARO, the Am-Be neutron source was loaded into the 3 irradiation holes, IP-15, NTD and CT. IP-15 and NTD holes are located at the outer core. And CT hole is located at the inner core. The tested neutron detectors are CIC (Compensated Ion-Chamber) and six fission chambers. Among six fission chambers, three are used for the RPS (Reactor Protection System) and other three are used for the RRS (Reactor Regulating System). Integrities of the neutron detectors were tested by installation of the neutron source at different positions of the core. Fig. 1 shows the responses of the fission chambers by installation of the neutron source. As shown in Fig. 1, when the neutron source was located around the fission chamber, output signals of the fission chambers except RRS CH-B was sharply increased. RRS CH-B did not respond due to overhaul.

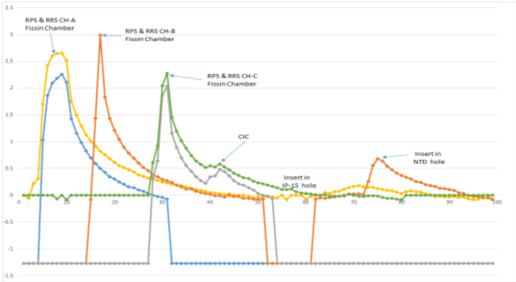

Fig. 1. Responses of the fission Chambers by Installation of Neutron Source

When the neutron source was loaded in the IP-15 hole which is the closest irradiation hole to the core, all fission chambers were not responded. Meanwhile, the neutron source was loaded in the NTD hole, only the RPS CH-B fission chamber was slightly reacted because the position of the RPS CH-B is close to the NTD hole. Fission chambers and CIC were not enough reacted at the IP-15 and NTD holes. It is determined that the installation position of the neutron source is CT hole. Because the CT hole is located in the center of the core, and neutrons from the source can most uniformly affect the fuel.

3.2 Start-up without Neutron Source

The critical position of the CARs was calculated by using VENTURE-Ⅳ that is the sub code of the HANAFMS. The calculated position is 232.12mm [4]. The critical position of the CARs was measured based on 1/M method. When SORs were withdrawn, all fission chambers and CIC were not reacted. Because the output current of the CIC was so weak, it was decided the only six fission chambers were used for start-up the reactor.

The uncertainty of six fission chambers was large under 100mm of CARs. When the CARs were withdrawn 100 mm from the bottom of the core, it could be checked enough output signals of the six fission chambers. It was confirmed that it could make a criticality using the neutron log-power signals of the six fission chambers. When the CARs were withdrawn 180 mm from the bottom of the core, log-power signals of the six fission chambers were converged. Fig. 2 shows the 1/M graphs by using the log-power signals of the six fission chambers. The critical positions of the CARs were determined by fitting the 1/M graph shown in Fig. 2. Table 3 shows the equations of the fitted lines for criticality. Average critical position of the six fission chambers is 229.14 mm. Calculated critical position is 232.12 mm. Hence, there is a difference of 2.98 mm between the measurement and the calculation.

However this discrepancy is acceptable enough. Because the neutron log power at the measurements was very low (about 5.3E-8 %FP), and thus the reactor was operated in manual mode. It needs much long time to increase the neutron power for auto mode operation. When the neutron log power higher than 1E-6, it can change the control mode from manual to auto. [5].

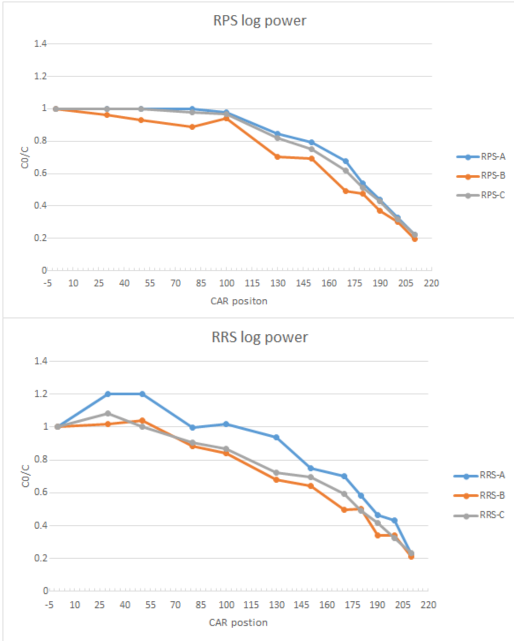

Fig. 2. 1/M Graph without Neutron Source

Table 3: Line Fitting Equation and Estimated Critical Position without Neutron Source

F.C	Equation	Critical Position
RPS Ch-A	y = -0.0105x + 2.4342	231.8
RPS Ch-B	y = -0.0107x + 2.432	227.5
RPS Ch-C	y = -0.0094x + 2.1933	233.4
RRS Ch-A	y = -0.0208x + 4.5974	221.1
RRS Ch-B	y = -0.0129x + 2.9137	225.9
RRS Ch-C	y = -0.0095x + 2.2351	235.3

*** F.C : Fission Chamber**

3.3 Start-up with Neutron Source

The critical position of CARs with the external neutron source in CT hole was calculated to be 242.86 mm [4]. If the neutron source is loaded into the CT hole, the CT hole is filled with water. Due to the neutron absorption by water, the calculated critical position was higher than without neutron source.

The critical position of CARs with the neutron source was measured by 1/M method. The measured neutron log power signals of the fission chambers were twice higher than those of the fission chambers without neutron source.

When SORs and CARs were withdrawn, the log power signals of the RPS fission chambers were converged. When the CARs were withdrawn 100 mm from the bottom of the core the log power signals of the RRS fission chambers were converged. When the CARs were withdrawn 180 mm from the bottom of the core, the log power signals of the all fission chambers were converged.

The test was stopped at a position 20 mm below the expected critical position (242.86 mm) of the control rods. Fig. 3 shows the 1/M graphs by using the log-power signals of the six fission chambers. Table 4 shows the equations of the fitted lines for criticality. Average critical position of the six fission chambers is 241.3 mm. There is a difference of 2.56 mm between the measurement and the calculation.

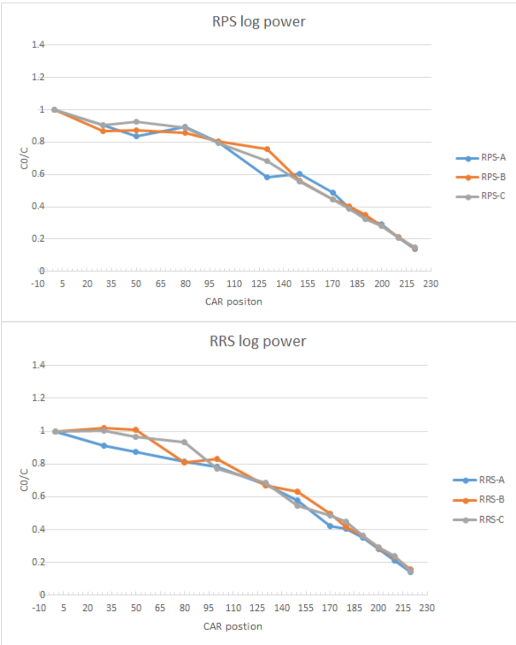

Fig. 3. 1/M Graph with Neutron Source

Table 4: Line Fitting Equation and Estimated Critical Position with Neutron Source in CT hole

F.C*	Equation	Critical Position
RPS Ch-A	y = -0.0068x + 1.6248	238.9
RPS Ch-B	y = -0.0064x + 1.5597	243.7
RPS Ch-C	y = -0.0058x + 1.4294	246.4
RRS Ch-A	y = -0.0069x + 1.6692	241.9
RRS Ch-B	y = -0.0076x + 1.8288	240.6
RRS Ch-C	y = -0.0091x + 2.1491	236.2

*** F.C : Fission Chamber**

4. Conclusions

Neutron detectors of the HANARO core were tested using the neutron source. It is confirmed that there is no problem in the integrity of detectors. And the critical positions of the CARs were measured and calculated before the normal operation of the HANARO. It is confirmed that HANARO can be restarted without external neutron source. The CARs were withdrawn step by step, and there was not prompt neutron jump.

In conclusion, it is decided that HANARO is restarted without neutron source. In the test, initial neutron log power was too low, therefore, it is expected that it will takes much time for safe HANARO restart-up. It needs enough time to reach the stable state of the core.

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