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The Design and Safety Review for a Creep Capsule With Four Specimens

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1. Introduction

To review the safety in the irradiation test of a creep capsule with 4 specimens, the design analysis for the in-core creep test in the normal and abnormal operation condition was performed. In the normal operation condition, the reactivity effect was estimated and the analysis on the stress and temperature was performed. In the abnormal operation condition, the effect exerted on the capsule body by a leakage or breakage of the stress loading unit was analyzed.

2. Reactivity Analysis

To estimate the reactivity effect caused by loading a creep capsule into HANARO, the k-effectives were calculated for 5 kinds of core conditions and shown in table 1[1].

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

Core condition	k-effective	Error	Reactivity worth(mk)
Capsule loading	1.03207	0.00033	-
Capsule half breakage	1.03355	0.00033	1.4
Capsule unloading	1.03569	0.00029	3.4
Ir rig loading	1.03555	0.00033	3.3
Dummy fuel loading	1.03991	0.00036	7.4

In this calculation, the breakage was assumed that a half of the capsule was lost. The reactivity worth is no more than -2.1mk if the Ir rig was put in the IR2 hole instead of the capsule. This indicates the reactivity effect is not so great. As a result, the reactivity effect by loading, unloading and the breakage of an experimental object does not exceed +12.5mk, which is the specified requirement.

3. Analysis of the Structural Integrity

The result of the structural analysis is shown in table 2. The outer tube of the creep capsule, of which the critical buckling stress is calculated to be 15.52Mpa[2], ensures a safety against the acting forces. The assembled stress in the outer tube at HANARO 30 MW_{th} power, in which the primary membrane stress and the secondary thermal stress(91.7 MPa) were assembled, is 796.06 MPa and has s sufficient margin when compared with the allowable stress(344.76MPa) applied as 3Sm.

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

Item		Calculation	Allowable	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	96.06	344.76	$P_m+P_e < 3S_m$

* Coolant pressure(P=0.4Mpa)

4. Thermal Analysis

The required test temperature of the specimen is 600℃(±10℃). The heating rate by neutron and gamma for parts of the capsule loaded in IR2 was calculated for the axial position range of 250~550mm. The heating rate according to the position of the control rods is shown in the figure 1.

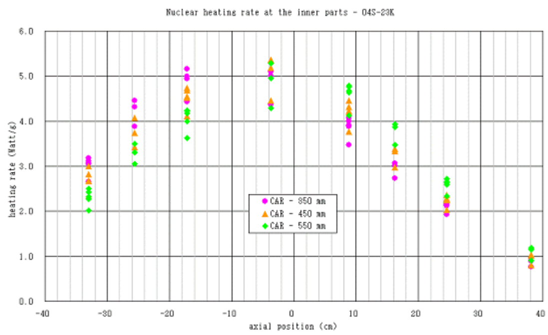

Figure 1. Heating rate according to the position of the control rods

The thermal analysis was performed by using the ANSYS program. The maximum heating rate at the position of the lower specimen is expected to be 5.16 W/g when the control rod is located at the height of 50mm. The range on the heating rate at the specimen is not so big according to the position of the control rods. When HANARO is being operated at a 30 MW_{th} power, the temperatures of the specimen and LVDT are in the range of 300~360℃ and 100~215℃ respectively. The temperatures of the specimen and LVDT are less than the melting temperatures of the corresponding materials. The temperature at the center rod of the bellows can be very high because a He gas gap exists in the space necessary for the expansion and contraction of the bellows. The center rod was made as a hollow tube shape of ϕ12mm(O.D.) x 2.2mmt of Ti material instead of a STS304 rod having the low melting temperature. The temperature of the center rod of the bellows was estimated less than 954℃. Therefore, the center rod does not melt as the melting temperature approaches[3].

4.1 Temperatures at the section of the specimen

The temperature at the specimen section is 360℃ at the lower specimen and 219℃ at the upper specimen for the gap thickness of 0.05mm. By this result, the lower specimen is expected to reach the target temperature(600℃) easily but for the upper specimen it is difficult to reach the target temperature. The temperature of the specimen was re-evaluated for different gap thicknesses. The estimated maximum temperatures of the specimen are shown in table 3.

Table 3. Maximum temperatures for various gap thicknesses

Gap thickness(mm)	0.05	0.1	0.15	0.2
Temperature at specimen	219	262	301	339

The temperature of the specimen at the gap thickness of 0.15mm is relatively lower than the target temperature. However, if the gap is 0.2mm or more, the temperature may be greatly affected by a vacuum condition. Therefore, the gap thickness was determined to be 0.15mm. Temperatures at the specimen section are shown in table 4. These will be compared with the temperatures measured at the thermocouples fitted on to the capsule parts.

Table 4. Temperatures on the specimen section

Section	C/R	Node					
		1	129	279	429	578	878
Upper	550	301	394	368	213	205	42
	450	268	262	238	190	183	42
Lower	550	308	298	257	170	156	46
	450	338	327	282	196	180	47

4.2 Temperature at the bellows section

Temperatures estimated on the bellows section are listed in table 5. The temperature at the lower section of the bellows is 954℃. This is lower than the melting temperature 1,668℃ of Ti material. The stress analysis at this temperature was performed at the operating pressure of 30 kgf/cm^2.

Table 5. Temperature distribution on the bellows section

Section	C/R	Node					
		1	151	201	603	301	903
Upper	550	889	483	122	111	110	42
	450	850	462	117	107	106	42
Lower	550	940	511	128	117	116	43
	450	954	517	130	119	118	43

The calculated stress was lower than the yield stress at the corresponding temperature. The temperature distribution at the specimen section in the capsule is shown in figure 2.

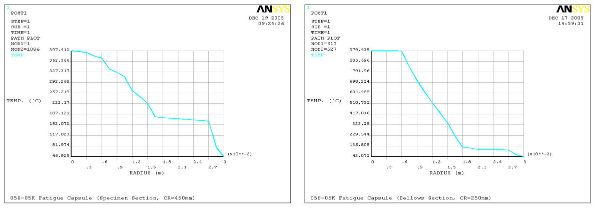

Figure 2. Temperatures at the specimen and bellows section

5. Structural Integrity in case of Abnormal Increase of Internal Pressure

A damage or breakage of the bellows in the stress loading unit can occur because it works normally at a high pressure of 30~40kgf/cm^2. For this case, the stress analysis was performed to confirm the structural integrity of the capsule outer tube. Design pressure was assumed to be 50kgf/cm^2. The analysis shows that the maximum circumferential stresses is estimated to be 71MPa. The stress resulting from the abnormal internal pressure is less than the allowable stress of the outer tube material. As a result, the integrity is ensured even if an abnormal pressure increase occurs.

6. Conclusion

In the design of the creep capsule, the reactivity effect satisfies the limit condition required in HANARO and the structural integrity was confirmed for normal and abnormal test conditions. The temperature was estimated for the bellows, specimen and LVDT, which satisfies the requirement conditions for the irradiation tests. As a result, the integrity for the irradiation tests can be maintained for the operation at a 30 MW_{th} power of HANARO.

ACKNOWLEDGEMENT

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