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Analysis of Irradiation Holes of In-Core Region

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1. Introduction

HANARO has been maintained in optimal condition for offering high neutron flux to the test facilities. In addition, new materials and fuels, which are used for fuel cladding in a commercial nuclear power plant and fuels for Ki-Jang reactor, are irradiated in the irradiation holes in HANARO. Test fuels and materials are irradiated in the in-core region in side of the chimney. The inner chimney is composed of In-Core and Out-Core regions. The In-Core region has 23 hexagonal vertical irradiation holes named from R01 to R20, CT, IR1 and IR2 and 8 cylindrical irradiation holes named from CAR1 to CAR4 and SOR1 to SOR4. The Out-Core region is composed of 8 cylindrical irradiation holes named from OR1 to OR8 which are installed near the inner shell of the reflector tank. Seven irradiation holes named from OR3 to OR6, CT, IR1 and IR2 are used for test fuel irradiation and producing of long term half-life radio-isotopes.

2. Analysis

WIMS-VENTURE system, that is HANAFMS (HANAro Fuel Management System), has been used for analyzing the reactor characteristics and in-core fuel management. It can describe a fuel rod as a node, hole-site flux and analyze the power and burnup history of each rod at the equilibrium core [1]. Table 1 shows the neutron flux which are calculated values by HANAFMS and written in SAR values in each vertical irradiation hole. The calculated values means that irradiation holes are satisfied to irradiate test. It means the HANFMS is well managed. Unfortunately, The OR4 and OR5 are not commented in SAR. So we suppose that the reference value for OR4 and OR5 is OR3 written in SAR. These neutron flux data are obtained from HANAFMS of the 96th period. CARs are located at 250mm in free Xenon state in BOC.

CT, IR1 and IR2 are operated with high fast and thermal neutron flux because they are surrounded by fuels. These conditions are very suitable for irradiating test fuels and performing high burnable tests. The other irradiation holes are operated with low neutron flux for both fast and thermal neutron. These holes are being used in long-term irradiation test for newly developed material and different types of test fuels. When there are no test materials or Radio-Isotope. Dummy fuel is loaded in the location. Accordingly, irradiating location is determined by neutron flux and its purpose. The IR1 hole, in particular, is currently not available due to installed FTL (Fuel Test Loop) equipment.

Table 1, Major Vertical Irradiation Holes of Neutron Flux

HOLE ID.	Fast Neutron Flux (> 0.821 MeV) (x 10^{12} n/cm2-sec)		Thermal Neutron Flux (< 0.625 eV) (x 10^{14} n/cm2-sec)	
	Maximum	Average	Maximum	Average
CT	192.30	143.73	4.19	3.12
	(209.75)	(152.70)	(4.39)	(3.13)
IR1	187.64	139.56	3.87	2.89
	(187.81)	(136.49)	(3.82)	(2.73)
IR2(Cap)	176.79	134.49	2.31	1.27
	(195.17)	(141.48)	(3.93)	(2.81)
OR3	21.30	16.43	3.21	2.64
	(21.27)	(16.06)	(3.06)	(2.50)
OR4(Dup)	18.36	12.20	2.42	1.75
OR5(Rig)	19.65	13.40	2.26	1.73

*( ): main vertical irradiation holes flux values in SAR

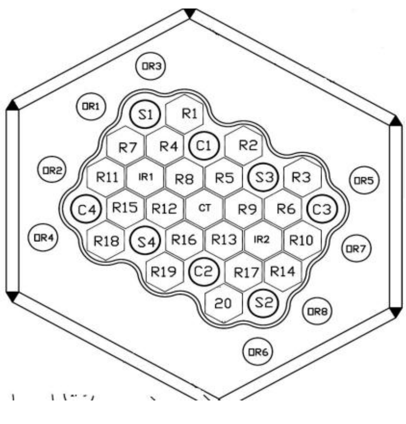

Fig.1.Location of the Irradiation Holes in the HANARO Core

2.1 CT Irradiation Hole

The capsule 07M-13N which was designed for evaluating neutron irradiation properties of X-Gen PWR fuel assembly requested by KEPCO NF(Korea Electric Power Cooperation of Nuclear Fuel) was irradiated from 51st to 53rd operating period in 2008 [2]. Pressurizer vessel alloy steel named 08M-01K was loaded and irradiated for 7 days in 54-1st period in 2008 [3]. The capsule 09M-09K which contains Ti thermal-medium material was irradiated in 62nd period in high temperature condition [4]. The capsule 10M-01K was irradiated in 64th period in 2010 for SMART steam generator's heat transfer pipe material [5]. The capsule 11M-22K which contains Ti/Graphite thermal-medium material was irradiated from 75th to 77th period in high temperature condition [6]. The capsule 11M-25K for testing high intensity RPV-steel was irradiated in 78th period for 12 days in 2012 [7]. The capsule 11M-20K was irradiated for five periods after 85th period in 2013 for testing research reactor material. Lastly, 11M-21K was irradiated from 82nd to 85th period in CT irradiation hole and reloaded in IR2 hole from 86th to 90th period [8].

Table 2, Specification of Irradiation Materials in CT

Name	Test material	Irr. time
07M-13N	Charpy/Tensile/Hardness/ SP/TEM (463ea)	96 days
08M-01K	RPV materials (151ea)	6.5 days
09M-09K	Ti, Graphite, STS304 (25ea)	610 days
10M-01K	SMART S/G material Inconel 690 (173ea)	25.29 days
11M-22K	STS304 16eaC-C 5 Zr-4 Tensile 45/S-tensile 12/ring 59 (137ea)	57.10 days
11M-25K	High-strength RPV alloy steel SA508(58ea)	12.13 days
11M-20K	Research Reactor material for Irradiation Capsule Graphite(80ea),Be(102ea), Zry-4(84ea)	4 periods (3023.63MWD) 100.79 days

2.2 IR1 Irradiation Hole

IPS (In-Pipe Section), which is the fuel bundle of FTL for a mock-up test, was loaded from 54th to 58th period. And then KF08E03A, which is a test fuel of FTL, was loaded to verify the performance of the FTL facility and burn-up for fuel of FTL. Test result shown on Table 3. The temperature, pressure and flow are well controlled the desired values for irradiation test of PWR fuels. After the performance test, it was replaced with HANARO dummy fuel [9].

Table 3, FTL operation values at HOP mode

Items	Desired value	Measured value
IPS inlet temperature	300.3 ℃	300.3 ℃
IPS inlet pressure	15.2 MPa	15.2 MPa
IPS inlet flow	1.65 kg/s	1.65 kg/s

2.3 IR2 Irradiation Hole

05S-05K (STS316L(N)) was designed to get core characteristic data to use at the reactor structure materials for the fatigue test. It confirms the stability of materials using in the commercial plants. It was irradiated in 46th period in 2007 for the material fatigue test. After the performance test, IR2 was replaced with IR capsule to produce radio isotopes [10].

2.4 OR5 Irradiation Hole

Instrumented fuel capsule 05F-01K which was designed and manufactured for a design verification test dual instrumented fuel rods was loaded from 46th to 52nd period in 2007 [11]. The instrumented capsule 07M-21K was designed, fabricated and irradiated for an evaluation of the neutron irradiation properties of high-temperature materials in 52nd period in 2008 [12]. The instrumented capsule 08M-09K whose structure was designed based on a previous 07M-21K capsule was manufactured and irradiated in 57th period in 2009 for the Gen-IV project [13]. The instrumented capsule 09F-08K was designed to verify the performance of double cladding fuel rod under a high temperature circumstance during in 62nd period in 2010 [14]. The instrumented capsule 09M-02K was designed and irradiated in 74th period for an evaluation of the neutron irradiation properties of Alloy 690 for the National Project of 'SMART Development' [15]. The instrumented capsule 10M-15K which will be used for a pressure vessel in the 4th generation reactor VHTR was irradiated to evaluate neutron irradiation properties in 71st period in 2011 [16]. The instrumented capsule 13M-02K was designed for an evaluation of the neutron irradiation properties of the PRV irradiation materials [17]. The capsule 12F-01K for a coated particle fuel which will be using in VHTR was irradiated from 89th to 93rd period in 2014 [18].

Table 4, Specification of Irradiation Materials in OR5

Name	Test material	Irr. time
07M-21K	Gen-IV for RPV	24.62 days
08M-09K	Gen-IV for RPV (Grade 911)	23.57 days
09F-08K	UO2 pellet (NU) 0.71 w/o (10) 2rod	24 days
09M-02K	SMART S/G Alloy 690 (132)	25.46 days
10M-15K	VHTR material Mod.9Cr-1Mo(73ea) Tensile, charpy, Hv	28 days
13M-02K	SA508 Gr 3 Cl 1 alloy steel	53.58 days
12F-01K	coated particles(14ea)	133.07 days

2.5 OR4 Irradiation Hole

The non-instrumented test rig for a dual-cooled annular fuel test, which is to complete a basic of the power uprating dual-cooled fuel's structural components for an actual using in the existing nuclear power plants, was loaded from 55th period in 2008 to 58th period in 2009. The non-instrumented test rig for the hybrid fuel was loaded from 74th period to 96th period [19]. Hybrid fuel is composed a ring shape UO2 pellet and cylindrical shape UO2 pellet. These are irradiated at a time, we verify the behavior of two pellets at the middle range burnup to obtain the core-technology of nuclear fuel and increasing the irradiation holes usage.

2.6 OR3 Irradiation Hole

U-Mo test fuel named KH08C-001 was irradiated from 56^{th} to 61^{st} period in 2008. A rod type of U-Mo fuel named KOMO-5 was irradiated from 73^{rd} to 81^{st} period [20]. We know that coarse powder and alloying element are effective to stabilize the fuel performance at high BU. U-Mo/Al-5Si dispersion fuel with 5.0 g-U/cm^3 is promising for the HANARO reactor to improve fuel economy.

3. Conclusions

HANARO is the multi-purpose research reactor which utilizes in-core irradiation holes, which is being used in various field. Over the past 7 years we have used CT 8 times, IR once, IR2 and OR3 twice, OR4 three times and OR5 ten times. These irradiation holes are used to perform an evaluation of the neutron irradiation properties and the tests were all completed and done successfully. HANARO has been used successfully, and it still will be used continuously in various fields such as nuclear in-pile tests, the production of radioisotopes, neutron transmutation doping, neutron activation analysis, neutron beam research, radiography, environmental science, health science, agriculture, and bio-engineering.

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