Design and Thermal Evaluation of Material Irradiation Capsule (25M-02K)

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1. Introduction

Currently, an irradiation test for structural materials of the i-SMR is planned at the HANARO OR test hole under a temperature condition of 290±10℃. An instrumented capsule utilizing a 6-hole specimen layout was designed to accommodate user requirements for increased specimen loading capacity. While the 6-hole configuration has been previously utilized in the 60 mm diameter CT test hole, this marks its first application in the smaller 56 mm diameter OR test hole, which required close collaboration with the manufacturer. Additionally, this capsule was uniquely designed for a HANARO thermal power condition of 27 MW, distinguishing it from conventional capsules typically designed for 30 MW.

2. Methods and Results

The capsule accommodates a total of 60 SA508 Charpy specimens (10 mm × 10 mm × 55 mm), arranged with 12 specimens per stage across 5 stages. During the design phase, the reference circle diameter for specimen placement was adjusted from 27.5 mm to 26.5 mm to prevent interference with heating elements and thermocouples during assembly.

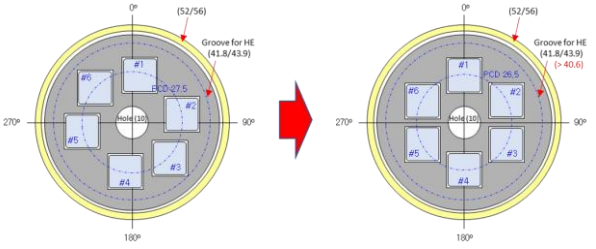


Fig. 1. Adjustment of reference circle for specimens

Furthermore, to ensure thermal and structural safety, the placement angles of four specimens were modified from 30° to 27.41° relative to the horizontal axis. This adjustment secured a sufficient thermal medium thickness of 1.56 mm to 2.0 mm between the specimens.

Gamma heating rates were calculated using the MCNP code, explicitly modeling the HANARO OR test hole conditions at 27 MW. These calculations evaluated the Beginning of Cycle (BOC), Middle of Cycle (MOC), and End of Cycle (EOC) stages, assuming a 20% delayed gamma fraction.

Table I: Evaluated Gamma Heating Rate (MOC)

Stage	Gamma Heating Rate (W/g)	
	Specimens	Holder
5	6.36E-01	5.54E-01
	7.24E-01	
	7.98E-01	
	8.67E-01	
4	9.72E-01	8.56E-01
	1.10E+00	
	1.21E+00	
	1.31E+00	
3	1.42E+00	1.11E+00
	1.48E+00	
	1.51E+00	
	1.49E+00	
2	1.48E+00	1.07E+00
	1.45E+00	
	1.43E+00	
	1.35E+00	
1	1.25E+00	8.29E-01
	1.16E+00	
	1.08E+00	
	9.52E-01	

For the thermal temperature evaluation using the 1D GENGTC code, the Equivalent Radius Design Method was applied to simplify the complex cross-sectional structure into concentric rings.

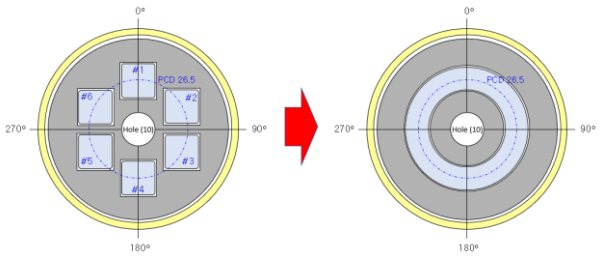


Fig. 2. Simplification of structure for thermal evaluation

Corrected densities for the inner thermal medium, SA508 specimens, and outer thermal medium were derived to convert the geometry into 1D input parameters. The thermal properties of SA508 were adopted from the GENGTC code's built-in library, and the heating rate of the outer tube was conservatively

applied as a 1.05 proportionality factor relative to the specimen heating rate. Because the GENGTC code requires 1D inputs, the average heating rates of the specimens located at the same height were utilized. The initial gap between the thermal medium and the outer tube was determined under MOC conditions across four height stages.

Table II: Evaluated Temperature of Specimen (MOC)

Stage	Temperature of Specimen (℃)					
	1atm, Heater (W)			0.4K, Heater (W)		
	0	1,800	2,800	0	1,800	2,800
5	173	389	461	311	594	667
	173	372	439	310	567	635
	174	357	421	309	545	608
	176	350	411	312	533	593
4	178	315	364	309	475	522
	180	304	349	309	459	502
	181	296	338	309	446	486
	182	291	332	310	438	476
3	185	278	313	310	415	447
	186	276	310	311	411	442
	185	272	305	308	405	436
	187	276	310	311	412	443
2	185	275	309	309	410	442
	185	278	313	309	414	447
	185	278	313	310	414	447
	186	284	321	312	425	459
1	182	297	339	311	447	487
	182	303	347	312	456	498
	181	311	358	311	469	514
	177	317	367	308	480	528

To achieve a uniform temperature profile aiming for an actual target temperature of 290℃ (design temperature of 310℃) under a 0.4K vacuum condition, this gap was finely adjusted into an 8-step configuration. Finally, the design integrity was verified by evaluating the specimen temperatures with the determined gap sizes across both BOC and EOC conditions.

3. Conclusions

The first 6-hole irradiation capsule for the HANARO OR test hole was successfully designed under a 27 MW operating power condition. The final 8-step gap design between the thermal medium and the outer tube was verified to be reasonable when compared to previous CT-hole capsule designs. These design procedures and findings will serve as a valuable reference for future capsule developments. Because high-purity aluminum (A1050) is used as the thermal medium, its structural integrity may weaken at high temperatures; therefore, special attention will be required to strictly maintain the normal temperature range during the actual irradiation test.

REFERENCES

[1] S.W. Yang, "Calculation Data for Heating Rate of OR Hole 6-Hole Structure Instrumented Capsule," Internal Email, 2026.01.13., 2026.04.09.

[2] C. J. Werner et al., "MCNP6.2 Release Notes", Los Alamos National Laboratory, Los Alamos, NM, LA-UR-18-20808 (2018).

[3] K.N. Choo, "Design Report of Instrumented Capsule (24M-05K) for CT Hole Irradiation Test of Thermally Embrittled Stainless Steel (TP 304H)," HANARO Technical Report, KAERI/TR-10802/2024, 2024.12.16.

[4] H. Someya, T. Kobayashi, M. Niimi, T. Hoshiya and Y. Harayama, GENGTC-JB: A computer program, JAERI-M 87-148 (1987).

[5] M.S. Cho, "Design, Fabrication, and Test Report of Instrumented Capsule (13M-02K) for Reactor Vessel Steel OR Hole Irradiation Test," HANARO Technical Report, KAERI/TR-5449/2014, 2014.02.

[6] M.S. Cho, "Design, Fabrication, and Test Report of Dual Thermal Medium Material Instrumented Capsule (13M-01K) for High-Temperature Irradiation Test," HANARO Technical Report, KAERI/TR-6836/2017, 2017.07.05.

[7] K.N. Choo, "Design of OR 6-Hole Structure Irradiation Capsule," MEMO-26-001, 2026.01.23.