Structural Integrity Evaluation of Decay Heat Exchanger of TRU Burner reactor

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Abstract

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. In this study, the structural integrity evaluation according to ASME III, Div.5-HBA design rules is performed for the conceptual designed DHX of 3800 MWt TRU burner reactor.

Introduction

■ Design Characteristics

- Fig. 1 shows the conceptual drawing for DHX of 3800 MWt transuranic (TRU) burner sodium-cooled fast reactor.
- 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 933 mm.
- The heights of nozzles connected to hot and cold piping are designed to be 1340 mm and 3040 mm from the reactor head [1].

■ Design Conditions

- Component class: class A
- Seismic class : class A
- Design material: 9Cr-1Mo-V steel
- Design life time: 60 years

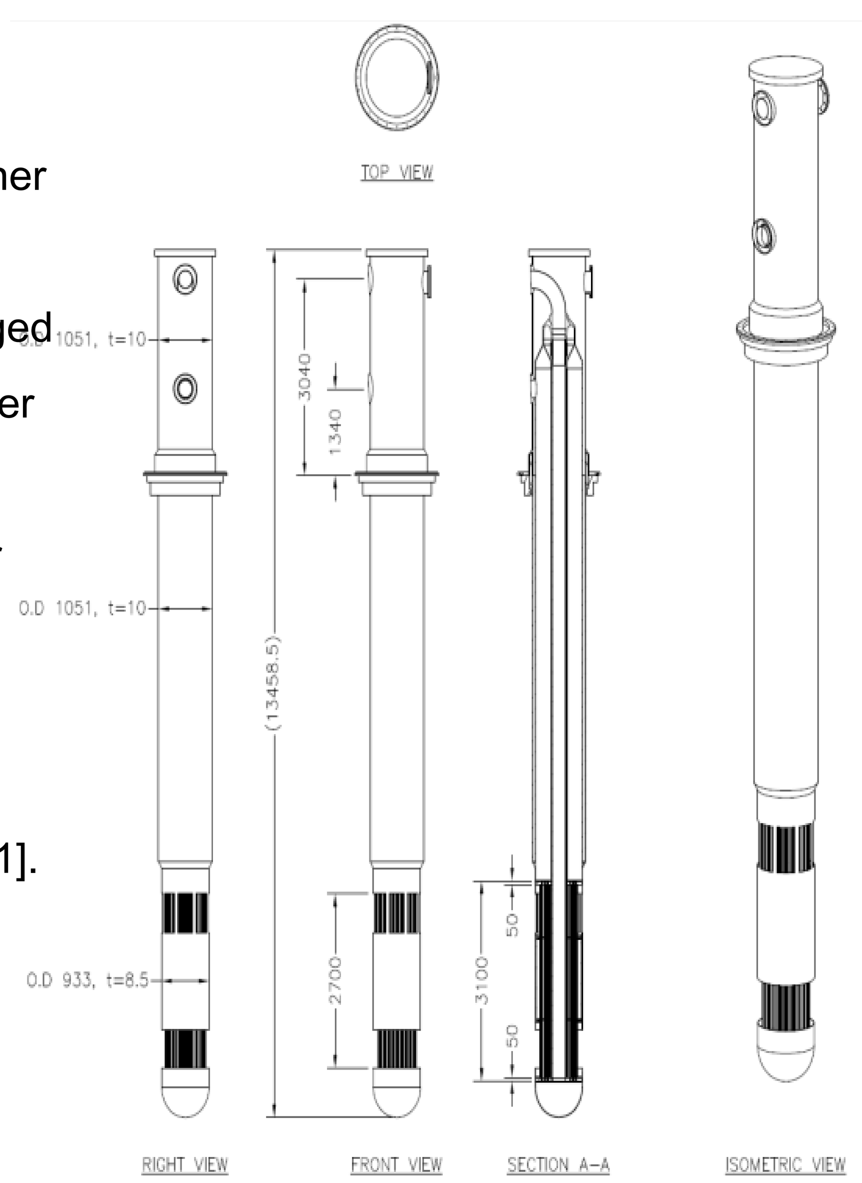


Fig. 1 Conceptual drawing for DHX of TRU burner reactor

3D Modeling of Decay Heat Exchanger

■ Analysis Model

- Half symmetry model [2]
- In the case of heat exchange tubes, equivalent stiffness model of the cylinder type for the simplification of the analysis is applied.

■ Applied Loads

- The dead weight including the sodium weight inside DHX is considered.
- The blow-off load of 19.33 MPa at the inlet and outlet nozzle of secondary sodium is applied.
- The design pressure of 1.0 MPa is applied to all faces contacted with the secondary sodium inside DHX (Fig. 3 (a)).
- In the case of thermal load, the temperature distribution in steady state operating condition is assumed (Fig. 3 (b)).

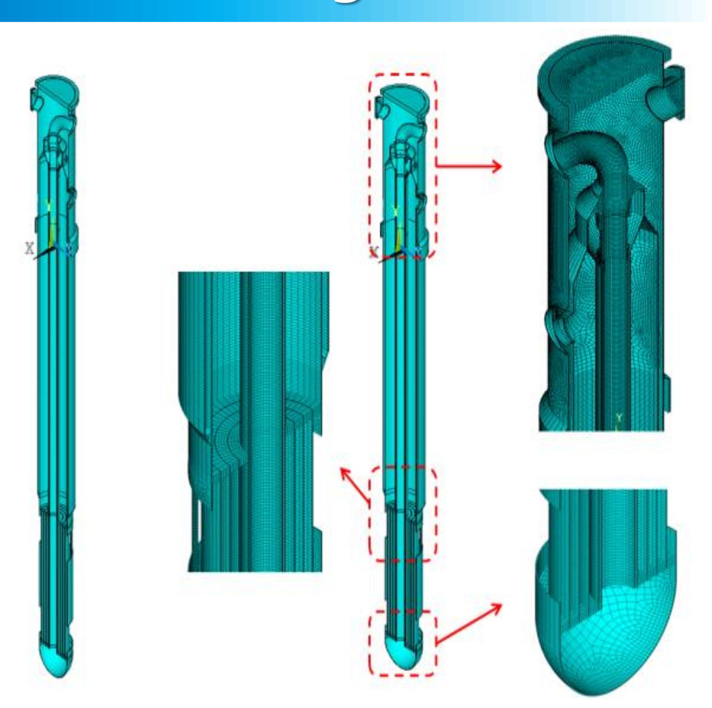
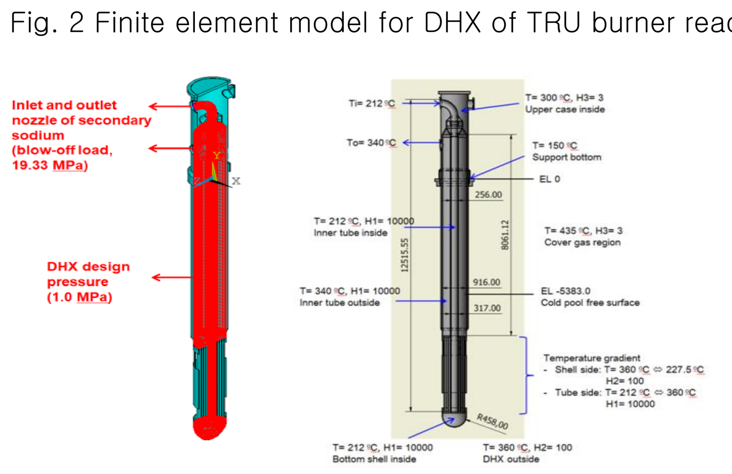


Fig. 2 Finite element model for DHX of TRU burner reactor



(a) Pressure (b) Thermal load

Fig. 3 Applied load for DHX of TRU burner reactor

■ Boundary Conditions

- The degree of freedom for the bottom side of DHX support flange is constrained for the displacements in the upward and radial directions.

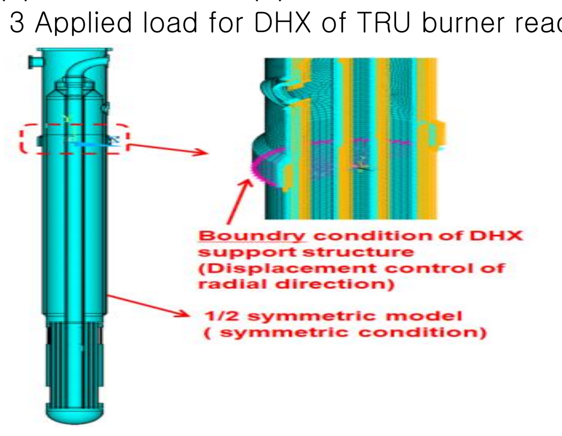


Fig. 4 Boundary condition for DHX

Analysis Results of Decay Heat Exchanger

■ Structural Integrity Evaluation Section A

- The maximum stress for the dead weight is 6.9 MPa, which occurs at the geometrical discontinuous part of the DHX support flange.
- The evaluation section for the structural integrity check of dead weight is shown in Fig. 5.

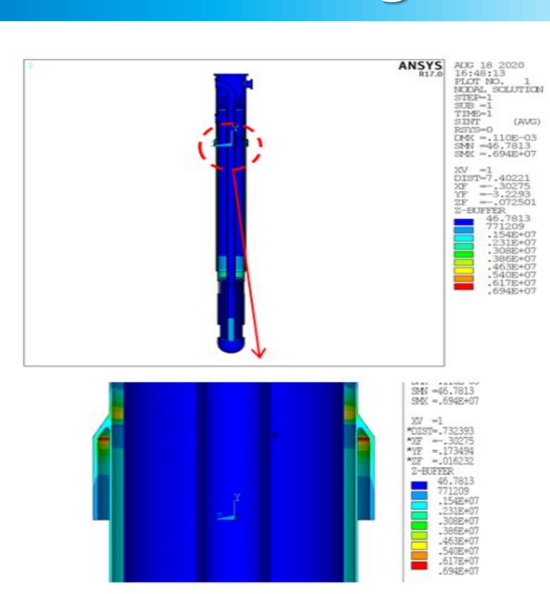


Fig. 5 Stress analysis result and evaluation section for dead weight

■ Structural Integrity Evaluation Section B

- The maximum stress by sodium weight is 5.7 MPa, which occurs at the Y-junction discontinuity of the DHX outer cylinder.
- The structural integrity evaluation section for the sodium weight filled inside DHX is shown in Fig. 6.

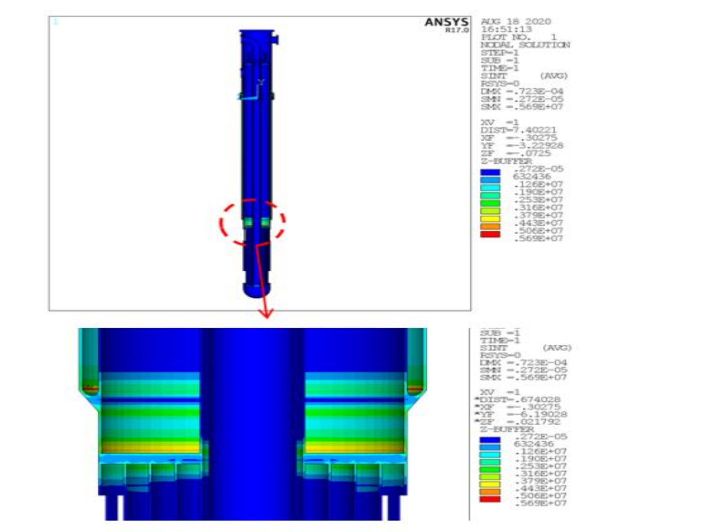


Fig. 6 Stress analysis result and evaluation section for sodium weight

■ Structural Integrity Evaluation Section C

- 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.
- The structural integrity evaluation section for the pressure load is shown in Fig. 7.

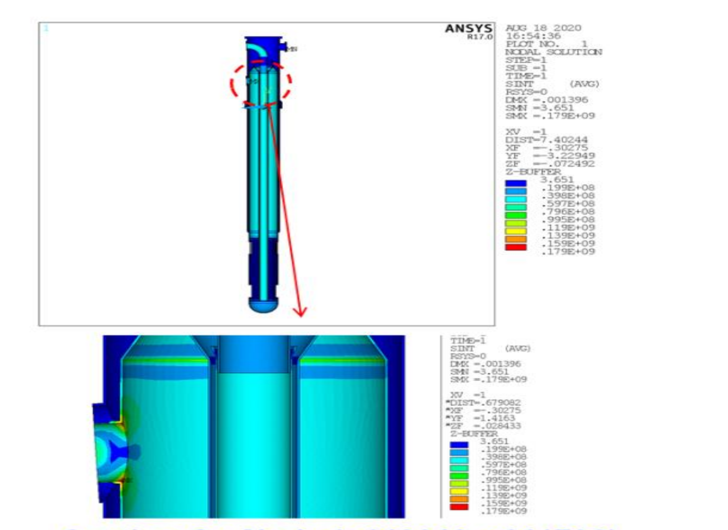


Fig. 7 Stress analysis result and evaluation section for internal pressure

■ Structural Integrity Evaluation Section D

- 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.
- The structural integrity evaluation section for thermal load is shown in Fig. 8.

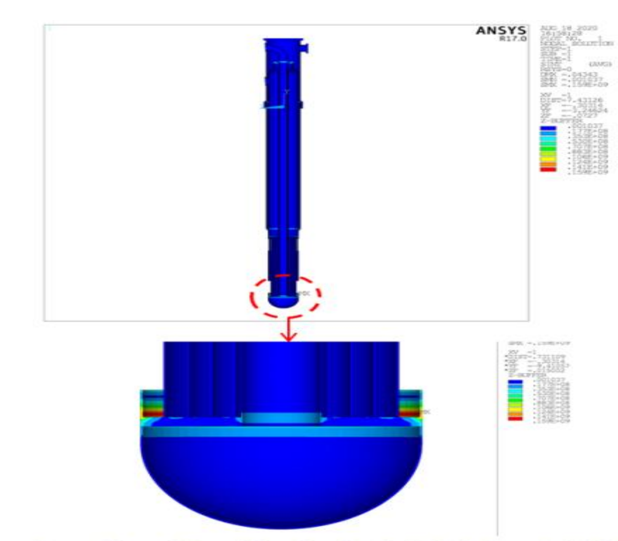


Fig. 8 Stress analysis result and evaluation section for thermal load

Structural Integrity Evaluation of Decay Heat Exchanger

■ Structural Integrity Check Results

- Structural integrity evaluation was performed for the DHX in the design condition and the service level A condition
- ASME Sec. III, Div.5–HBA regulations [3] are applied because the maximum temperatures of the evaluation sections are kept below the creep temperature.
- ASME allowable stress limits are satisfied and design margin is 0.49 or higher in the design condition.

Table 1 Structural integrity check results (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 results (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		

Conclusion

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.

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.