Structural Integrity Evaluation for Decay Heat Exchanger of TRU Burner Reactor

S. H. Kim [a*], S. K. Kim [a]
[a]*Korea Atomic Energy Research Institute, Daejeon 305-600, The Republic of Korea*
[*]*Corresponding author: shkim5@kaeri.re.kr*

1. Introduction

The conceptual design of transuranic (TRU) burner sodium-cooled fast reactor of 3800 MWt is being performed by KAERI. In this type TRU burner reactor, the decay heat exchanger (DHX) is connected to the passive decay heat removal system (PDHRS) and the active decay heat removal system (ADHRS), and consists of the inner piping of the DHX where the secondary sodium enters and the upper and lower tube sheets separated by a straight tube.

Fig. 1 shows the design concept of a DHX. In this figure, primary sodium enters the inlet groove of the DHX at the bottom and flows vertically downward parallel to the heat exchange tube. The primary sodium that the heat exchanged inside the DHX is discharged from the lower part outlet inside the DHX. The external diameter of the DHX cylinder is designed as 933 mm considering the arrangement of the piping of the decay heat removal system and the heat exchange tubes. As shown in Fig.1, the heights of nozzles connected to hot and cold piping are designed to be 1340 mm and 3040 mm from the reactor head [1]. The cylindrical body and heat exchange tubes of the DHX are classified as safety grade 1. This is because DHX tubes provide a pressure boundary between radioactive primary sodium and non-radioactive secondary sodium. The material of heat exchange tubes of the DHX and internal structure is 9Cr-1Mo-V steel.

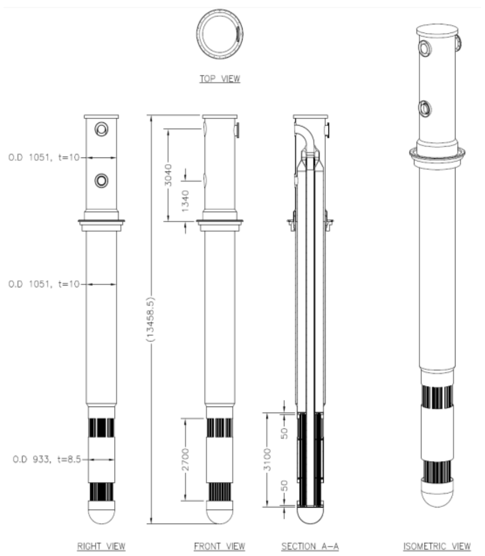


Fig. 1. Conceptual drawing for DHX of TRU burner reactor

2. Stress Analysis of DHX

2.1 Analysis Model

Modeling of three-dimensional finite element analysis is performed for the structural integrity evaluation of the DHX of TRU burner reactor [2].

A half-symmetric model for structural analysis is used, and in case of heat exchange tubes, equivalent stiffness model of the cylinder type for the simplification of the analysis is applied. The finite element model used in the structural analysis is shown in Fig. 2.

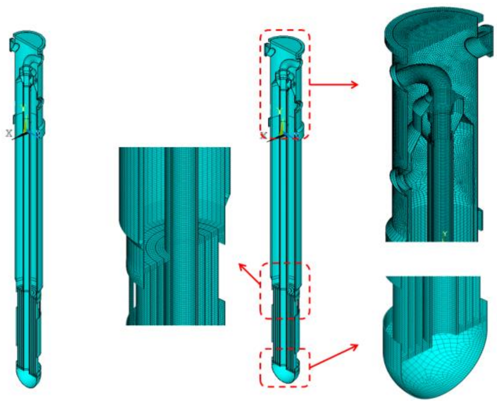
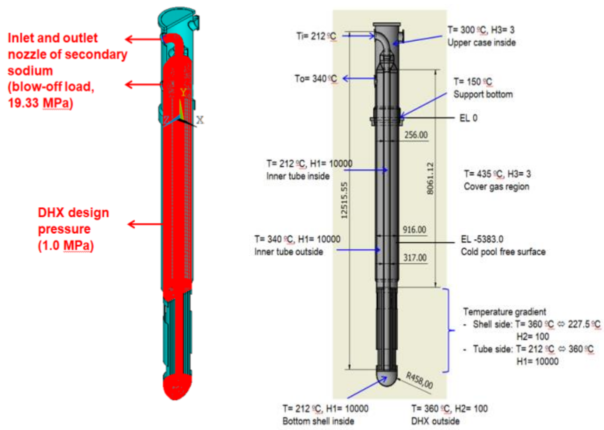


Fig. 2. Finite element model for DHX of TRU burner reactor

Fig. 3 is the loading conditions for pressure and thermal load. The design pressure of 1.0 MPa is applied to all faces contacted with the secondary sodium inside DHX as shown in Fig. 3 (a). In the case of thermal load, the temperature distribution in steady state operating condition is assumed as shown in Fig. 3 (b). The analysis boundary condition of DHX is shown in Fig. 4.



(a) Pressure (b) Thermal load

Fig. 3. Applied load for DHX of TRU burner reactor

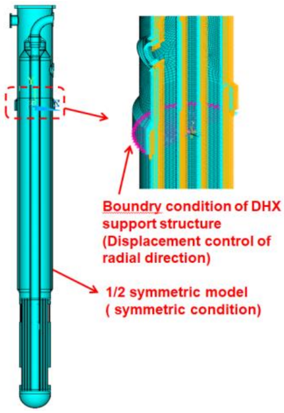


Fig. 4. Boundary condition for DHX of TRU burner reactor

The degree of freedom for the bottom side of DHX support flange is constrained for the displacements in the upward and radial directions, taking into account the conditions under which it is installed in the reactor head.

2.2 Analysis Results

The structural analysis considers the dead weight, pressure, and steady state thermal load, and the result of the stress analysis for the dead weight is shown in Fig. 5. The maximum stress for the dead weight is 6.9 MPa, which occurs at the geometrical discontinuous part of the DHX support flange. The stress analysis result for the sodium weight filled inside DHX is shown in Fig. 6. The maximum stress by sodium weight is 5.7 MPa, which occurs at the Y-junction discontinuity of the DHX outer cylinder.

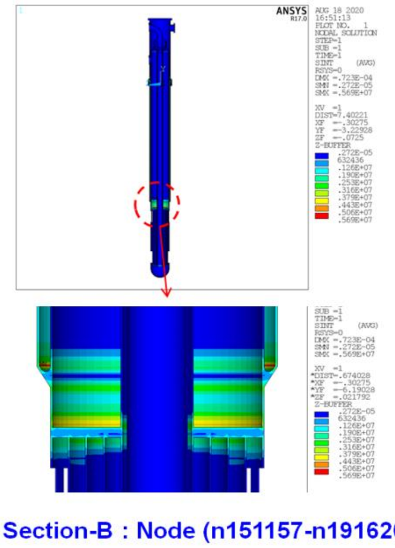


Fig. 6. Stress analysis result for sodium dead weight

For the evaluation according to the ASME design rule for stress analysis results, the stress evaluation sections for the high stress generation parts are selected, and the stress linearization for such sections is performed. The locations and corresponding nodes for the structural integrity evaluation sections are presented in Figs. 5 and 6, respectively

As a result of the stress analysis of the pressure load inside DHX, the maximum stress is 179 MPa as shown in Fig. 7, which occurs at the discontinuity of the nozzle exit for the secondary sodium system of the DHX. As a result of the stress analysis of the thermal load, the maximum stress is 159 MPa and occurs at the DHX lower tube sheets as shown in Fig. 8.

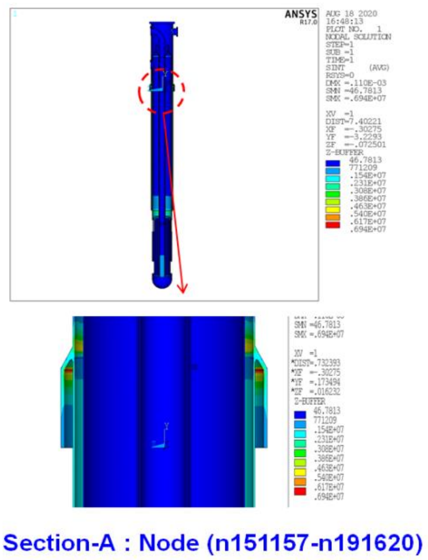


Fig. 5. Stress analysis result for dead weight

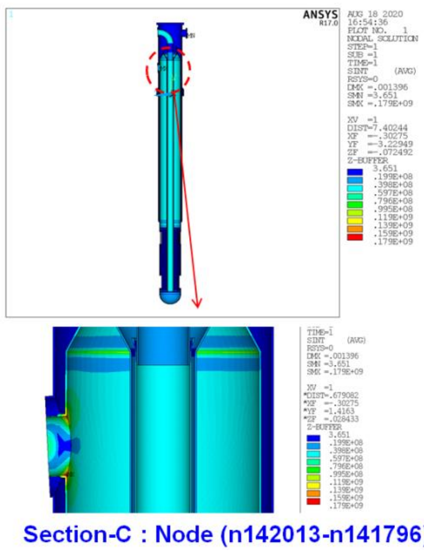


Fig. 7. Stress analysis result for Pressure

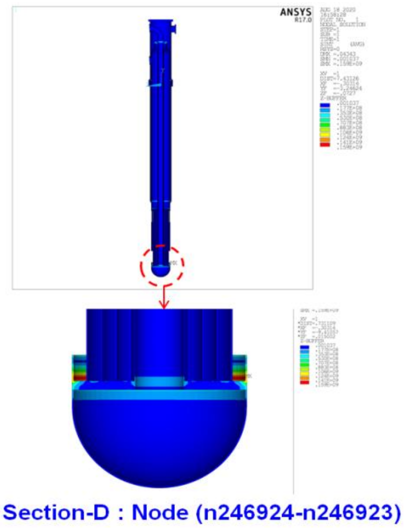


Fig. 8. Stress analysis result for thermal load

The locations and corresponding nodes for the structural integrity evaluation sections are shown in Figs. 7 and 8, respectively.

3. Structural Integrity Evaluation of DHX

The structural integrity evaluation results for DHX are shown in Table 1 and Table 2. The ASME III, Div.5-HBA design rules are applied because the maximum temperatures of the evaluation sections are kept below the creep temperature [3].

Table 1 Structural integrity check result (design condition)

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	Margin	Temperature (°C)	C&S
Section-A	Inner (28698)	Pm	10.26	194.06	17.91	197.13	ASME Sec III Div5-HBA
		PL + Pb	16.67	291.09	16.46		
	Outer (28606)	Pm	10.26	116.49	10.35	195.86	ASME Sec III Div5-HBA
		PL + Pb	4.78	174.74	35.56		
Section-B	Inner (25504)	Pm	8.54	186.41	20.83	353.66	ASME Sec III Div5-HBA
		PL + Pb	11.05	279.62	24.30		
	Outer (42645)	Pm	8.54	186.11	20.79	355.57	ASME Sec III Div5-HBA
		PL + Pb	13.91	279.16	19.07		
Section-C	Inner (43710)	Pm	126.23	188.20	0.49	339.99	ASME Sec III Div5-HBA
		PL + Pb	180.40	282.30	0.56		
	Outer (40879)	Pm	126.23	188.21	0.49	339.90	ASME Sec III Div5-HBA
		PL + Pb	120.52	282.32	1.34		
Section-C	Inner (43710)	Pm	16.61	193.04	10.62	274.07	ASME Sec III Div5-HBA
		PL + Pb	32.51	289.56	7.91		
	Outer (40879)	Pm	16.67	192.99	10.58	275.24	ASME Sec III Div5-HBA
		PL + Pb	20.63	289.49	13.03		

Table 2 Structural integrity check result (service level A condition)

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	Margin	Temperature (°C)	C&S
Section-A	Inner (28698)	PL + Pb +Pe + Q	34.10	590.14	16.31	197.13	ASME Sec III Div5-HBA
		Thermal Ratcheting	17.61	0.167E5	947.32		
	Outer (28606)	PL + Pb +Pe + Q	13.31	590.14	43.34	195.86	ASME Sec III Div5-HBA
		Thermal Ratcheting	8.78	0.167E5	1901.05		
Section-B	Inner (25504)	PL + Pb +Pe + Q	26.32	590.14	21.42	353.66	ASME Sec III Div5-HBA
		Thermal Ratcheting	22.27	0.200E5	897.07		
	Outer (42645)	PL + Pb +Pe + Q	14.00	590.14	41.15	355.57	ASME Sec III Div5-HBA
		Thermal Ratcheting	18.42	0.201E5	1090.21		
Section-C	Inner (43710)	PL + Pb +Pe + Q	180.41	590.14	2.27	339.99	ASME Sec III Div5-HBA
		Thermal Ratcheting	0.08	0.136E4	16999.00		
	Outer (40879)	PL + Pb +Pe + Q	120.64	590.14	3.89	339.90	ASME Sec III Div5-HBA
		Thermal Ratcheting	0.14	0.136E4	9713.29		
Section-D	Inner (43710)	PL + Pb +Pe + Q	127.12	590.14	3.64	274.07	ASME Sec III Div5-HBA
		Thermal Ratcheting	158.39	0.103E5	64.03		
	Outer (40879)	PL + Pb +Pe + Q	105.20	590.14	4.61	275.24	ASME Sec III Div5-HBA
		Thermal Ratcheting	123.39	0.103E5	82.48		

As a result of the structural integrity evaluation of the design condition and operating level A condition for the corresponding evaluation sections of DHX, ASME allowable stress limits are satisfied and design margin is 0.49 or higher in the design condition.

4. Conclusions

As a result of the structural integrity evaluation for the DHX of TRU burner reactor, it is confirmed that the ASME allowable stress limits are satisfied for the dead weight, pressure, and steady state thermal load and the DHX is structurally adequate in this evaluation condition.

Acknowledgements

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REFERENCES

[1] S. L. Choi and J. W. Han, Preliminary Safety Analysis Report for TRU Burner Reactor System, SFR-050-P2-486-001, KAERI, 2018.
[2] ANSYS User's Manual for Revision 17.0, ANSYS Inc.
[3] ASME B&PV Section III, Division 5-HBA, Low Temperature Service, 2013.