Design and Structural Evaluation of the ABTR IHTS Piping for Representative Duty Events of a Level A Service

Chang-Gyu Park[a*], Gyeong-Hoi Koo[a]
[a]*Fast Reactor Technology Development Division, Korea Atomic Energy Research Institute*
[*]*Corresponding author: chgpark@kaeri.re.kr*

1. Introduction

The ABTR(Advanced Burner Test reactor) developed at Argon National Laboratory is a 95MWe(250MWt) pool-type Sodium-cooled Fast Reactor. The primary objectives of the ABTR are 1) to demonstrate reactor-based transmutation of transuranics as part of an advanced fuel cycle, 2) to qualify the transuranics-containing fuels and advanced structural materials needed for a full-scale ABR(Advanced Burner Reactor), 3) to support the research, development and demonstration required for certification of an ABR standard design by the U.S. Nuclear Regulatory Commission[1]. The structural design of the ABTR preconceptual design can accommodate the specified duty cycle events to assure its structural integrity. In this study, the structural integrity of the IHTS piping is evaluated for the representative duty cycle events for Level A Service.

2. System Description

2.1 IIHTS Features

The IHTS(Intermediate Heat Transport System) circulates secondary sodium coolant, transporting heat from the primary heat transport system(PHTS) to the power generation system. Though both supercritical CO_2($S\text{-}CO_2$) Brayton and Rankine steam cycle power generation systems are under consideration for the ABTR, the IHTS description provided in this study is based on the reference $S\text{-}CO_2$ power conversion system. Figure 1 shows the ABTR IHTS layout. The IHTS is composed of two completely independent loops as shown in the Figure. Major components in each of the two loops include the EM pump, PCHE(Printed Circuit Heat Exchanger), sodium storage tank, and the piping connecting these components to each as well as the IHX and PCHE[1].

2.2 Evaluation Model

The IHTS piping primarily consists of the main system hot and cold legs which make the necessary connections between the IHX and the PCHE. The hot leg piping connects to the secondary sodium outlet of the IHX directly to the PCHE sodium inlet[1]. The selected model in this study is the IHTS hot leg piping because a hot leg is exposed to a creep environmental and thus its structural integrity may be easily vulnerable. The IHTS hot leg piping is constructed from 40.6cm OD, 1.27cm thick-walled Type 304 stainless steel piping. It is attached to the $S\text{-}CO_2$ and IHX as shown in Fig.1. Since the reference document[1] does not provides the adequate piping layout, the new piping layout is proposed with additional 2 elbows as shown in Fig.2 by considering the building space and piping size.

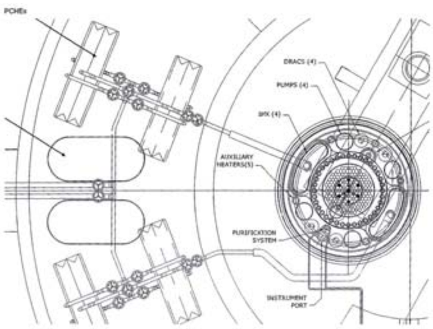

Fig. 1. ABTR IHTS layout.

2.3 Mechanical and Thermal Loads

The mechanical loads under consideration are the structure and coolant dead weights and the coolant pressure of 0.5MPa inside the piping.

The two specified duty cycle event types for Level A Service thermal transient operations in this study are considered as thermal loads as follows.

(a) Cycle type-1(CT-1) : heatup from a hot standby (355℃) to a full power(488℃) for 1.55 hours and a reverse operation with a hold time at full power operation.

(b) Cycle type-2(CT-2) : heatup from a refueling (204℃) to a full power(488℃) through hot standby (355℃) for 6.95 hours and a reverse operation with a hold time.

3. FE Analysis and Structural Integrity Evaluation

3.1 General Assumptions for Analysis

The used heat transfer mechanisms used are assumed as follows;

(a) Piping is supported at the IHX and PCHE only and the intermediate support is not applied.

(b) Piping is assumed to be fixed at the components and piping nozzle analysis is not considered in this preconceptual design.

(c) The linearized transient temperature behavior for heatup and cooldown operation is assumed.

(d) Coolant temperature is not affected by the piping heat transfer and maintained constantly through the whole piping layout

(e) Coolant temperature is same at a given time

(f) A small heat flux exists from the outer surface of the piping to the surrounding air by natural convection with heat transfer coefficient of 1.0W/㎡ · ℃

The FE transient heat transfer and stress analysis are carried out by using ANSYS[2] with 3-D elements. The two critical sections(S1, S2) are selected from the results of the stress intensity analysis as shown in Fig.2

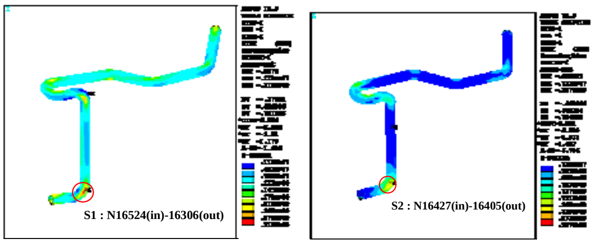

Fig. 2. Selection of the critical sections by stress analysis

3.2 Thermal Transient Analysis

Fig. 3 shows the transient temperature history of selected section for CT-2. As shown in Figure, the temperature behavior is very similar to the coolant temperature because the piping is assumed to be nearly insulated and coolant temperature is not affected from the piping heat transfer. The CT-1 temperature history is not shown for lacks of paper space but its behavior is also similar to the coolant temperature behavior.

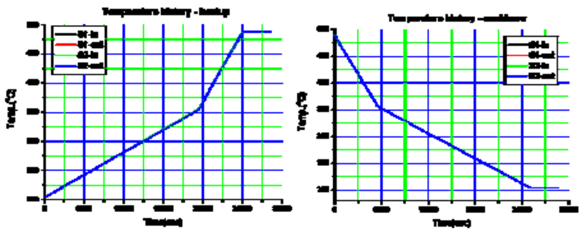
Fig. 3. Temperature history of selected regions for CT-2

3.3 Stress Analysis

The stress intensity analysis is carried out for each case of a primary loading and thermal transient loadings. Fig.4 shows the thermal stress history of the selected section for CT-2. The structural integrities for the primary and secondary load conditions are evaluated with the calculated current stress and strain components for each load cycle type.

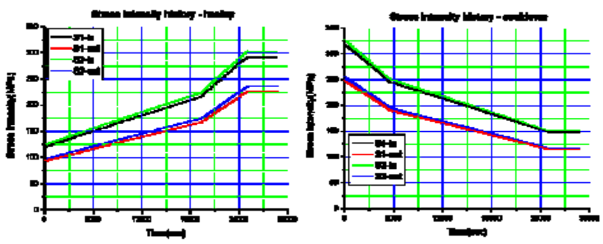
Fig. 4. Stress intensity history of selected regions for CT-2

3.4 Structural Integrity Evaluation

The normal operating temperature of the IHTS hot leg piping is 488℃ and thus the structural integrity evaluations should follow the ASME Subsection NH[3] procedure. Since the ASME-NH procedure is very complex and calculation errors and a long calculation time may occur, the structural integrity evaluation in this study is performed by using the SIE ASME-NH[4] program which is a computerized program of ASME Pressure Vessels and Piping Code Section III Subsection NH.

4. Conclusions

Table 1 shows a summary of the evaluation results for the structural integrity associated with the stress and strain limits and the creep-fatigue damage limits. As shown in the results, the proposed design of the IHTS hot leg piping layout satisfies the Level A Service limits for the two selected sections. For the creep-fatigue evaluation results, it is found that the calculated creep damage is very severe compared with the fatigue damage and the enveloped load cycle induces more conservative evaluation results for both creep and fatigue damages

Generally the events in a Level A Service include the daily and weekly loadings and these events may effect the fatigue damage. Therefore, a further study will be followed by considering the enveloped condition with the daily and weekly loadings of Level A Services as well as the Level B Service events.

Table 1: Evaluation summary for selected sections

		P_m (MPa)	P_L+P_b (MPa)	Strain limits	Creep damage	Fatigue damage
S1	CT-1	8.1	31.8	0.026	0.640	0.27e-3
	CT-1 + CT-2				0.643	0.33e-3
S2	CT-1	12	18.2	0.141	0.859	0.36e-4
	CT-1 + CT-2				0.863	0.43e-3

ACKNOWLEDGEMENTS

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[4] G. H. Koo, Computer Program of SIE ASME-NH Code, KAERI/TR-3526/2008.