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Design and Fabrication of the Capsule for Irradiation of RPV Material (16M-01K) in HANARO

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1. Introduction

An instrumented capsule was designed, fabricated for evaluation of the neutron irradiation properties of the reactor pressure vessel low alloys (SA 508 Gr. 3 Cl.1 BNPP4 inter-shell). The basic structure of the capsule (16M-01K) was based on the previously tested capsule which was successfully irradiated in the OR test hole of HANARO. Various specimens such as 0.4 RCT, ST-PCVN, C_v, plate tensile, hardness test specimens of SA508 material were placed in the capsule. The capsule is composed of 5 stages including many kinds of specimens and an independent electric heater at each stage. During the irradiation test, the temperature of the specimens and the fast neutron fluence will be measured by 14 thermocouples installed in the capsule. 5 sets of neutron fluence monitors were installed. A friction welded tube was introduced to prevent a coolant ingression inside the capsule. The capsule will be irradiated in the OR test hole of HANARO of a 30MW thermal output at 290±10℃ up to a fast neutron fluence of 9.10×10^{19} n/cm^2 (E>1.0 MeV).

2. Design and Fabrication

2.1 Specimens

This capsule was designed to evaluate the neutron irradiation properties of the reactor pressure vessel (RPV) material SA 508 Gr. 3 Cl. 1 low alloys. 104 specimens such as 0.4 RCT, ST-PCVN, Cv, plate tensile, impact test specimens of SA508 RPV model alloys as shown in Table 1 were put in the capsule. Specimens were inserted into an Al thermal media as a square bar shape with spacers of a similar material to simplify the handling and thermal calculation of the capsule as shown in Figure 1.

Table 1. Specimens of the 16M-01K capsule

Specimen	Size (mm)	Location in capsule	No
ST-PCVN	55x10x10	Stage 2, 3&4	13
1/2 PCVN	27.5x10x10	Stage 1	47
0.4 RCT	ϕ25	Stage 5	4
Plate Tensile	15x10x66	Stage 2 & 4	10
Small Tensile	27.5x5x0.5	Stage 3 & 4	15
Cv impact etc.	55x1x10	Stage 1 & 5	15

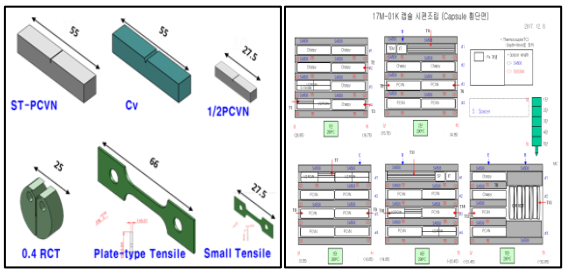

Figure 1.The specimens and arrangements

2.2 Capsule Design and Fabrication

The instrumented capsule 16M-01K was designed and fabricated for evaluation of the neutron irradiation properties of the RPV SA 508 Gr 3 Cl.1 steel at a higher neutron fluence as shown in Figure 2. The capsule was designed to be irradiated at the temperature of 290±10℃ in the OR5 hole. The irradiation test of the capsule was proven to be safe for the irradiation tests of SA 508 steel through the previous irradiation tests such as 11M-25K and 13M-02K capsules in HANARO.

The capsule of 56 mm in the outer diameter was composed of 5 stages including many kinds of specimens and an independent electric heater at each stage. During the irradiation test, the temperatures and the neutron fluences of the specimens will be measured with 14 thermocouples and 5 sets of Ni-Ti-Fe and Nb-Al-Co neutron fluence monitors installed in the capsule. A new friction welded tube made of STS304 and Al1050 alloys was also introduced in the capsule to prevent the coolant penetration into the capsule during the capsule cutting process in HANARO. The appearance of capsule before and after assembly was shown in Figure 2.

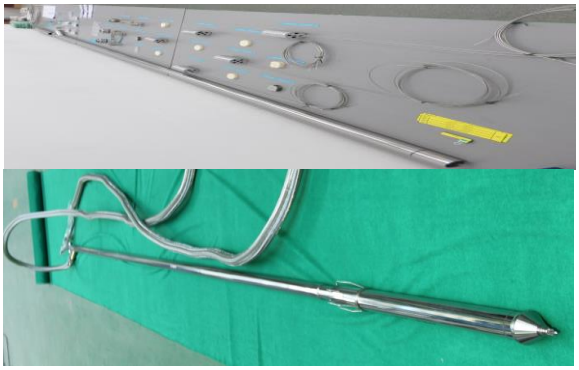
Figure 2. 16M-01K irradiation capsule

3. Saftey and Thermal Analysis

3.1 Safety Analysis of the Irradiation

The reactivity is calculated to be +0.96 mk on the basis that the control rod is 450mm and the capsule is fully inserted at OR5 [1]. The irradiation test is safe because it is less than +12.5 mk of the limited value required at HANARO. Fig. 3 shows the neutron spectrum distribution in the hole, which is the average values at all specimen.

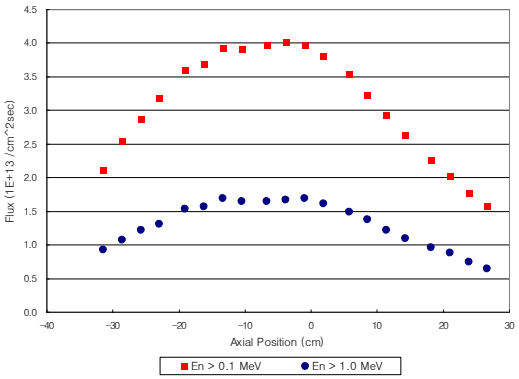

Figure 3. Average fast neutron spectrum distribution

3.2 Thermal Analysis

The heat generation rates were determined by referring to the data recently calculated for a safety analysis of 08M-02K, 11M-02K and 13M-02K etc.. In this calculation, the values at a 450mm height of the control rod were used. The heat generation rates are shown in Fig. 4.

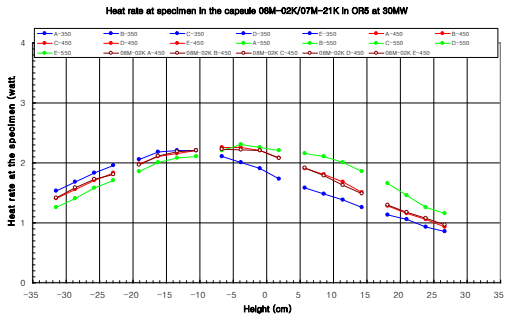

Figure 4. Heat generation rate in the OR capsules

The GENGTC program was used for the thermal analysis. A one-dimensional model for the specimen section was generated and used for calculation. The temperature of the cooling water in the reactor in-core is about 33 ℃, and the heat transfer coefficient at the outer surface of external tube is 30.3 x 10^3 W/m^2℃, which was determined experimentally [2].

Fig. 4 shows the calculated and the previously measured temperatures of the specimens. This indicates the temperatures at the condition without heater at 1 atm. The temperatures rise as the power of the reactor increases and the internal pressure drops.

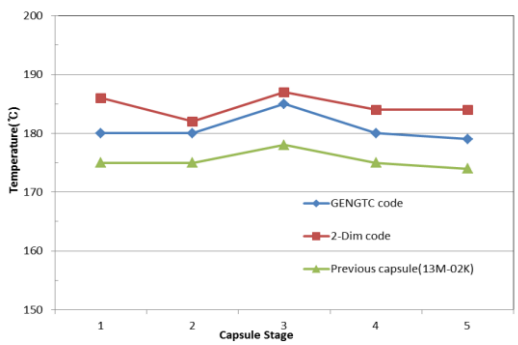

Figure 5. Temperatures of the calculation codes and the previously tested capsule

Table 2 shows the temperature analysis results by GENGTC and ANSYS code at the condition of 0.4K He pressure. A 2-dimensional code predicts the temperatures lower than GENCTC code. As the internal pressure and the heat power change, The irradiation temperatures reach the target values

Table 2. Estimation of target temperatures at 0.4K

Stage	Gap size (mm)	Temperature(0.4K)	
		GENGTC	ANSYS
1	0.33	292	289
2	0.20	291	264
3	0.12	292	265
4	0.16	291	263
5	0.19	292	265

4. Conclusions

The capsule for irradiation of the RPV SA508 Gr. 3 Cl.1 steel was designed and fabricated. Various types of specimens such as PCVN, Charpy, plate tensile specimens of SA508 alloys were included in the capsule. It is now installed in the core of HANARO and will be irradiated during 2 cycles (56 days) when HANARO will be operated again.

Acknowledgements

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REFERENCES

[1] S.Y. Oh, “Analysis of Nuclear Characteristics of 09M-01K Capsule,” KAERI Internal Memo,” HAN-NE-CR-920-09-17 (2009)
[2] M. H. Choi, et Al., Temperature Evaluation of an Instruments Capsule after Material Irradiation Tests in HANARO, J. of Nuclear Mat., 362 (2007) 19-25