# Integrity Evaluation of the UIS Bottom Plate in PGSFR regarding the Thermal Striping

Jae-Hun Cho [a*], Chang-Gyu Park [a], Sung-Kyun Kim [a], Jong-Bum Kim [a]
[a] *Korea Atomic Energy Research Institute,111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, The republic of Korea*
[*]*Corresponding author: jhc@kaeri.re.kr*

## 1. Introduction

UIS (upper internal structure), a one of the internal components of PGSFR, consists of the perforated cylinders, three support plates, CRDM (control rod drive mechanism) guide tube and thermocouples. As shown in Fig. 1, it is located above the core closely so as to measure core outlet coolant temperature. Also it supports the CRDM guide tubes, ranging sensor guide tubes and other various measuring instruments.

The bottom plate of UIS is continuously exposed to the sodium that comes from different location such as FAs and CRs so that it is exposed on the fast fluctuating sodium temperature. This thermal change causes the thermal fatigue damage so called thermal striping.

In this paper, the thermal striping evaluation method based on ASME B&PV Sec.III Div.5 [1] is introduced and the evaluation results for the bottom plate of UIS are described herein.

## 2. Methods and Results

### *2.1 A method to evaluate the integrity*

The evaluation applies ASME B&PV Code Sec. III Div. 5-HB [1]. According to the code, the design criteria for the evaluation are determined by metal temperature. In case of the UIS which is made of 316 stainless steel, the design criteria applies the subsection HB subpart A if the metal temperature is less than 427℃. it applies the subsection HB subpart B if it is more than 427℃.

The metal temperature of the UIS exceeds to 427℃ so that it applies the subsection HB subpart B. The ASME code has been defined that the subsection HB subpart B applies Div. 1-NH [2]. The Creep-fatigue evaluation follows the NH-T-1400.

### *2.2 Assumption*

1) Thermal fluctuation load is applied to the entire bottom surface of the plate.
2) Top surface of the plate applies the hot pool temperature.
3) Film coefficient for convection analysis applies the 100,000 W/m$^2$-K, which is the forced convection condition of the liquid sodium [3].

### *2.3 FEM Model*

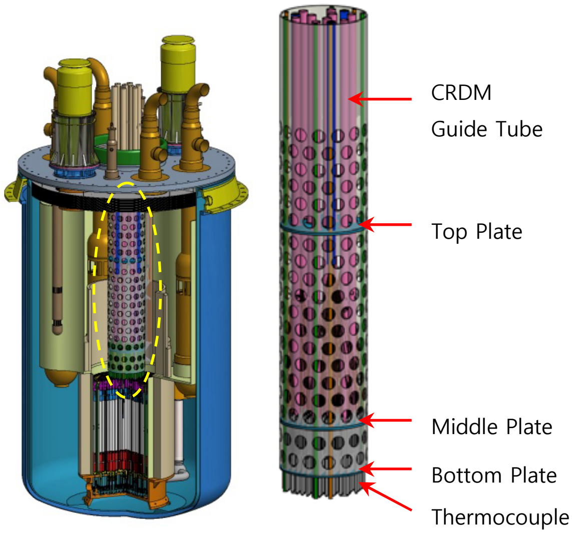



Fig. 1. Configuration of the UIS of PGSFR

The FEM program used ANSYS APDL v.15.0 [4]. CRDM guide tube and thermocouples were excluded from FEM model like Fig. 2 (a). Details are below.

- Model type : 3-D Half Symmetric Model
- Element type :
  Solid185 (8-node Structural Solid)
  Solid77 (8-node Thermal Solid)

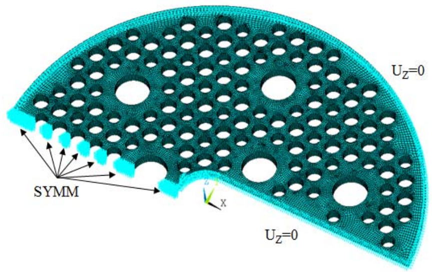
### *2.4 Load and Boundary Condition*

The load condition considered the level A condition following the load combination like table I. All loads operate the UIS at the same time so that it should combine the stress components calculated by the stress linearization. In table I, details of each load are below.

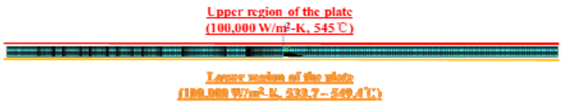
<u>Structural Load</u>
1) Load-S1 : dead weight of the bottom plate.
<u>Thermal Load</u>
2) Load-T1 : thermal fluctuation during the 4.5s.
(Temperature diff': 15 degree)
(Time block: 0.001s)

Table I: UIS normal operation load condition

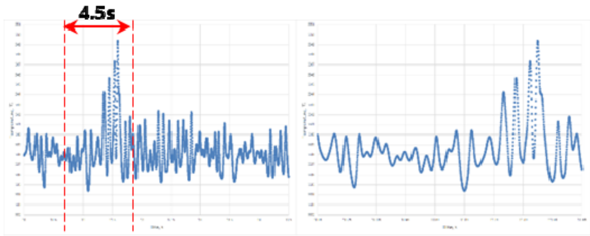
| Service Level | Event Name | Service Time | No. of the Cycle |
|---|---|---|---|
| Level A | Load-S1, T1 | 60 years | 4.20e+08 |




(A) Structural boundary condition




(B) Thermal boundary condition




(C) Time history of the thermal fluctuation

Fig. 2. FEM model and boundary conditions

Fig. 2 shows the FEM model of the bottom plate and boundary conditions. The bottom plate has a large penetration holes for CRDM guide tube and a small penetration holes for thermocouple, ranging sensor guide tube and sodium flow. Also it has a slot for making the IVTM (in-vessel transfer machine) get into the UIS. In Fig. 2 (a), the axial degree of freedom of the boundary lines between the plate and cylinder is fixed. In Fig. 2 (b), the bottom surface of the plate applies the transient thermal condition of the thermal fluctuation and the top surface of the plate applies the steady-state thermal condition of the hot pool. In Fig. 2 (c), it shows the time history of the transient thermal condition. Left is the time history of the sodium temperature under the bottom plate which is measured at the point with the largest temperature difference from the CFD analysis result [5]. To apply the more conservative condition, the section (4.5s) with the largest temperature difference is considered as the thermal fluctuation load.

### *2.5 Analysis result*

Fig. 3, 4 show the equivalent stress distribution of each load. According results, the maximum stress (4.39 MPa) of the structural load-1 occurs at the inner region of the bottom plate slot and axial deformation of the plate is about -0.012 mm. The maximum stress (78.30 MPa) of the thermal load-1 occurs at the inner region of the bottom plate slot, too. The thermal fluctuation effect is found to get through the almost 6 mm at the bottom surface of the plate.

### *2.6 Stress linearization*

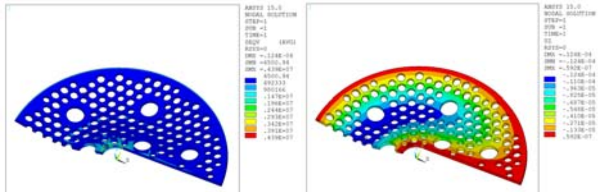


Fig. 3. Equivalent stress distribution (L) and axial deformation (R) of the dead weight

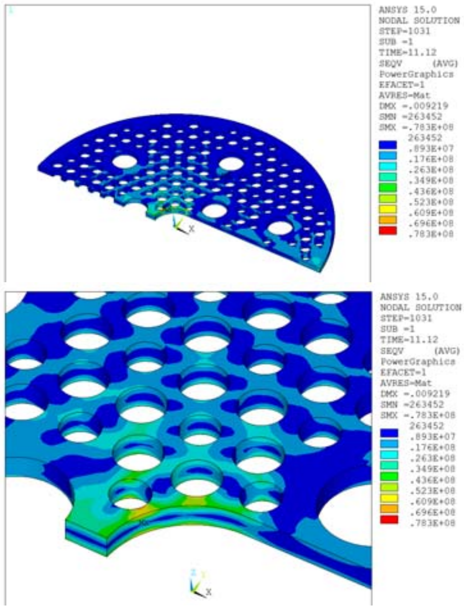



Fig. 4. Equivalent stress distribution of the thermal fluctuation

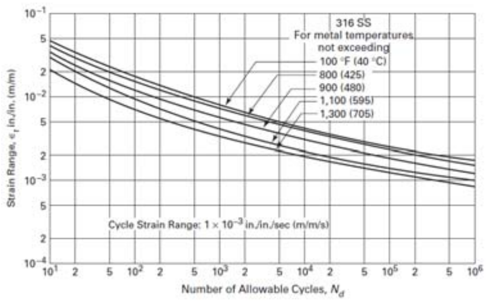



Fig. 5. Design fatigue strain range for 316 SS [2]

In order to calculate the stress linearization, the evaluation section selects four positions distributed the maximum stress like Fig. 6.

- Section A, B: the top surface of the plate
- Section C, D: the bottom surface of the plate

To evaluate the creep-fatigue, it is necessary to know the secondary stress intensity range [2]. The maximum stress intensity range is one of the important values to determine the strain range. Once calculated strain range, it is able to estimate the number of allowable cycles following the fig. 4. The thermal fatigue damage is calculated by comparing the number of allowable cycles and the number of cycles for thermal striping.

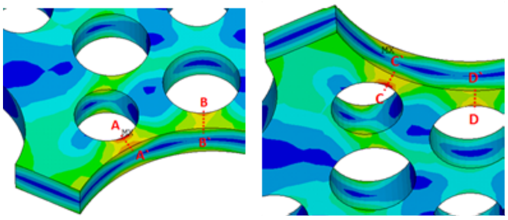



Fig. 6. Positions of section line for stress linearization

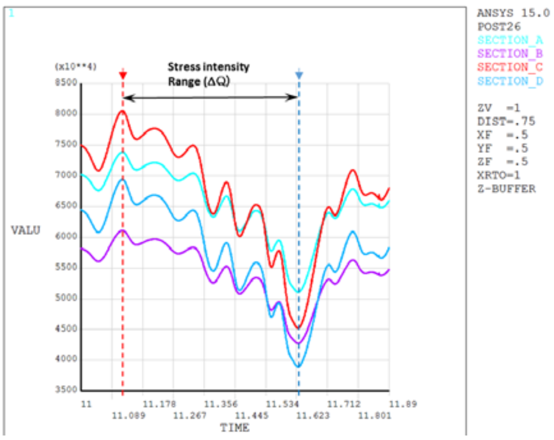



Fig. 7. Secondary stress intensity range of the section A ~ D

Table II shows the evaluation results of the section A ~ D with respect to level A condition. The evaluation result having the minimum design margin is below.

Section C (inner)

Pm=1.65MPa < Smt=76.3MPa : OK
PL+Pb=2.08MPa < 1.5Sm=156.9MPa : OK
PL+Pb/Kt=1.99MPa < St=76.3MPa : OK
Fatigue damage=0.11e-01 < 1 : OK

As a result, the plate design regarding the level A condition has enough design margins and satisfies the design criteria.

Table II: Problem Description

| Section | node | Linearized Stress | Calculated Stress (MPa) | Allowable Stress (MPa) |
|---|---|---|---|---|
| Section A | Inner (A) | Pm | 0.63 | Smt=76.3 |
| | | PL+Pb | 0.35 | 1.5Sm=156.9 |
| | | PL+Pb/Kt | 0.37 | St=76.3 |
| | | Fatigue damage | 0.60e-03 | 1 |
| | | Creep damage | 0 | 1 |
| | Outer (A`) | Pm | 0.63 | Smt=76.3 |
| | | PL+Pb | 1.20 | 1.5Sm=156.9 |
| | | PL+Pb/Kt | 1.08 | St=76.3 |
| | | Fatigue damage | 0.16e-03 | 1 |
| | | Creep damage | 0 | 1 |
| Section B | Inner (B) | Pm | 0.70 | Smt=76.3 |
| | | PL+Pb | 0.72 | 1.5Sm=156.9 |
| | | PL+Pb/Kt | 0.60 | St=76.3 |
| | | Fatigue damage | 0.15e-03 | 1 |
| | | Creep damage | 0 | 1 |
| | Outer (B`) | Pm | 0.70 | Smt=76.3 |
| | | PL+Pb | 1.47 | 1.5Sm=156.9 |
| | | PL+Pb/Kt | 1.31 | St=76.3 |
| | | Fatigue damage | 0.21e-04 | 1 |
| | | Creep damage | 0 | 1 |
| Section C | Inner (C) | Pm | 1.65 | Smt=76.3 |
| | | PL+Pb | 2.08 | 1.5Sm=156.9 |
| | | PL+Pb/Kt | 1.99 | St=76.3 |
| | | Fatigue damage | 0.11e-01 | 1 |
| | | Creep damage | 0 | 1 |
| | Outer (C`) | Pm | 1.65 | Smt=76.3 |
| | | PL+Pb | 1.23 | 1.5Sm=156.9 |
| | | PL+Pb/Kt | 1.32 | St=76.3 |
| | | Fatigue damage | 0.13e-02 | 1 |
| | | Creep damage | 0 | 1 |
| Section D | Inner (C) | Pm | 1.32 | Smt=76.3 |
| | | PL+Pb | 1.62 | 1.5Sm=156.9 |
| | | PL+Pb/Kt | 1.56 | St=76.3 |
| | | Fatigue damage | 0.50e-02 | 1 |
| | | Creep damage | 0 | 1 |
| | Outer (C`) | Pm | 1.32 | Smt=76.3 |
| | | PL+Pb | 1.03 | 1.5Sm=156.9 |
| | | PL+Pb/Kt | 1.09 | St=76.3 |
| | | Fatigue damage | 0.91e-03 | 1 |
| | | Creep damage | 0 | 1 |

## 3. Conclusions

This paper evaluated the integrity of the UIS bottom plate with respect to service level A condition regarding the thermal striping. According evaluation results, the bottom plate design has enough design margins and satisfies the design criteria defined ASME code.

## 4. Acknowledgement

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