Design and Safety Review of a Fatigue Capsule

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1. Introduction

To review the safety level during an irradiation test of a fatigue capsule, a design analysis for the in-core fatigue test in the normal and abnormal operation conditions was performed. In the normal operation condition, the reactivity effect was estimated and an analysis of 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 fatigue 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	1.03259	0.00032	-
Capsule half breakage	1.03425	0.00018	1.6
Capsule unloading	1.03569	0.00029	2.9
Ir rig loading	1.03555	0.00033	2.8
Dummy fuel loading	1.03991	0.00036	6.8

In this calculation for the breakage, it was assumed that a half of the capsule was lost. The reactivity worth is no more than -2.8mk 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 fatigue 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 a HANARO 30 MW_{th} power, in which the primary membrane stress and the secondary thermal stress(91.7 MPa) were assembled, is 796.06MPa and it has a 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 550℃(±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.

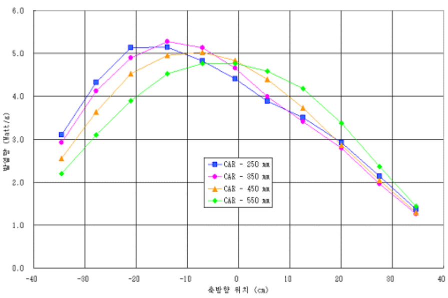

Figure 1. Heating rate according to the position of the control rods

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 5.47 W/g when the control rod is located at 350mm. 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 382~397℃ and 153~172℃ 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 determined as a hollow tube shape of ϕ12mm(O.D.) x 2.2mmt of Ti material instead of a STS304 rod having a lower melting temperature. The temperature of the center rod of the bellows was estimated as less than 979℃. The maximum stress was estimated to be 26.7MPa[3].

4.1 Temperatures at the section of the specimen

The gap between the outer tube and the thermal media was determined to be 0.5mm by an analysis. The temperature of the specimen is 382~394℃ according to a given position of the control rod. By the experiences of the creep capsules, the specimen is expected to reach the target temperature(550℃) easily. The temperatures of the specimen are shown in table 3.

Table 3. Temperatures for various control rods

Control rod positions (mm)	250	350	450	550
Temperature at specimen	382.6	393.8	397.4	393.9

4.2 Temperature at the bellows section

Temperatures estimated on the bellows section are listed in table 4. The maximum temperature is 979℃ at the push rod when the control rod was located at 250mm. At that time, the temperature of the convolution was 387℃, the case was 124℃, and the thermal media was 105℃, so their temperatures were sufficiently low when compared with the temperature of the push rod. The maximum stress at this temperature was estimated to be 26.7MPa.

Table 4. Temperature distribution on the bellows section

Parts	Control rod position(mm)			
	250	350	450	550
rod	979	943	846	761
convolution	387	373	337	305
case	124	110	110	101
thermal media	105	101	94	87
outer tube	42	41	41	40

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.

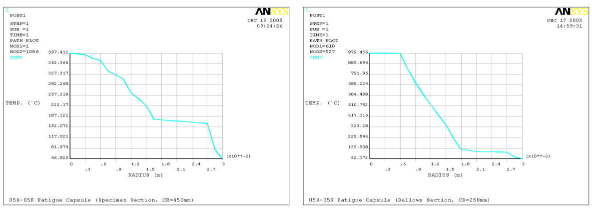

Figure 2. Temperatures at the specimen and bellows section

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 stress 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, its integrity is ensured even if an abnormal pressure increase occurs.

6. Conclusion

In the design of the fatigue 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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