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Preliminary Structural Analysis of a Reactor Internal Structure in a SMFR

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1. Introduction

The reactor internal structure of a SMFR(Small Modular Fast Reactor) is evaluated for the thermal and mechanical loads during a normal operating condition. It is a single integrated unit that separates the hot pool from the cold pool, and provides for a communication of the hot sodium from the discharge of the reactor core to the inlet of the intermediate heat exchanger. In the case of a normal operation, the cold pool and hot pool temperatures around the reactor internal structure are 355 °C and 510 °C, respectively. The material of a reactor internal structure is 316 stainless steel, which is classified as a class 1 component in this report. At the evaluation sections for which the maximum temperatures of the reactor internal structure are above 371°C, the creep effect is significant. Thus, the structural integrity of a reactor internal structure is evaluated with the requirements of the ASME Section III, Subsection NH and the load controlled and strain controlled design limits are checked[1]. The mechanical and thermal stresses and strains are compared with the allowable design and service limits. The elastic approach, the simplified inelastic approach and the creep fatigue evaluation are applied to provide a quantitative assessment of the deformation and strain.

2. Modeling of Reactor Internal Structure

The reactor internal structure of a SMFR consists of multiple plates welded together that form a contoured shape around the intermediate heat exchangers and the upper internal structure. The intermediate heat exchangers and the upper internal structure are located within the reactor internal structure. The primary pumps are located outside the reactor internal structure in the cold pool. The reactor internal structure contains the hot sodium from the core outlet and helps to minimize leakage from the hot sodium to the cold sodium sides of the reactor internal structure. It is supported vertically by the lower internal structure and seal welded core barrel. The reactor internal structure is one of the permanent structures within the reactor vessel.

The main dimensions are 11.1 m in height and 0.02 m in thickness. The finite element analysis was performed using FEA software ANSYS. Three dimensional geometry is modeled and the simple model without a mechanical seal between the IHX and reactor internal structure are presented in Fig. 1. The used temperature dependent material properties of 316 stainless steel are based on ASME Section II, Part A, Part D and Section III, NH[2]. Fig. 2 shows the coolant temperature distribution around the reactor internal structure during normal operation. The coolant temperature in the hot region and the gas region are 510 °C and 500 °C in the steady state condition, respectively. During the cool down, they are decreased to the temperature of 200 °C and 150 °C for 12 hours as shown in Fig. 3.

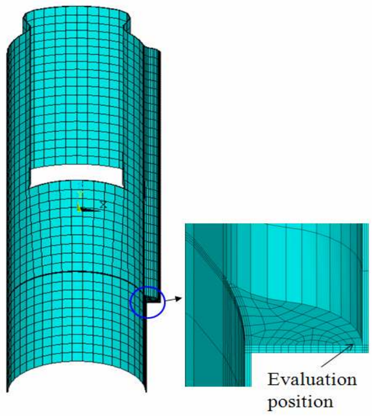

Fig. 1 Finite element model of reactor internal structure

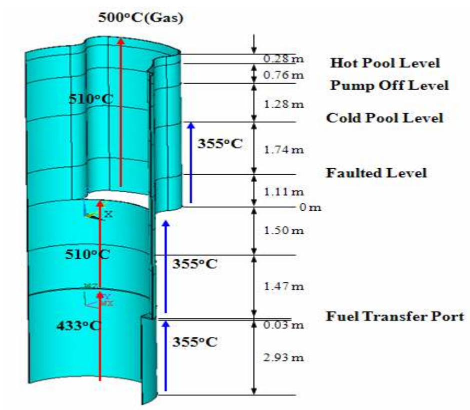

Fig. 2 Boundary conditions of reactor internal structure

The total design life time for the structural evaluation is assumed as 30 years. The maximum temperature of the normal operation is 510 °C and the hold time is 12,000 with 20cycle. The reactor internal structure is analyzed for the dead weight and thermal load given from the normal operation condition.

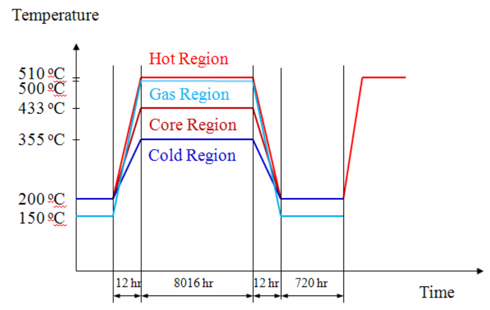

Fig. 3 Coolant temperature distribution of reactor internal structure

In this evaluation stage, a detailed thermal load and a seismic load are not considered because the detailed design loads are not decided yet. Thus, a detailed design and structural integrity evaluation of the reactor internal structure will be carried out in the next stage.

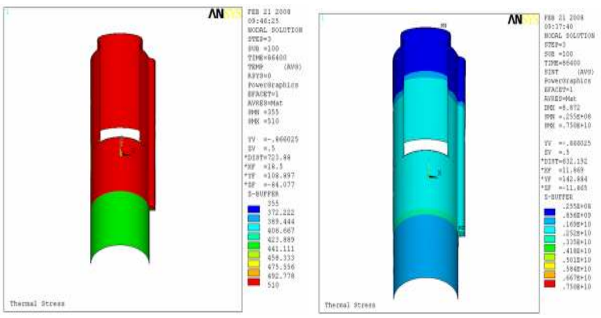

Fig. 4 Temperature and stress intensity distribution of reactor internal structure

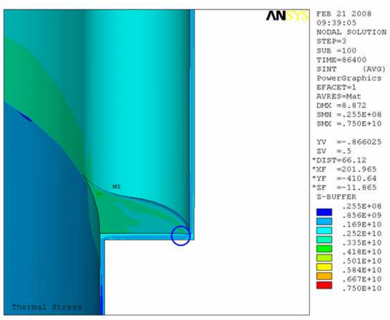

Fig. 5 Critical location of reactor internal structure

3. Results and Discussions

The reactor internal structure was evaluated for the thermal load and the dead weight during a normal operating condition. Fig. 4 shows the temperature and stress intensity distributions of a reactor internal structure. The critical location as indicated in Fig. 5 is located in the geometrical discontinuity of the fuel transfer port. The structural integrity check results in this position are represented as shown in Table 1. The membrane and bending stresses due to the primary stresses are very small because consider only the dead weight, and the primary stresses are acceptable with great design margins. In the case of the inelastic strain results, the elastic approach does not satisfy the limit value of 1.0 because the effect due to the secondary stress is great, but the simplified inelastic approach satisfies the limit value of 1.0%. For the check results of creep fatigue limit, the calculated fatigue and ceep damage is 0.00053 and 0.03075, respectively. As shown in Table 1, the fatigue and creep damage limits value are 0.9283 and 0.9988. Thus, the calculated fatigue and creep damage are negligible. The calculated mechanical and thermal stresses and strains are acceptable with enough margins against the allowable stress limits.

Table 1. Structural integrity check results

Evaluation Items	Calculated	Limit value	Check
❑ Primary Stress Limits			
Membrane	0.0001	109.4	OK
Membrane + Bending	0.0004	142.3	OK
❑ Inelastic Strain Limits			
Elastic Approach	2.2714	1.0	Not OK
Simplified Inelastic Approach	0.0 %	1.0 %	OK
❑ Creep-Fatigue Limits			
Fatigue Damage	0.00053	0.9283	OK
Creep Damage	0.03075	0.9988	OK

4. Conclusions

The structural integrity for a reactor internal structure of a SMFR to sustain a normal operation load and limiting accident loads has been confirmed through a comparison of their structural responses with the ASME code stress limits and the structural deformation limits.

Acknowledgements

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REFERENCES

[1] ASME Boiler and Pressure Vessel Code Section III, Subsection NH, ASME, 2004.
[2] ASME Boiler and Pressure Vessel Code Section II, Part A, Part D, ASME, 2004.