Creep-Fatigue Damage Evaluation of a Model Reactor Vessel and Reactor Internals of Sodium Test Facility according to ASME-NH and RCC-MRx Codes

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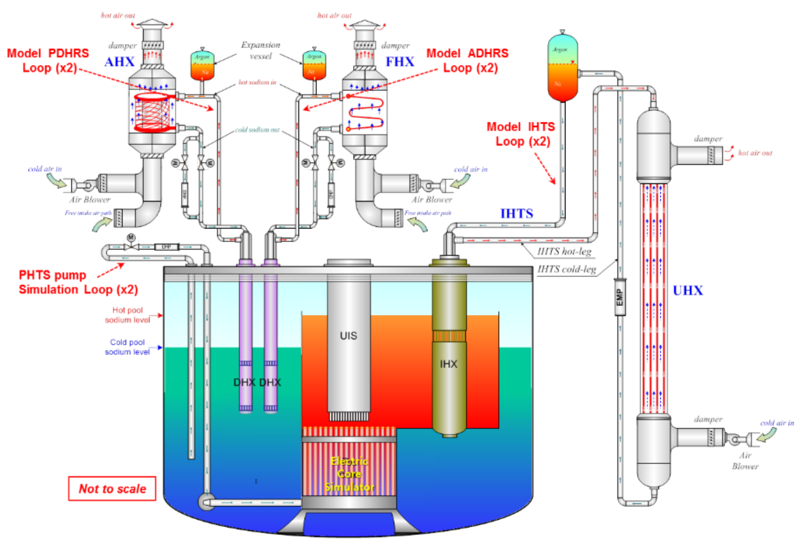
Introduction: STELLA-2

❖ Sodium Integral Effect Test Loop for Safety Simulation and Assessment

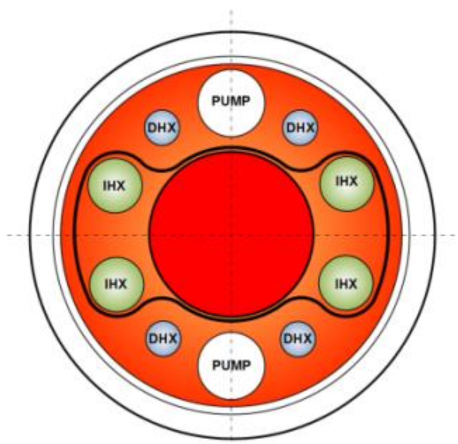
(Reference Plant: PGSFR, Prototype Gen-IV Sodium-cooled Fast Reactor)

❖ Objectives

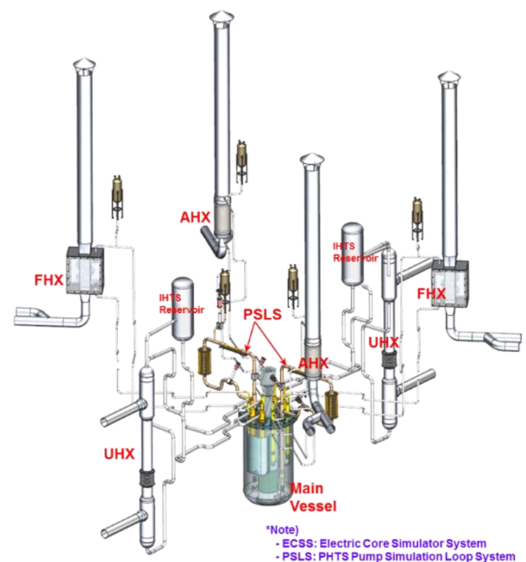
- Synthetic Review of Key Safety Issues and Code Validation
- Support of PGSFR Design Approval



STELLA-2



STELLA-2 Head (Top view)

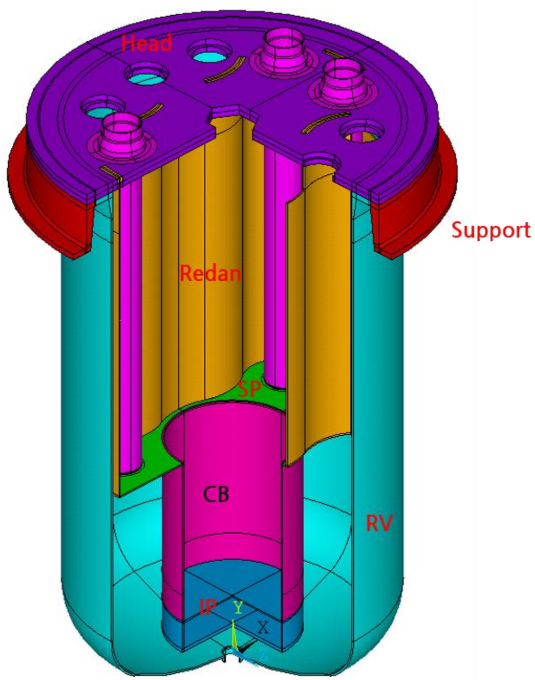


STELLA-2 (Iso-view)

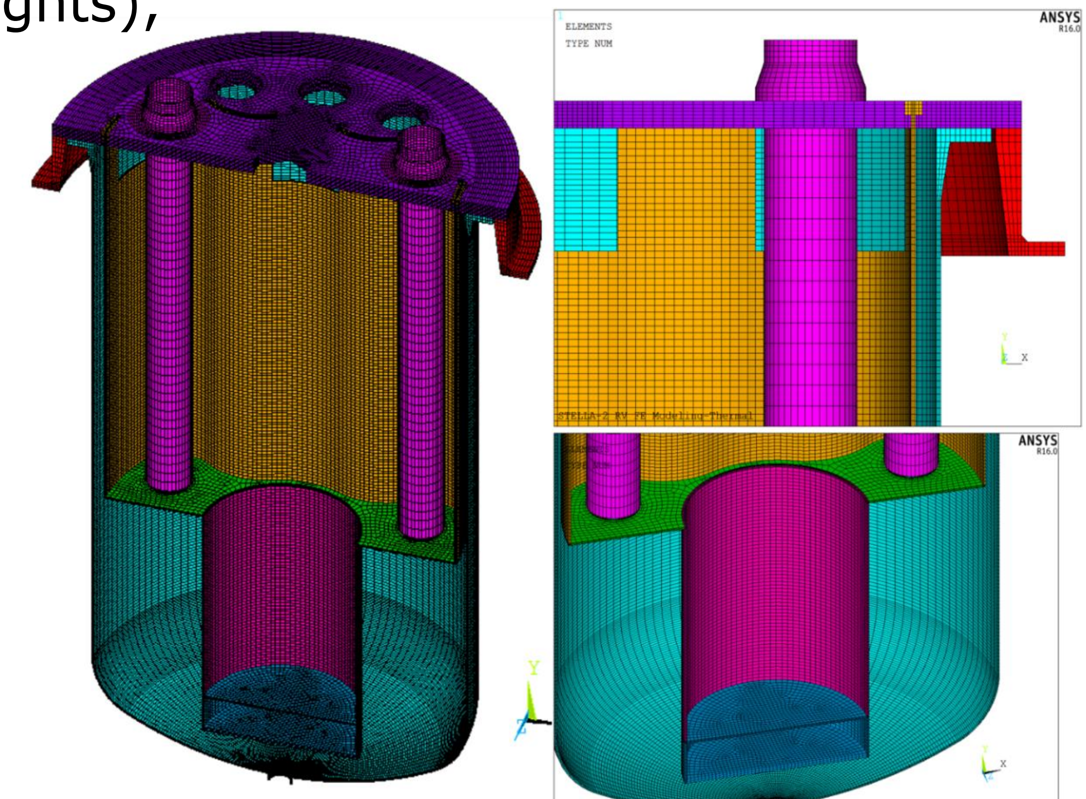
Finite Element Analysis

- A half 3D finite element model STELLA-2 from 3D Computer-Aided Design geometry of the vessel with internals

- 3D Element: SOLID70 (heat transfer), SOLID185 (thermal stress) MASS21 (Sodium, IHX weights),
  170031 elements



STELLA2 geometry model

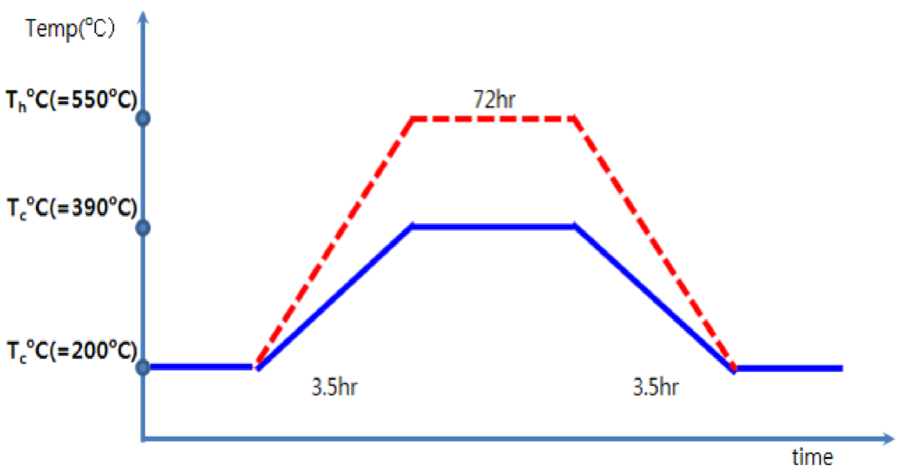


STELLA2 mesh model

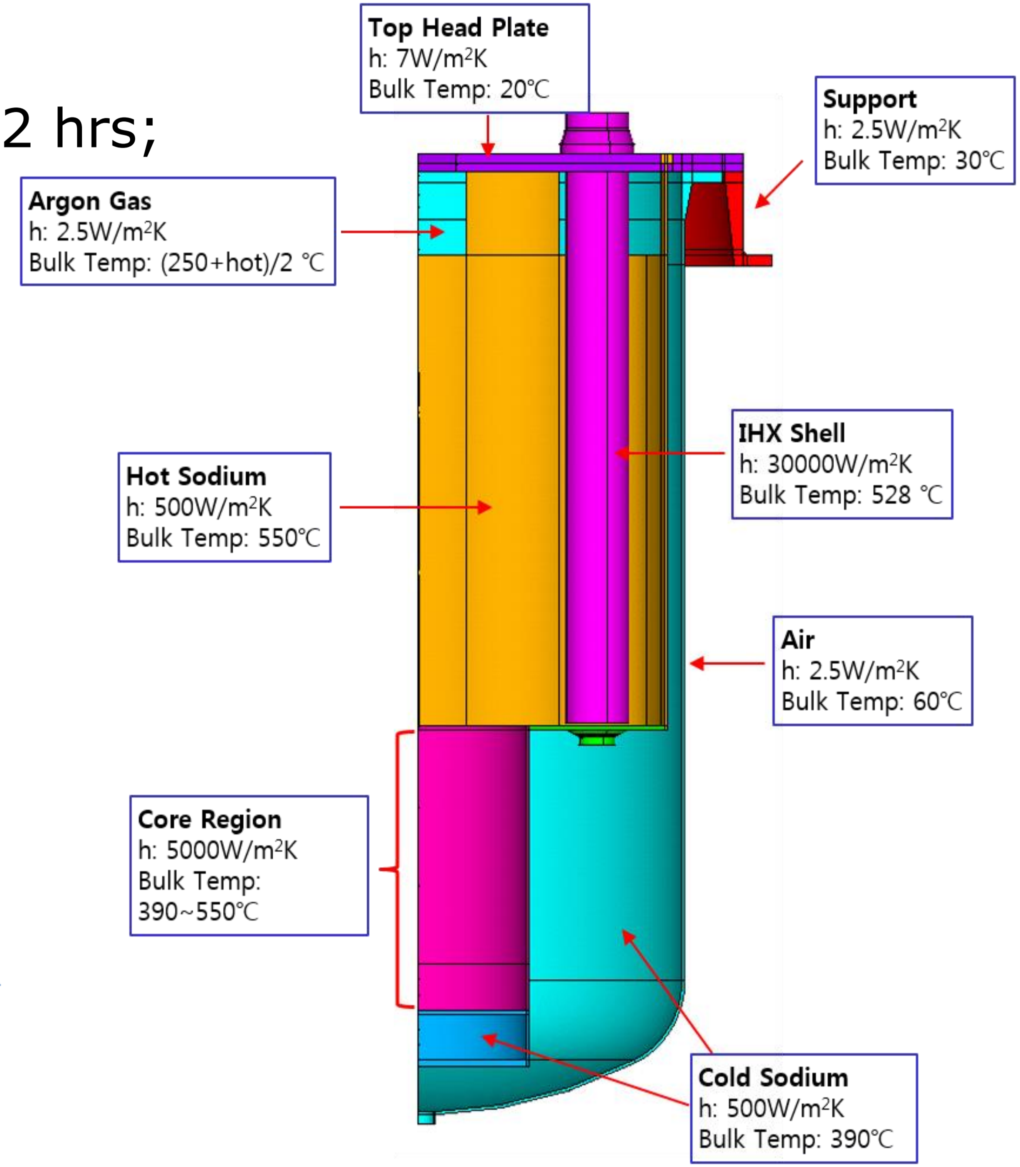
Analysis Setup

- Transient operational conditions:
  heat-up, 3.5 hrs; steady-state, 72 hrs;
  cool down, 3.5 hrs

- Core outlet: 550°C;
  Cold plenum: 390°C

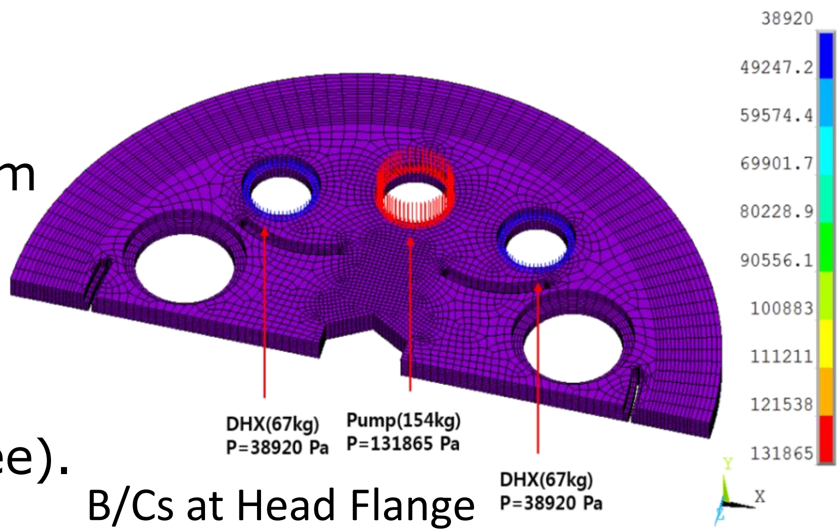


Operation schedule

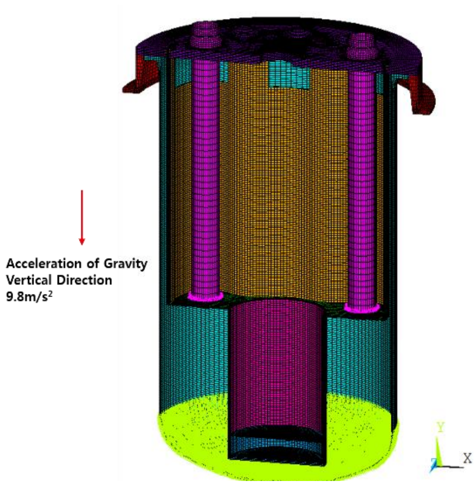


Analysis Setup

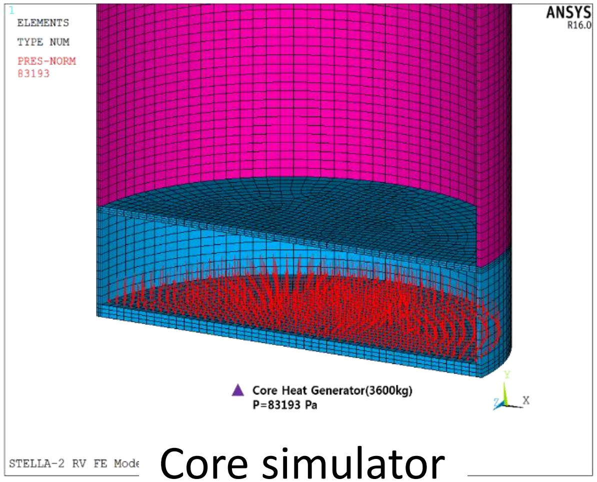
- Equivalent pressure loads for IHX, DHX, Core simulator, and Sodium coolant
- Sodium coolant: linearly increasing pressure from free surface to inlet plenum
- Setting symmetry B/Cs for a half model, only normal and circumferential contact faces are constrained (a radial DOF is free).



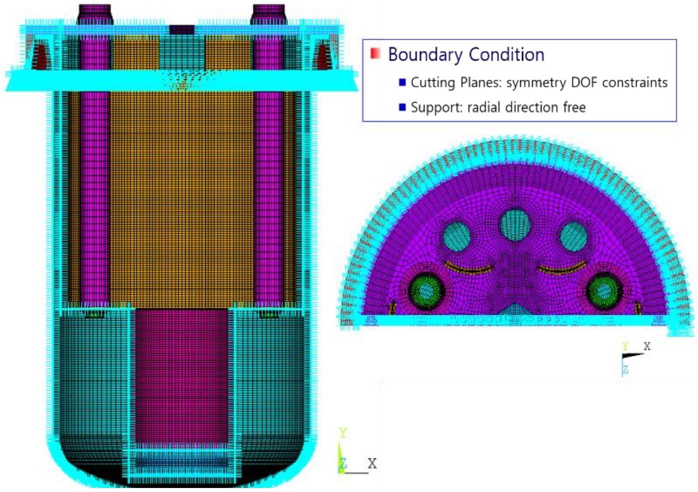
B/Cs at Head Flange



Sodium Coolant



Core simulator



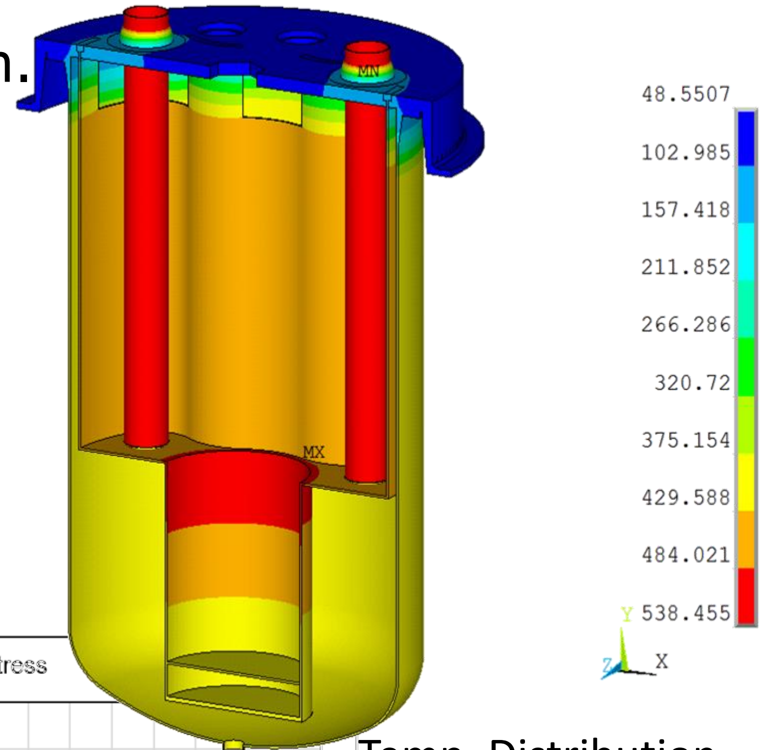
Constraint settings for a half model

Simulation Results: Temperature

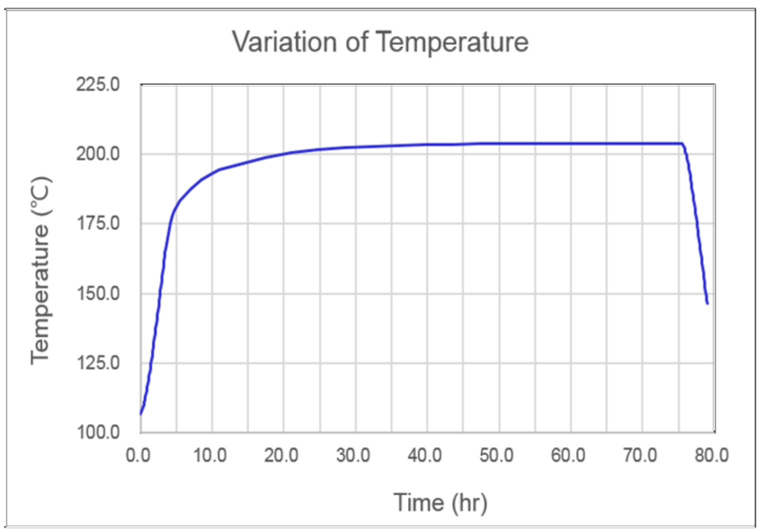
❖ At 4.25 hr, stresses reach to the maximum.

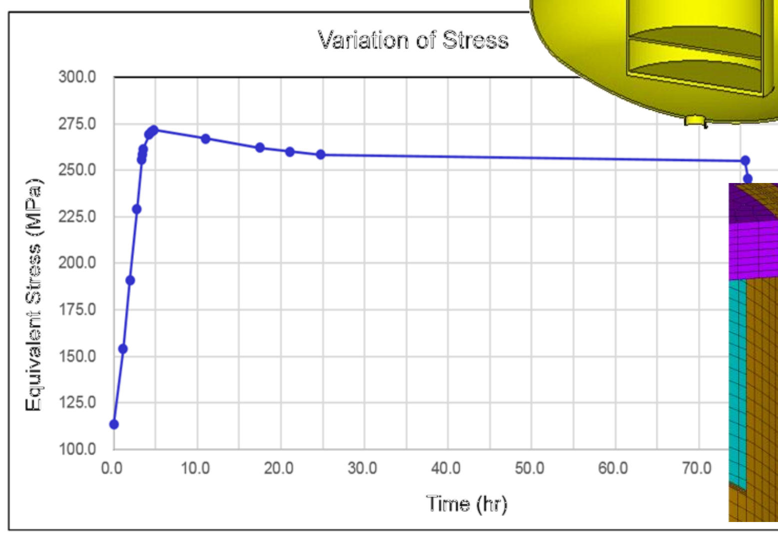
❖ Core exit is the max. at 540°C, and Redan is up to 480°C.

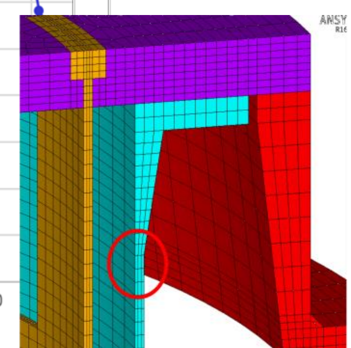
❖ Locations of a steep temperature gradient are investigated.



Temp. Distribution





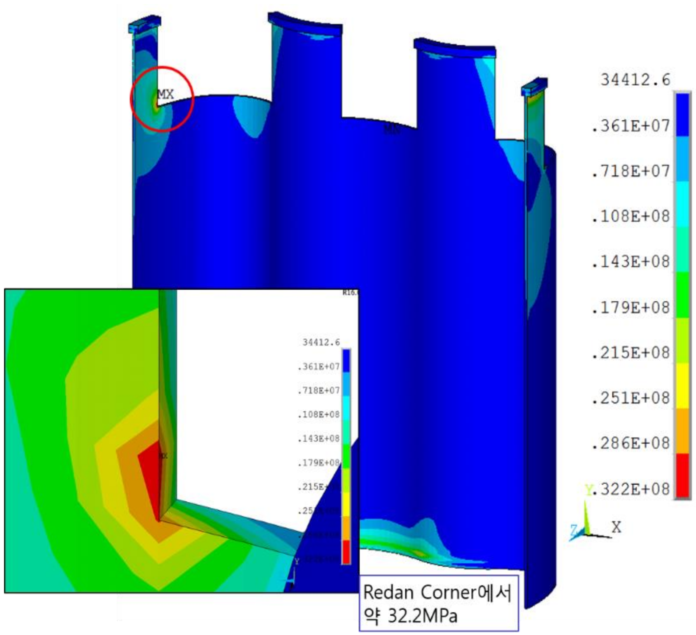


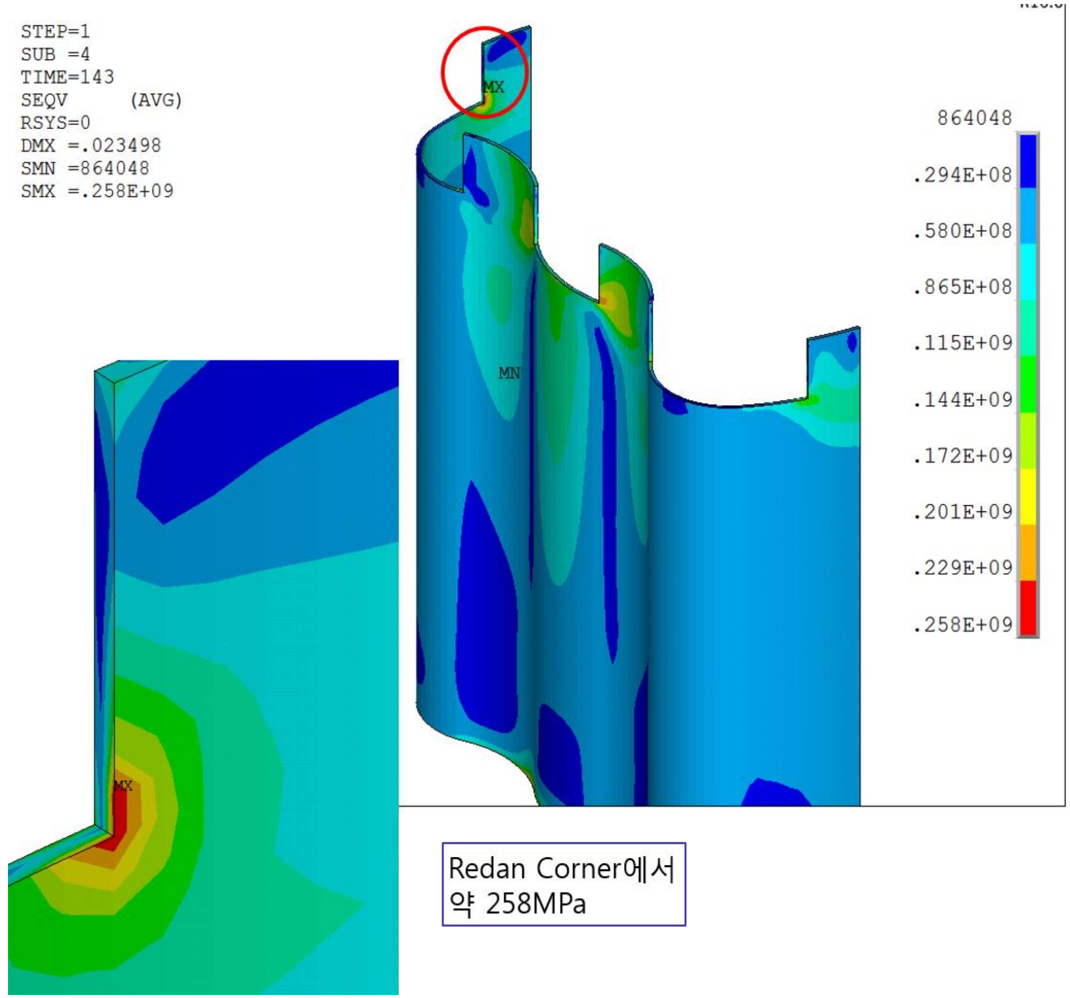
Vessel Rim to the Head

Simulation Results: Thermal Stress

❖ A location at the Redan corner is a critical point subjected to an elevated temperature, and analyzed for creep-fatigue damage.
→ RCC-MRx and ASME-NH

❖ Max stress: 258 MPa
* Allowable stress: 321 MPa





Structural Integrity Evaluation

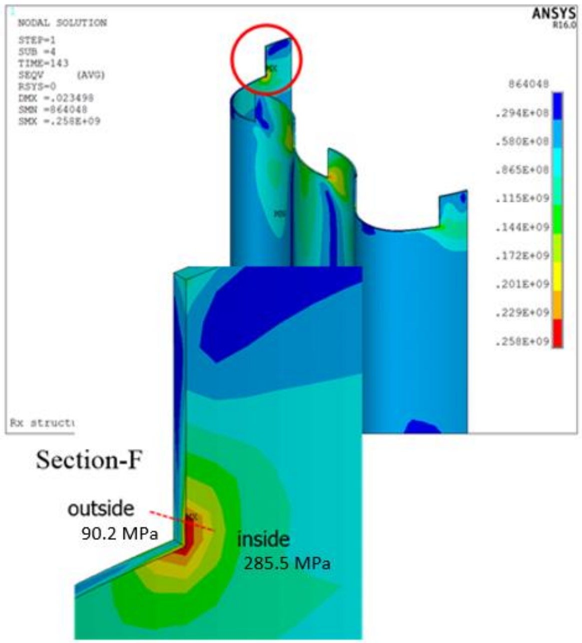
❖ ASME Section III Subsection NH and RCC-MRx are applied.

❖ Evaluation (Design By Analysis, DBA) needs a stress linearization → obtain membrane, bending, and peak stresses.

- **Stress linearization results (Primary + Secondary loads, Redan corner, Unit: MPa)**

	S1	S2	S3	SINT	SEQV	Note
Membrane	8.1	-12.6	-64.6	72.7	64.8	
Membrane +bending	23.1	-9.4	-223	246	231	In
	96.7	-1.3	-24.5	121	111	Out
Peak	9.1	6.1	-1.0	10.1	9.0	In
	0.1	-6.0	-7.8	7.7	7.2	Out
Total	25.0	-2.9	-217	242	229	In
	91.3	-7.3	-26.7	118	110	Out

Total Strain is obtained.



Creep-Fatigue Evaluation Results

❖ The linear damage summation rule is applied.

$$\sum_{j=1}^{p}\left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q}\left(\frac{\Delta t}{T_d}\right)_k \le D$$

❖ From the stress linearization,

$\varepsilon_t = 0.317$ % **(ASME-NH)**

$\Delta\bar{\varepsilon} = \Delta\bar{\varepsilon}_{el+pl} + \Delta\bar{\varepsilon}_{cr} = 0.168(\%)$ **(RCC-MRx)**

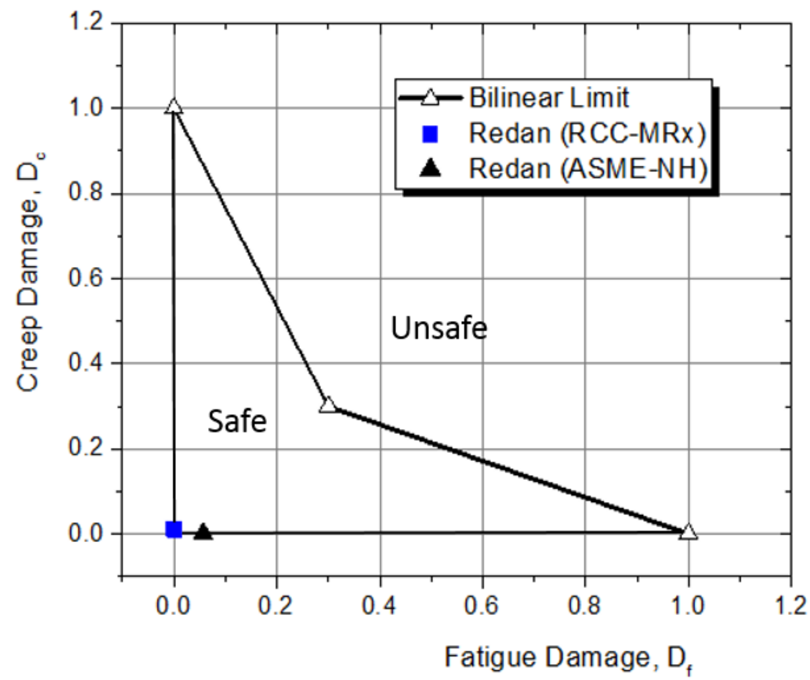
, and determine D_f and D_c.

❖ For ASME-NH

$$D_{f1} = \frac{500}{8788} = 0.057 \qquad D_{c1} = \frac{30}{300000} = 0.0001$$

❖ For RCC-MRx

$$D_{f2} = \frac{500}{2910806} = 0.000172 \qquad D_{c2} = \frac{30}{1573450} = 0.01020$$



High Temperature Creep-Fatigue Evaluation of the Redan Corner

Conclusions

❖ Summary

- ☐ A design integrity was evaluated for the model reactor vessel with its internal structure of STELLA-2.
- ☐ Guarding against a creep-fatigue damage failure operating at high temperature has been considered.
- ☐ The high temperature design codes, ASME-NH and RCC-MRx, were used for the evaluation.
- ☐ Both the design codes utilize a 3D finite element analysis model to calculate damage factors (DBA).
- ☐ The ASME-NH yielded a conservative evaluation.

❖ Future work

- ☐ Analyses for various working conditions including off-design settings (e.g., accidents) are to be carried out.

Thank you