A Safety Review for Irradiation Test of the Creep Capsule(02S-08K)

M.S.Cho, C.G.Seo, M.H.Choi, K.N.Choo, J.M.Sohn, Y.H.Kang, and B.G.Kim
KAERI, 150 Dukjin-dong, Yuseong-gu, Daejeon, Korea 305-353
mscho2@kaeri.re.kr

1. Introduction

The creep capsule(02S-08K), which is aimed to confirm the design characteristics and the structural integrity, will be irradiated at the IR2 test hole in October, 2004. To review a safety in the irradiation test of the capsule, the reactivity effect in HANARO was analyzed and stress and temperatures on the capsule were estimated. In the abnormal operating condition during the test of the capsule, the effect exerted on the capsule outer body by leakage or breakage of the stress loading unit equipped in the capsule was analyzed.

2. Reactivity effect

The creep capsule(02S-08K) is planned to be irradiated at IR2 test hole for 33-2 cycle of HANARO operation. To estimate the reactivity effect caused by loading the capsule in the test hole of HANARO, the k-effectives were calculated for 5 kinds of core conditions as listed in Table 1.

Table 1. k-effectives at the different core conditions.

Core condition	k-effective	Error	Reactivity worth(mk)
Capsule loading	1.03329	0.00016	-
Capsule half breakage	1.03351	0.00017	0.2
Capsule unloading	1.03569	0.00029	2.2
Ir rig loading	1.03555	0.00033	2.1
Dummy fuel loading	1.03991	0.00036	6.2

In this estimation, the capsule half breakage was assumed that half of the capsule was lost for irradiation test. The reactivity worth is no more than -2.1 mk if Ir rig were put in the IR2 test hole instead of the capsule. This indicates the reactivity effect is not so great. As a result, the reactivity effect by loading, unloading and breakage of an experimental object does not exceed +12.5 mk specified in "HANARO operation technique guide"[1].

3. Structural integrity

The structural integrity analysis for the capsule outer tube was performed. The critical buckling stress[2] of the outer tube is calculated as 15.52 MPa, and this value is higher than the buckling stress (3P) due to the applied coolant pressure (P= 0.4 MPa). The combined stresses (primary membrane + secondary thermal) in the outer tube are 78.16 and 96.06 MPa for 24 and 30 MW_{th}, HANARO power, respectively. Table 2 represents the results of the stress analysis and the strength evaluation based on the ASME code requirements. These results meet the allowable stress value, 344.76 MPa for the combined stress.

Table 2. Stress in the capsule outer tube. (unit : MPa)

Item		Calculation stress	Allowable stress	Code requirement
P_{cr}		1.2	15.52	$P_{cr} > 3P^*$
P_m		4.36	114.92	$P_m < S_m$
24MW	P_m+P_e	78.16	344.76	$P_m+P_e < 3S_m$
30MW	P_m+P_e	96.06	344.76	$P_m+P_e < 3S_m$

* Coolant pressure (P=0.4 MPa)

During the irradiation test, some abnormal accidents can be assumed by damage or breakage of bellows in the stress loading unit in the capsule because it works normally at high pressure of 30~40 kgf/cm^2. For this case, a stress analysis was performed to confirm the structural integrity of the capsule outer tube. The design pressure (p) is assumed to be 50 kgf/cm^2 and the hoop stress of the capsule outer tube can be calculated by the following equation

$$\sigma_h = \frac{pr}{t} \quad (1)$$

Where, r and t are the radius(30mm) and the thickness(2mm) of the capsule, respectively. The hoop stress using Eq. (1) due to the abnormal internal pressure is calculated as 73.5 MPa, which is less than the allowable stress(114.92 MPa) of the outer tube material (STS316LN). As a result, the structural integrity of the capsule is ensured even if the abnormal pressure increase occurred.

4. Thermal analysis

During the irradiation test, the required temperature of the specimen is 600□(±10%)[3]. The heating rate by neutron and gamma on the parts of the capsule loaded in IR2 was calculated for the position range 250~550mm of the control rods expected in 33-2 cycle of HANARO operation. The heating rate according to position of the control rods is shown in Fig. 1.

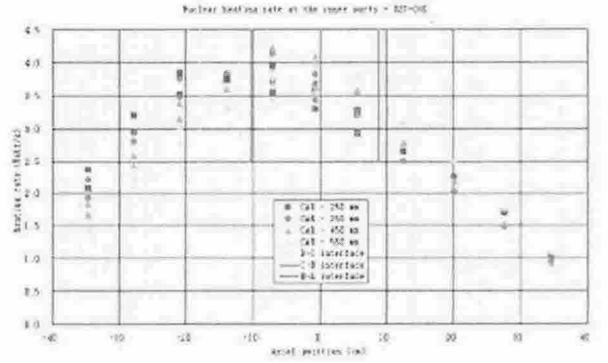

Figure 1. Heating rate according to position of the control rods

The maximum heating rate is expected to be 4.23 W/g at the specimen when the control rods are in the height of 450 mm. The range of fluctuation on the heating rate at the specimen is not so big according to position of the control rods. The model for temperature calculation in the cross section of the capsule is shown in Fig. 2.

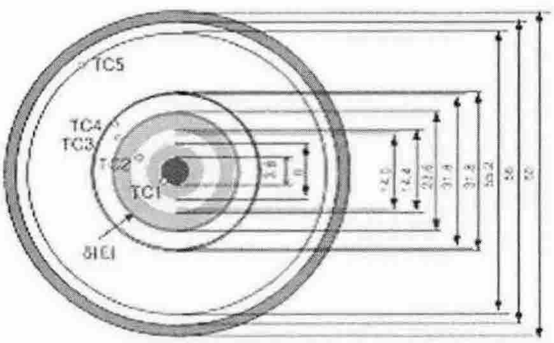

Figure 2. Model for temperature calculation

4.1 Temperatures at the vertical positions

Temperatures calculated at various vertical positions of the capsule are listed in Table 3. These will be compared with the measured temperatures by thermocouples installed on the capsule parts.

Table 3. Temperatures on the vertical positions of the capsule.

Parts	Temperature (□)	
	0.6K(~70torr)	1K(1atm)
LVDT	113	87
Specimen	664	544
Thermal media	184	106
Bellows outer tube	449	439

4.2 Temperature distribution around specimen

The estimated temperature distribution at 24 MW_{th} HANARO power is shown in Table 4. The specimen temperature can be controlled from 664 □ to 544 □ by change of the internal He pressure in the capsule. Therefore, the requirement for the specimen temperature is satisfied. At 30 MW_{th} HANARO power, the specimen temperature is estimated to be from 745 □ to 614 □. This range is a little higher than the required temperature 600 □(±10%). Therefore, HANARO operation at 30 MW_{th} is not desirable considering the temperature requirement of the in-core creep test.

Table 4. Temperature distribution (IR2, control rod 450mm)

Parts	24MW		30MW	
	0.6K (~70torr)	1K (1atm)	0.6K (~70torr)	1K (1atm)
Specimen	664	544	745	618
Heater	499	415	551	466
Connector	438	357	479	398
Thermal media	365	307	392	337
Outer tube	44	44	46	46

5. Conclusion

In the irradiation test of creep capsule(02S-08K), the reactivity effect satisfies the limit condition(+12.5mk) in HANARO and the structural integrity of the capsule was confirmed in the normal and abnormal test condition. By thermal analysis at 24 MW_{th} HANARO power, the specimen temperature is in the range 544~664 □ and temperature requirement for the irradiation test of the specimen can be satisfied by control of the internal He pressure and heater power. Therefore, HANARO power is required to be at 24 MW_{th} during the creep test.

5. Acknowledgement

This study was supported by Korea Institute of Science & Technology Evaluation and Planning (KISTEP) and Ministry of Science & Technology (MOST), Korean government through its National Nuclear Technology Program.

REFERENCES

[1] C. G. Seo, Nuclear Characteristics for Irradiation of Creep Capsule(02S-08K), HAN-RR-CR-920-04-035, KAERI Internal Document, 2004. 9

[2] ASME Boiler and Pressure Vessel Code, Section III, Div. 1, Subsection NB, 1989 edition

[3] M. S. Cho, Irradiation Test Plan and Safety Analysis of Creep Capsule(02S-08K) for In-core Irradiation Test in HANARO, KAERI/TR-2790/2004, 2004. 7

[4] S.H. Crandall, N.C. Dahl and T.J. Lardner, An Introduction to the Mechanics of Solids, MacGraw-Hill, Inc.. 1978.