A Preliminary Conceptual Design of the KALIMER-600 Core Catcher

Chang-Gyu Park, Jong-Bum Kim, Jae-Han Lee
Korea Atomic Energy Research Istitute, 150 Dukjin-dong, Yuseong-gu, Daejeon
chgpark@kaeri.re.kr

1. Introduction

The core catcher is necessary to improve the safety of a reactor system from the severe accidents such as a fuel melting, initiated for example by a unprotected loss of primary flow without the dropping of one or more control rods. This study presents the preliminary core catcher structural concept applicable to KALIMER-600[1]. The criticality assessments of the molten core with an initial structure concept are carried out for some cases and the modified structure design maintaining the subcritical configuration is presented.

2. Preliminary Structure Design

A core catcher may generally be classified as catcher trays, cooled crucibles and so on according to its location and reactor system. The core catcher trays within the reactor vessel are proposed for the KALIMER-600 which is a pool-type sodium-cooled liquid metal reactor. Because it is expected that even if the occurrence of a core meltdown accident, the sodium would be retained in the reactor vessel allowing for a heat removal by a natural convection[2].

A preliminary design was based upon the Core Debris Tray concept of EFR. The core catcher is a box type structure and mainly consists of a shell support structure, a recovery tray, heat shield, and a support cylinder. The shell support structure comprises a bottom shell and radial and circumferential ribs. The recovery tray and heat shield are a circular plate with a conical edge to prevent a core debris overspill. They are welded on the support cylinder and slightly inclined from a support cylinder to the periphery to enhance the debris distribution towards to periphery. A support cylinder is located outside the central pivot and restrains the vertical and radial displacement of the core catcher.

In the preliminary conceptual design of the core catcher, it is assumed that the core catcher should support a whole molten core and maintain it in a subcritical configuration. The core catcher is located between the lower grid plate and the reactor vessel bottom head. So the structure dimensions should be determined by considering the reactor vessel bottom head space. The external diameter of the heat shield plate is determined form the reactor core layout. To retain a whole driver fuel on tray, its available external radius is over 2.0m. The height of the plate conical edge is calculated by the debris volume. The estimated weight of the structure is about 63.0ton and thus the total volume is about 5.25m^3[3]. So an available height of the conical edge is about 0.38m. Assuming that the whole debris is uniformly distributed upon the plate area and the debris contains a void and molten grid plate material, the external radius of the plate and the height of conical edge are 2.2m, 0.45m respectively. A radius of support cylinder is determined as 0.625m tentatively. The thicknesses of the radial and circumferential ribs, recovery tray, and bottom shell are the same at 1.5cm and the thickness of heat shield is 2.0cm. Figure 1 shows the preliminary design concept of the core catcher.

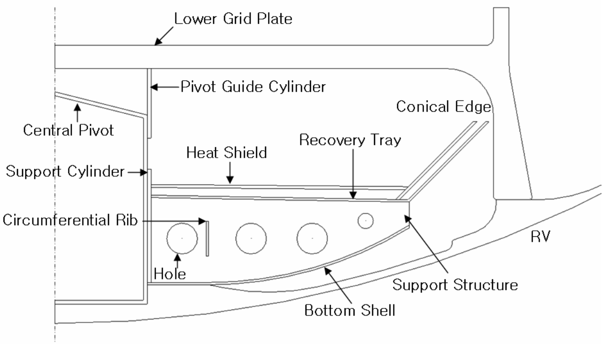

Figure 1. Preliminary design concept of the KALIMER-600 core catcher

3. Criticality Assessment

To ensure the validity of its design concept, the criticality assessment was carried out by the KALIMER Core Design Group by considering a whole molten core[4]. A debris shape assumed in the assessment is an annular cylinder. Criticality assessment was carried out for the following cases.

i) Case A : system boundary is the RV bottom head lower space only excluding RV and lower grid plate.

ii) Case B : system boundary extends to RV and lower grid plate

iii) Case C : lower grid plate is penetrated by a molten fuel including the Case B system boundary.

ⅳ) Case D : molten material of lower grid plate in the Case C is uniformly mixed with molten fuel.

ⅴ) Case E : molten 316SS is uniformly mixed with molten fuel including Case B system boundary

Table 1 shows the criticality calculation results for each case. As shown in Table 1, all the cases excluding Case B can maintain a subcritical configuration. The multiplication factor of Case B exceeds 1.0 due to a neutron defection of the SS316 material.

To satisfy the subcriticality of Case B, two modified concepts of the core catcher are proposed. One is that the structure concept has to be changed. One concept is to install a radial structure on a heat shield and the other is to change the dimensions of the heat shield plate and conical edge. The former concept is effective on maintaining a subcriticality but makes the structure complicated and increases its dead weight. So the dimensions of the external radius of the heat shield plate and the height of the conical edge by considering the reactor lower space are modified as 2.3m, 0.42m respectively.

Table 1. Criticality calculation results

Cases		Multiplication Factor	Standard Deviation
Initial Design	Case A	0.98278	0.00048
	Case B	1.01563	0.00052
	Case C	0.99883	0.00049
	Case D	0.91480	0.00046
	Case E-1 (mass ratio 10%)	0.97761	0.00048
	Case E-2 (mass ratio 20%)	0.94531	0.00047
Modified Design	Case B	0.99393	0.00047
	Case C	0.97934	0.00049

4. Structural Evaluation

The core catcher supporting a whole debris is submitted to a pressure load, mechanical load, and thermal load. In this preliminary conceptual design, the mechanical stress analysis associated with the debris dead weigh was carried out. The core catcher is made of SS316 which has a high thermal conductivity and satisfactory creep behaviour and thus leads to use of a single material for all the reactor internal structures. Figure 2 shows the stress analysis result by using an axisymmetric model. The maximum stress intensity is 128 MPa and the membrane and bending stress of the maximum stress section are 78.6MPa, 35.1MP respectively.

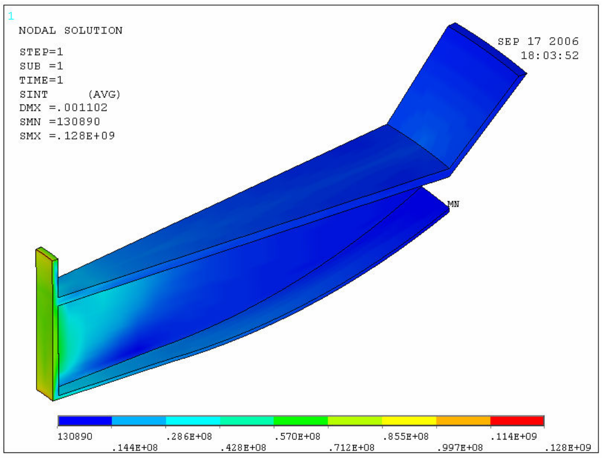

Figure 2. Mechanical stress analysis result

These stresses satisfy the 'membrane' and the 'membrane+bending' stress intensity limits associated with primary load from a Level D Service Limit of ASME Appendix F[5].

5. Conclusion

The occurrence of a core meltdown accident is an extremely low probability event. However, such an accident must be taken into account for a defense in depth.

In this study, the conceptual design of the core catcher applicable to KALIMER-600 was presented. Core catcher is a box type structure comprised of a shell support structure, heat shield, recovery tray, and central support. The plate must collect and support a whole molten core and thus the initial dimensions are determined after considering the debris volume. The criticality calculation with an initial structure concept was carried out for some cases and the modified structure dimensions for satisfying a subcritical configuration and RV bottom head space were proposed. The stress analysis for considering a mechanical load was performed and this showed that the primary stress limit was satisfactory.

Core catcher design has to be carried out related to the feasibility of a cooling and containment of active core debris, debris criticality, material, structural geometry and so on. This study was carried out on the preliminary conceptual design of the core catcher containing a somewhat uncertainty. Thus more additional and advanced researches such as a hypothetical core meltdown scenario, thermo-hydraulic calculation will be followed. Additionally, the stress analysis including the thermal load condition and its structural integrity evaluation will be carried out.

ACKNOWLEDGMENTS

This Study was supported by the Korean Ministry of Science & Technology through its National Nuclear Technology Program.

REFERENCES

[1] D. Hahn, et al., "Design Features of Advanced Sodium-Cooled Fast Reactor KALIMER-600," Proceeding of ICAPP'04, Pittsburgh, USA, 2004.

[2] Y. B. Lee, Dohee Hahn, A Review of the Core Catcher Design in LMR, KAERI/TR-1898/2001.

[3] C. G. Park, Preliminary Design of KALIMER-600 Core Catcher, IOC-MS-003-2005, KAERI, 2005.

[4] S. G. Hong, Criticality Calculation of KALIMER-600 Core Catcher, IOC-CD-010-2005, KAERI, 2006.

[5] ASME Boiler and Pressure Vessel Code, Section III Part 1 Appendix F, ASME, 2004.