A Nuclear and Thermal Analysis for a Creep Capsule(03S-07K)

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1. Introduction

In this paper, the reactivity effect was reviewed and an analysis for the structural and thermal integrity was performed to review the safety of the creep capsule 03S-07K, which will be irradiated at a temperature higher than 550℃. The irradiation test will be performed at the in-core IR2 hole for 23 days at the HANARO 30 MW_{th} power. In the irradiation test, the temperature of the parts in the capsule will be measured and compared with the design value for reviewing the design data, and also the integrity of the bellows and LVDT etc. will be confirmed.

2. Nuclear analysis

The reactivity effect, the neutron fluence and the heating rate caused by loading the capsule into the test hole were estimated. The reactivity worth by the insertion of the creep capsule is no more than +9.2mk, this indicates that the reactivity effect does not ecdeed +12.5mk as specified in "the HANARO operation technical specification[1]". This value appears to be a little bigger if it is compared with the reactivity worth +6.2mK[2] of the 02S-08K creep capsule previously installed in IR2. This is because the neutron absorbing materials, STS304 and STS316, in this capsule are used more than in the 02S-08K creep capsule.

The capsule model used for the estimation of the data in the core is as in Fig. 1. The calculation result is listed according to the marks of the model for the nuclear/thermal calculation in Fig. 1. The neutron fluence with E>0.1 MeV and 1.0 MeV is listed in Table 1. The heating rates on the specimen are 4.92 and 3.72 W/g at the lower and the upper position, respectively [2].

Table 1. Neutron fluence at the position of the specimen

		E>0.1MeV		E>1.0MeV	
Height(cm)		C-STS316(inner)		C-STS316	
lower	upper	$n/cm^2 \cdot s$	fsd	$n/cm^2 \cdot s$	fsd
-16.0	-9.8	5.63E+20	0.0167	2.66E+20	0.0166
-9.8	-3.6	5.93E+20	0.0167	2.85E+20	0.0163
-3.6	+2.6	5.83E+20	0.0167	2.75E+20	0.0166
+2.6	+8.8	5.42E+20	0.0167	2.63E+20	0.0171
+8.8	+15.0	4.68E+20	0.0167	2.24+20	0.0183

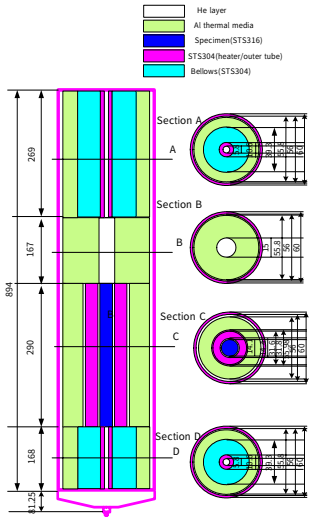

Figure 1. Model for nuclear/thermal calculation of creep capsule(03S-07K)

3. Structural integrity

The structural integrity analysis for the capsule outer tube was performed. The critical buckling stress[3] of the outer tube is calculated as 15.52MPa, and this value is higher than the buckling stress (3P) due to the applied coolant pressure (P=0.4MPa). The membrane stress (P_m) by the internal pressure on the capsule outer tube is 4.36Mpa and this satisfies the applied stress of 114.92Mpa. The combined stresses (primary membrane + secondary thermal) at the outer tube was calculated as 66.7Mpa. And this stress will be 96Mpa at 550℃ when considering the result of the 02S-08K capsule, but these values meet the allowable stress(344.76Mpa) by applying 3Sm. Table 2 represents the results of the stress analysis and the strength evaluation based on the ASME code requirements.

Table 2. Stress at 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	$P_m < S_m$
30MW	P_m+P_e	66.7	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 a damage or breakage of the bellows in the stress loading unit in the capsule because it works

normally at a high pressure of 30~40kgf/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 50kgf/cm^2 and the hoop stress of the capsule outer tube can be calculated[4]. The hoop stress due to the abnormal internal pressure is calculated as 73.5MPa, which is less than the allowable stress(114.92MPa) of the outer tube material(STS316LN). As a result, the structural integrity of the capsule is ensured even though an abnormal pressure increase has occurred.

4. Thermal analysis

During the irradiation test, the required temperature of the specimen is 550℃(±10%)[5]. The heating rate by neutron and gamma on the parts of the capsule loaded in IR2 was calculated for the position at 450mm of the control rods expected for the 38th cycle of the HANARO operation.

4.1 Temperatures at the vertical positions

The temperatures calculated at the various vertical positions are listed in Table 3. These will be compared with the measured temperatures by the thermocouples installed on the capsules parts during the irradiation test.

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

Vertical position	Parts	Temperature (℃)		
		0.4k (30torr)	0.6k (70torr)	1k (1atm)
Section A	Upper bellows	536	426	332
Section B	LVDT	280	276	274
Section C	Specimen	541	465	403
Section D	Lower bellows	1,095	888	698

4.2 Temperature distribution around the specimen

The model for the temperature calculation in the cross section of the capsule is shown in Fig. 4.

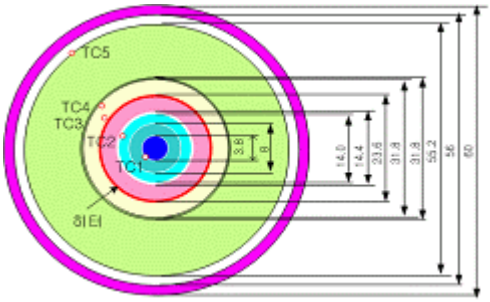

Figure 4. Model for the temperature calculation of the specimen section

The estimated temperature distribution at the 30MW$_{th}$ HANARO power is shown in Table 4. The temperature of the specimen ranged from 403℃ to 540℃ by a change of the internal He pressure in the capsule. Therefore, the requirement for the specimen temperature is satisfied. This range satisfies the required temperature 550℃(±10%).

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

Parts	30MW		
	0.4k (~30torr)	0.6K (~70torr)	1K (1atm)
Specimen	540	463	403
Spacer 2	495	426	368
Connector	216	195	171
Thermal media	108	106	102
Outer tube	46	46	46

4.3 Temperature limit of specimen during irradiation test

The test temperature of the specimen was decided to be 550℃ based on the creep test temperature for the STS316LN material at the outpile. The specimen does not melt even though the temperature on the specimen becomes 550℃ or above. The temperature of the specimen has nothing to do with the safety of the capsule as far as it is not higher than its melting temperature (1,400℃). Therefore, the upper limit of the test temperature was set for when the temperature of TC5 becomes 600℃ so that the temperature of the Al. thermal media is less than its melting temperature 660 ℃.

5. Conclusion

In the irradiation test of the creep capsule(03S-07K), 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 conditions. By a thermal analysis at the 30MW$_{th}$ power of HANARO, the specimen temperature is in the range of 403~540 ℃ and this meets the temperature requirements.

6. Acknowledgement

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