Comparison of RCC-MRx and ASME Subsection NH as Elevated Temperature Design Codes

25. Nov. 2015

Hyeong-Yeon Lee

KAERI **Korea Atomic Energy Research Institute**

Outline

I. Introduction

II. Elevated Temperature Design (ETD) Rules

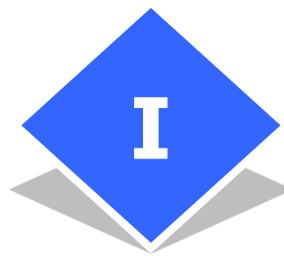**III. Comparison of ETD codes**

    - Material properties

    - Design evaluation procedures

IV. Application of the ETD rules to sodium test facilities

V. Design evaluation program, HITEP_RCC-MRx

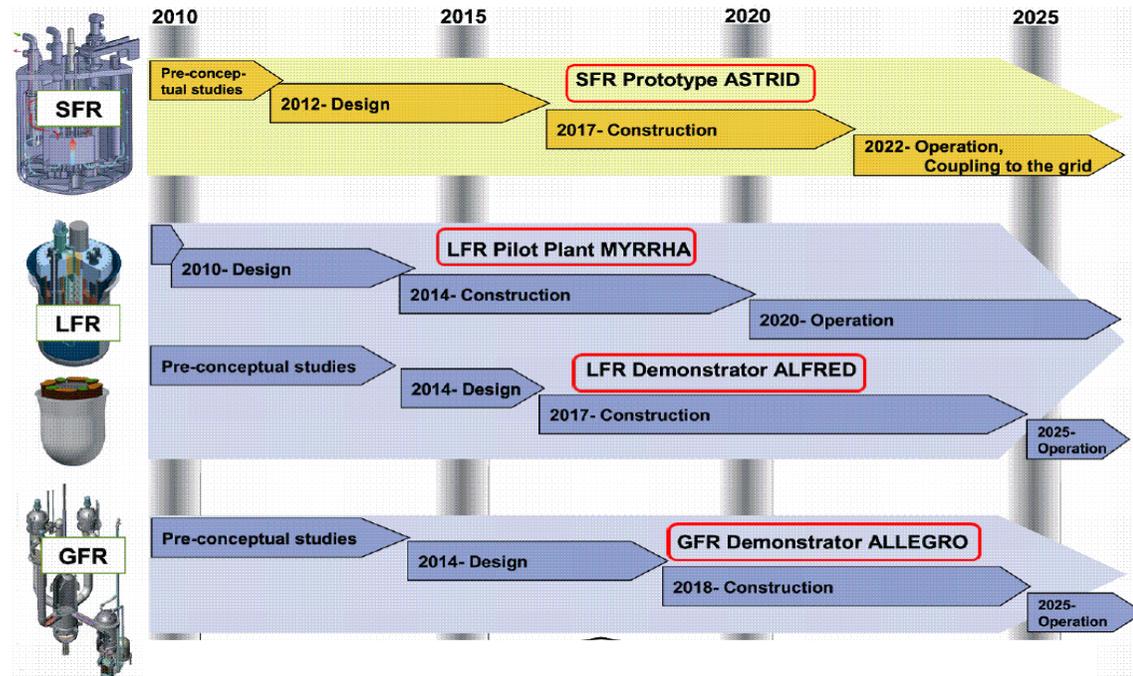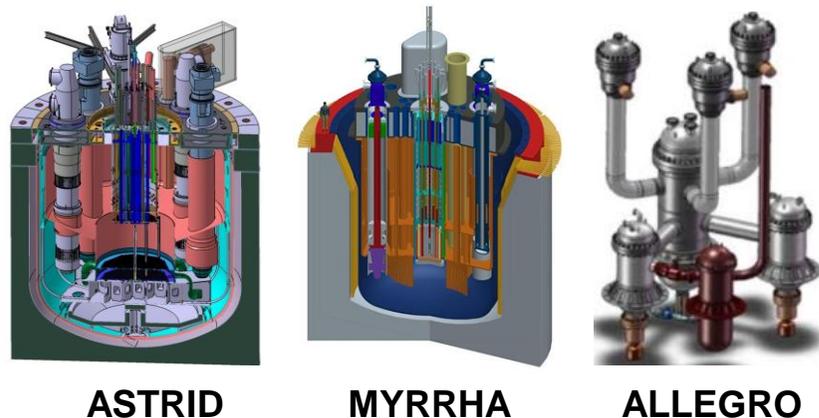**VI. NRC Licensing concerns on ETD rules**

VII. Summary

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I Introduction

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❖ **Generation IV Reactors under development in EU**

- ▪ **ASTRID (SFR)**

- ▪ **MYRRHA, ALFRED (LFR)**

- ▪ **ALLEGRO (GFR)**

❖ **ETD* rule for the Gen IV reactors (EU) and ITER**

- ▪ **RCC-MRx**

ASTRID   MYRRHA   ALLEGRO

Roadmap of Gen IV reactors in EU

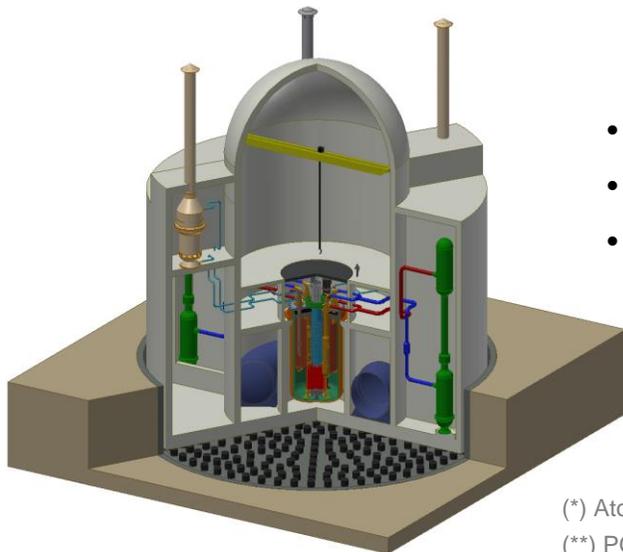(*) ETD : Elevated Temperature Design

❖ **Gen IV roadmap**[*] **of Korea**

- **PGSFR**[**] (SFR, prototype construction by 2028)
- **NHDD**[***] (VHTR, demonstration plant by 2026)

❖ **ETD rules for component design** (Korea)

- **(ASME Subsection NH+Div.5)** & **RCC-MRx** (for design)
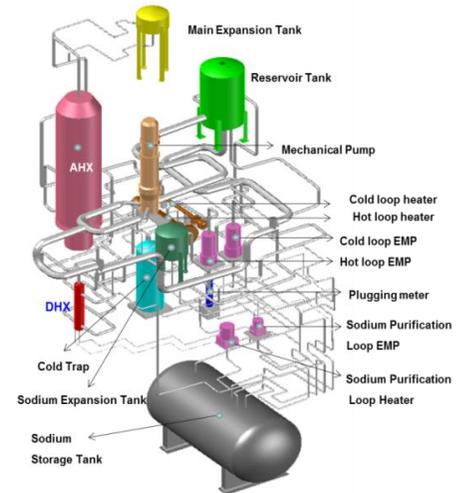- **RCC-MRx A16** (main for defect assessment including LBB)

❖ Application of ETD rules to sodium components in STELLA-1, STELLA-2 & SELFA test loop, and comparison of the design rules.
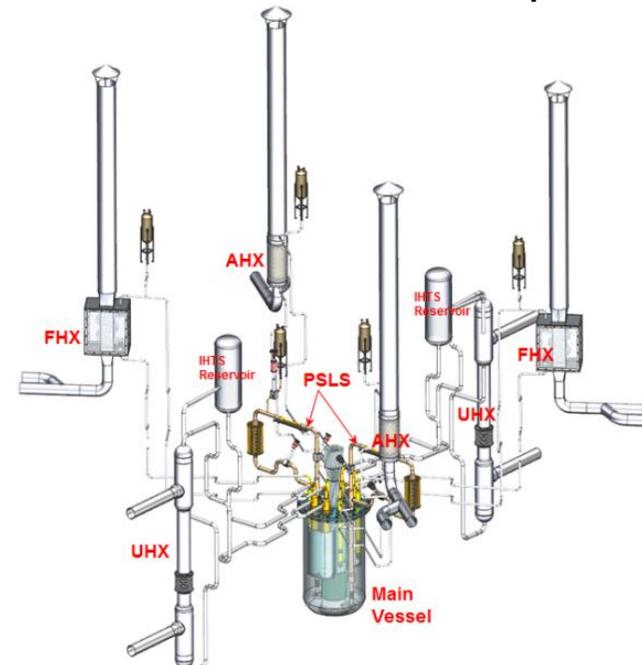

STELLA-1 Sodium test loop

PGSFR

- **150MWe**
- **545°C, ~1 bar(Pool type)**
- **RV : 8.7m (OD), 15.4m (H)**

(*) Atomic Energy Committee of Korean Government approved in Dec. 2008

(**) PGSFR : Prototype Gen IV Sodium-cooled Fast Reactor

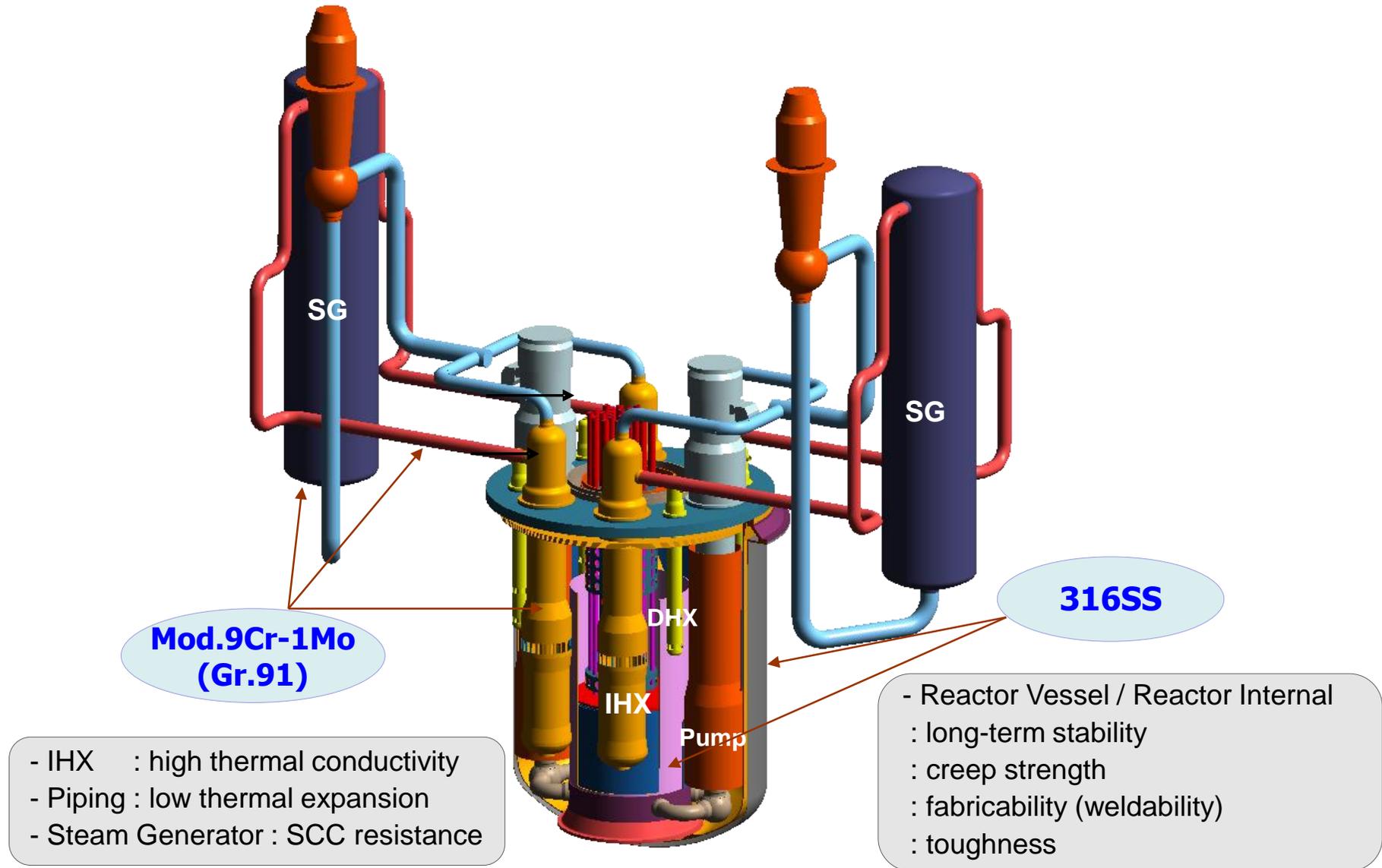(***) NHDD : Nuclear Hydrogen Development and Demonstration

STELLA-2 Sodium test loop

I.2 Two major materials in PGSFR*

SG

SG

DHX

IHX

Pump

316SS

Mod.9Cr-1Mo
(Gr.91)

- IHX   : high thermal conductivity
- Piping : low thermal expansion
- Steam Generator : SCC resistance

- Reactor Vessel / Reactor Internal
  : long-term stability
  : creep strength
  : fabricability (weldability)
  : toughness

(*) Prototype Gen IV Sodium-cooled Fast Reactor (KAERI)

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II ▸ ETD Rules

- **RCC-MRx**

- **ASME Section III Div.1 Subsection NH**

  Section IIII Div.5

(*) Elevated Temperature Design

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II.1 Elevated Temperature Design Codes

- **RCC-MRx** (2012 Ed. Dec. 2013 Addendum)

- **ASME Section III Subsection NH** (2015 Ed.) $\Rightarrow$ merge to Div.5 (2017)

- **ASME Section III Div. 5** (High Temp. Reactors, 2015Ed.)

  - From 2017Ed. ASME Div.5 only to exist & ASME-NH to disappear.

- ASME Draft Code Case for Alloy 617 (VHTR, 1989), to be Code Case in 2017

- JSME D&C code for Fast Reactors (JSFR), BDS(Monju) (SFR, Japan)

- KEPIC MNH (SFR, Korea)

ASME Section III Subsection NB (< 371°C(ferritic), 427°C(austenitic S.S))

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II.2 ASME Section III Div.5 - contents

Subsection HA — General Requirements
- Subpart A — Metallic Materials
- Subpart B — Graphite Materials
- Subpart C — Composite Materials

Subsection HB — Class A Metallic Pressure Boundary Components
- Subpart A — Low Temperature Service
- Subpart B — Elevated Temperature Service ⇐ N-499-1 : HBB / ASME-NH : to be merged in HBB ('17)

Subsection HC — Class B Metallic Pressure Boundary Components
- Subpart A — Low Temperature Service
- Subpart B — Elevated Temperature Service ⇐ CC-N253

Subsection HF — Class A and B Metallic Supports
- Subpart A — Low Temperature Service

Subsection HG — Class A Metallic Core Support Structures
- Subpart A — Low Temperature Service
- Subpart B — Elevated Temperature Service

Subsection HH — Class A Nonmetallic Core Support Structures
- Subpart A — Graphite Materials
- Subpart B — Composite Materials

Div.1 Class 1 & CS	⇒ Div. 5 Class A
Div.1 Class 2	⇒ Div. 5 Class B
Div.1 Class 3 & MC	⇒ N/A To Div. 5

❖ **Code Case N-499 ⇒ Div. 5 HBB**
(Use of SA-533 & SA-508 for Limited Elevated Temp Service)

❖ **Code Case N-253 ⇒ Div. 5 HCB**
(Construction of Class 2 or 3 Components)

❖ Section III Div.1

SECTIONS

I Rules for Construction of Power Boilers

II Materials
- Part A — Ferrous Material Specifications
- Part B — Nonferrous Material Specifications
- Part C — Specifications for Welding Rods, Electrodes, and Filler Metals
- Part D — Properties (Customary)
- Part D — Properties (Metric)

III Rules for Construction of Nuclear Facility Components
- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
  - Subsection NB — Class 1 Components
  - Subsection NC — Class 2 Components
  - Subsection ND — Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
  - Subsection NH — Class 1 Components in Elevated Temperature Service
- Division 2 — Code for Concrete Containments
- Division 3 — Containments for Transportation and Storage of Spent Nuclear Fuel Material and Waste
- Division 5 — High Temperature Reactors

❑ **Total strain**

➢ determined from total stress range (peak included)

$$\Delta\overline{\sigma}_{tot} = \Delta\overline{(P+Q+F)}$$

$$\Delta\overline{\varepsilon}_{el+pl} = \Delta\overline{\varepsilon}_1 + \Delta\overline{\varepsilon}_2 + \Delta\overline{\varepsilon}_3 + \Delta\overline{\varepsilon}_4$$

➢ Total strain

$$\Delta\overline{\varepsilon} = \Delta\overline{\varepsilon}_{el+pl} + \Delta\overline{\varepsilon}_{cr}$$

$$\Delta\overline{\varepsilon}_1 + \Delta\overline{\varepsilon}_2 + \Delta\overline{\varepsilon}_3 = K_\varepsilon \Delta\overline{\varepsilon}_{fic} + \Delta\overline{\varepsilon}_i$$

$$\Delta\overline{\varepsilon}_{fic} = \sqrt{\frac{2}{3}\frac{1+\nu}{E}\left(\Delta\overline{\sigma}_{tot} - \frac{3E}{2(1+\nu)}\cdot\Delta\overline{\varepsilon}_i\right)\cdot\left(\Delta\overline{\varepsilon}_1 + \Delta\overline{\varepsilon}_2 - \Delta\overline{\varepsilon}_i\right)}$$

$$\Delta\overline{\varepsilon}_1 = \frac{2}{3}(1+\nu)\frac{\Delta\overline{\sigma}_{tot}}{E}$$

$$\Delta\overline{\varepsilon}_2$$

$$\Delta\overline{\varepsilon}_4 = (K_\nu - 1)\Delta\overline{\varepsilon}_1$$

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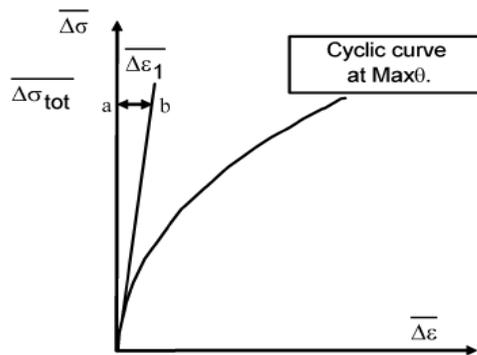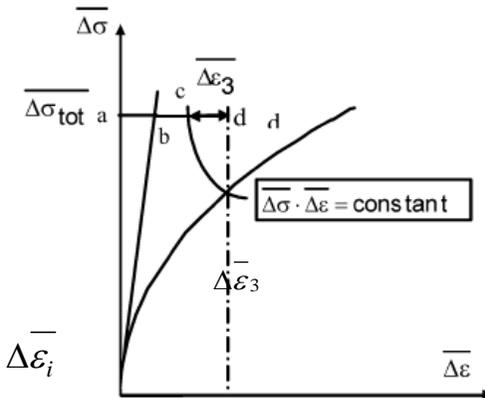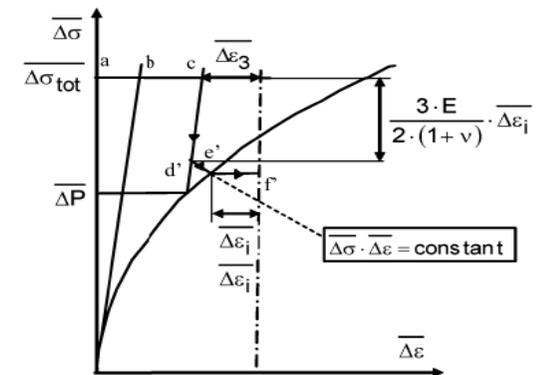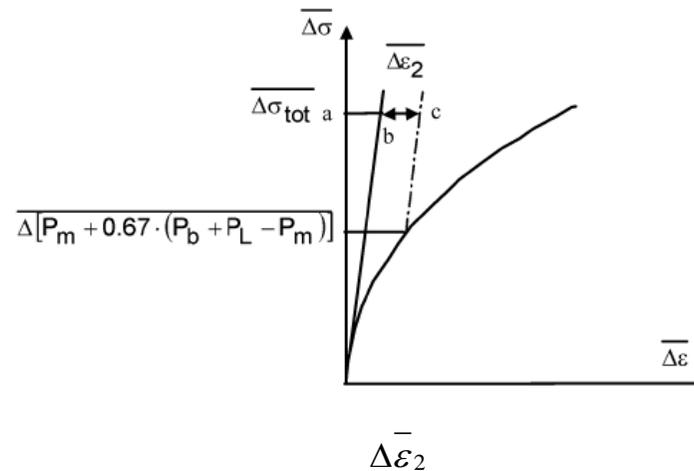
II.4 RCC-MRx Procedures : C-F Damage

$$\overline{\sigma}_k = \text{Mean } \overline{P} + K_s \Delta\overline{\sigma}*$$

$$\overline{\sigma}_k = \text{Mean } \overline{P} + K_s \sigma_r$$

Figure RB 3262.123c: determination of σ_k from s_r and $\overline{P}_{max}$

Reduced cyclic curve at temperature Maxθ.
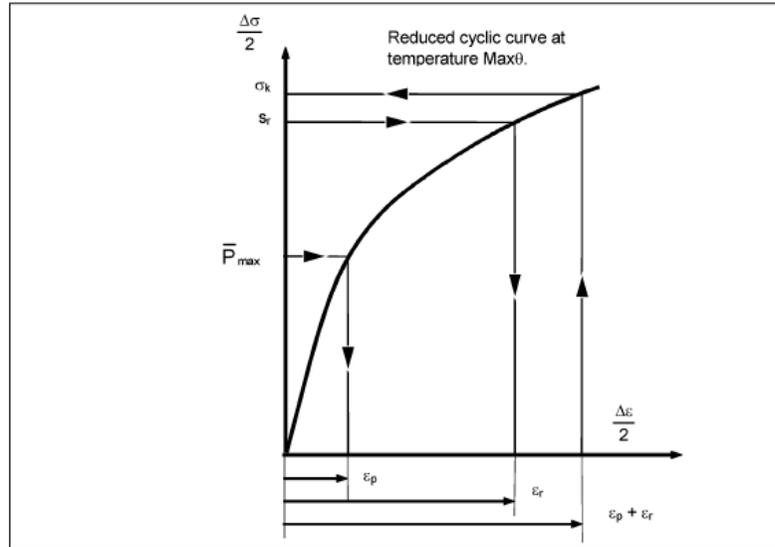
➢ **Fatigue damage**

$$V\left(\overline{\Delta\varepsilon}\right) = \sum \frac{n_i}{N_{ai}}$$

➢ **Creep damage**

$$W(\sigma) = \sum\left(\frac{\sigma_k}{0.9}; \theta\right)$$

316SS

Mod.9Cr-1Mo

Alloy 800 (RCC-MRx)

(0.3,0.3)

$\frac{\Delta t}{T_d}$

$\frac{n}{N_d}$

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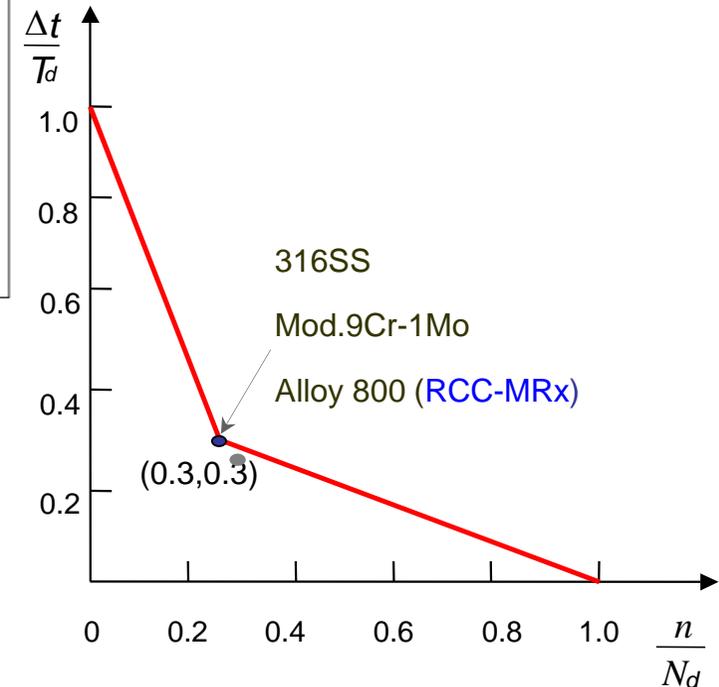
II.5 ASME-NH Overall Procedures

Thermal Analyses for the Specified Operating Conditions

Metal Temperature
T > 427°C for S.S.
T > 371°C for 2(1/4)Cr-1Mo
and 9Cr-1Mo-V

No → **ASME - NB**

Yes → **ASME - NH**

❏**Materials**
- 304SS
- 316SS
- 2.25Cr-1Mo
- Mod.9Cr-1Mo
- Alloy 800H
- Alloy 718

ASME - NB

Limits on Load-Controlled Stresses
(Time Independent)
+
Fatigue

ASME - NH

Limits on Load-Controlled Stresses
(Time Dependent/Independent)

Limits on Deformation Controlled Quantities

By Appendix T (Non-mandatory)

Inelastic Strain

Creep-Fatigue

Buckling

Plastic, Creep, Ratcheting Effects

Interaction Effects

Instability Effects

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II.6 Isochronous Curve in ASME-NH

- Used extensively in ASME-NH for the determination of ;

  + strain range,

  + fatigue damage & creep damage

- Based on uniaxial, monotonic data : very conservative

T-1800
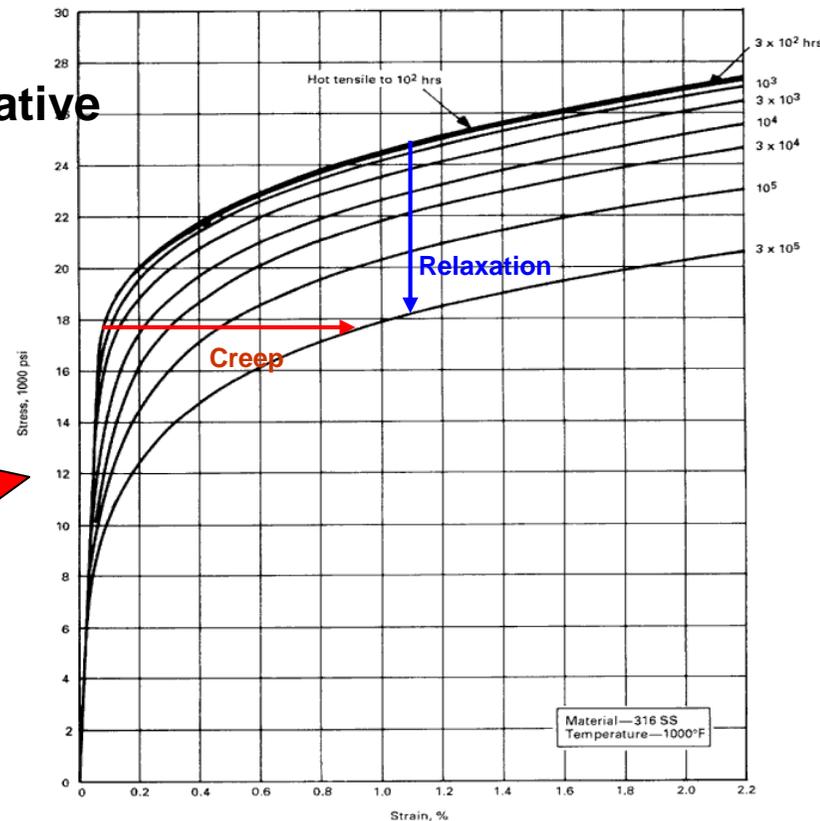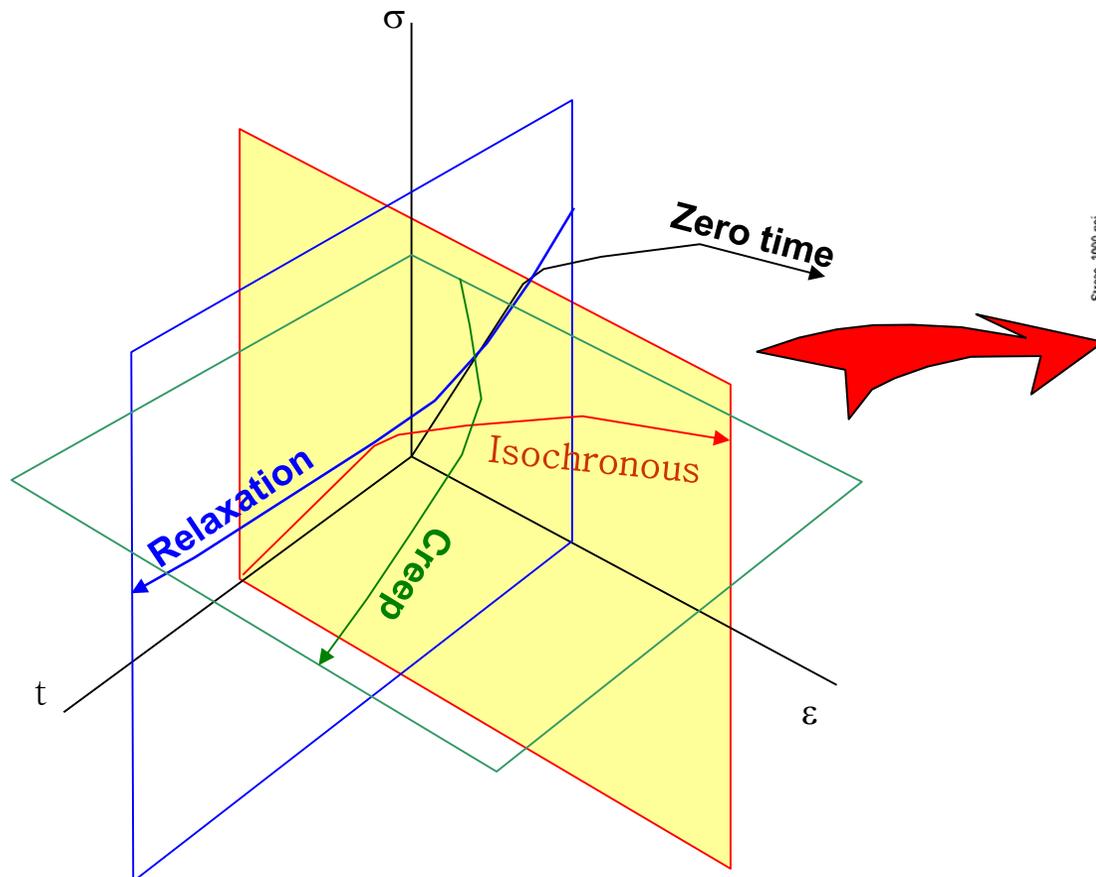
FIG. T-1800-B-5 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

Isochronous Curve 316SS - 540ºC

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III Comparison of ETD* Codes

- **Material Properties (chem. Composition incl.)**
- **Design evaluation procedures**

(*) Elevated Temperature Design

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III.1 Chemical compositions (316 & Gr.91)

❖ 316 Stainless steel

Code/Test	Grade	C	Mn	P	S	Si	Cr	Ni	Mo	N	B	other
ASME	316SS (**Sec.III** - NH)	0.04-0.06	1.0-2.0	<0.03	<0.02	0.6	17.0-18.0	11.0-12.5	2.5-3.0	0.04-0.07	0.003	Al 0.05
	316SS (**Sec.II**-part A)	0.08	2.0	0.045	0.03	1.0	16.0-18.0	10.0-14.0	2.0-3.0	…	…	
	316H (Sec.II-part A)	0.04-0.10	2.0	0.045	0.03	1.0	16.0-18.0	10.0-14.0	2.0-3.0	…	…	
	316LN (Sec.II-part A)	0.03	2.0	0.045	0.03	0.75	16.0-18.0	10.0-14.0	2.0-3.0	0.10-0.16	…	
	316L (Sec.II-part A)	0.03	2.0	0.045	0.03	0.75	16.0-18.0	10.0-14.0	2.0-3.0	0.1	…	
RCC-MRx	316LN	0.03	1.6-2.0	0.03	0.015	0.5	17.0-18.0	12.0-12.5	2.3-2.7	0.06-0.08	…	
	316L	0.03	2.0	0.03	0.015	1.0	16.5-18.5	10.5-13.0	2.5-3.0	≤0.11	…	

❖ Grade 91

Code/Test	Grade	C	Mn	P	S	Si	Cr	Ni	Mo	N	Nb	other
ASME	Gr.91	0.06-0.15	0.25-0.66	0.025	0.012	0.18-0.56	7.90-9.60	0.43	0.80-1.10	0.025-0.080	…	Al. 0.02
RCC-MRx	X10CrMoVNb9-1 (Gr.91)	0.080-0.120	0.30-0.60	≤0.020	≤0.005	0.20-0.50	8.00-9.50	≤0.20	0.85-1.05	0.03-0.07	0.06-0.10	Al. ≤0.040

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III.2 Comparison of Properties : YS, TS, S_m

❑ **Yield strength, Tensile strength & Design stress intensity of Gr.91 steel**

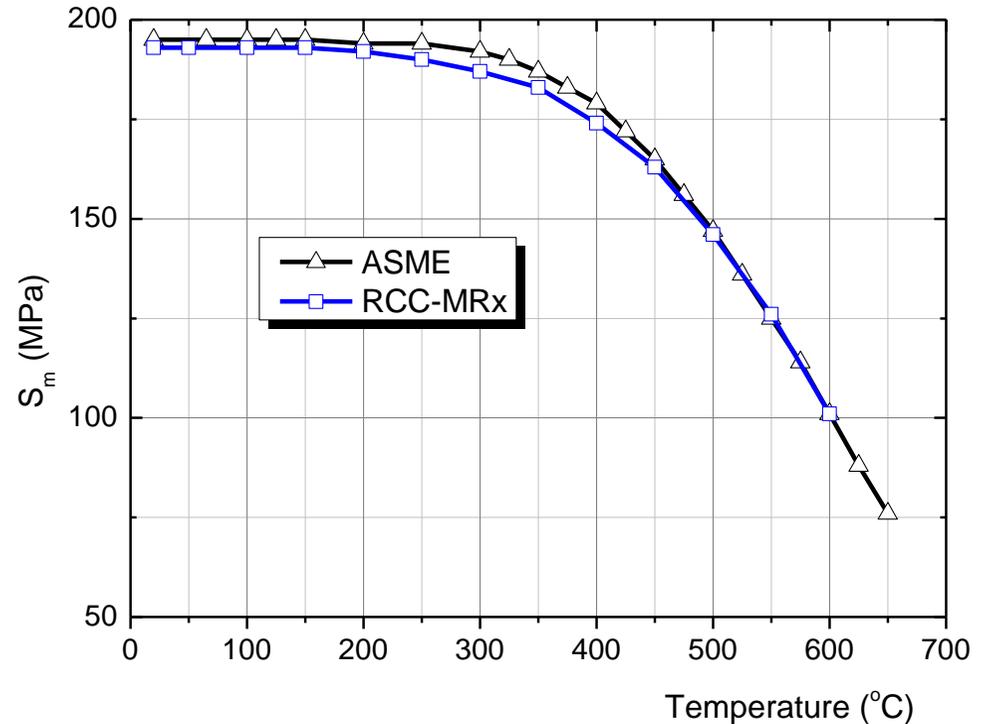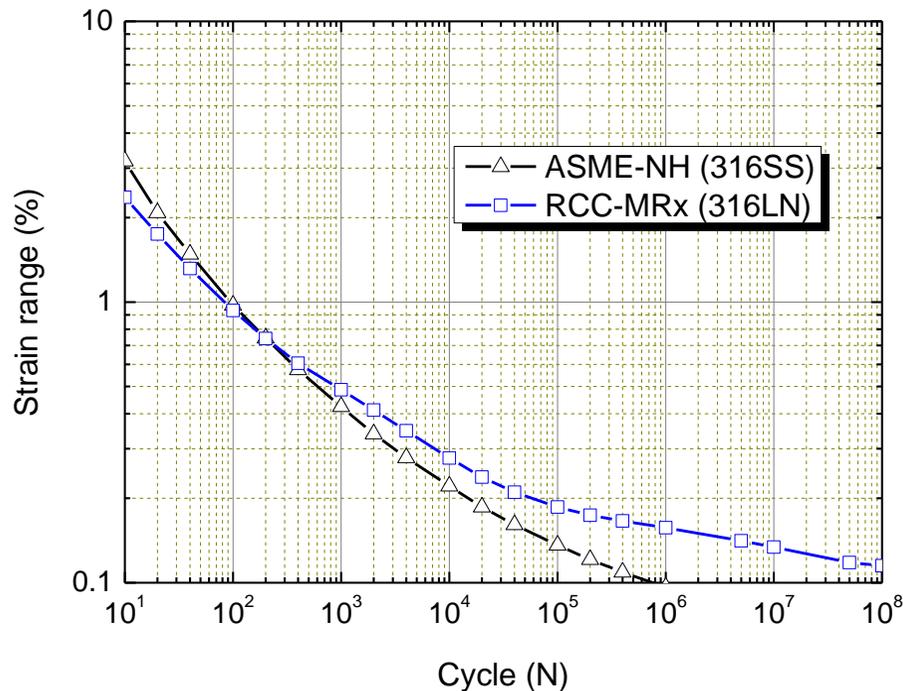➤ RCC-MRx properties are more conservative.

YS (Gr.91)
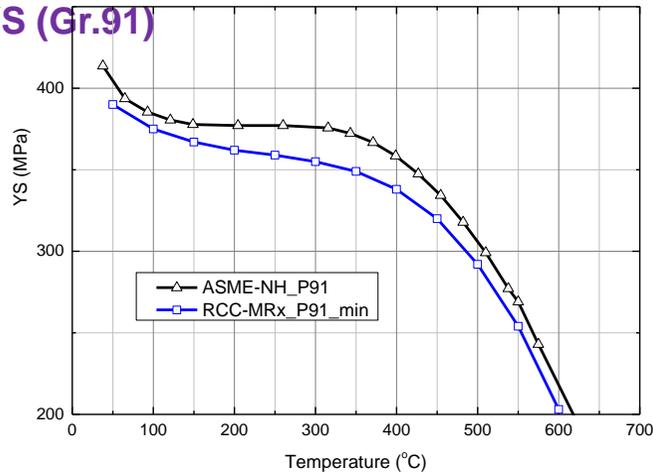
TS (Gr.91)
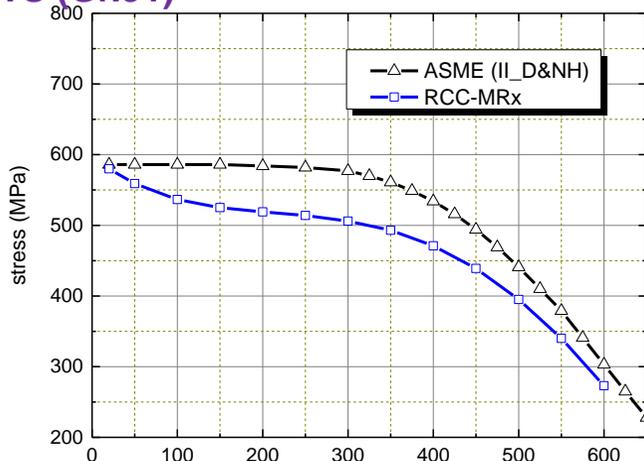
❖ **Design stress intensity, S_m of Gr.91**

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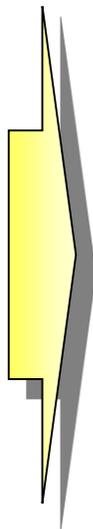
❑ **Fatigue strength data : RCC-MRx properties are higher for 316LN (N>200), lower for Gr.91 steel. (than ASME-NH)**
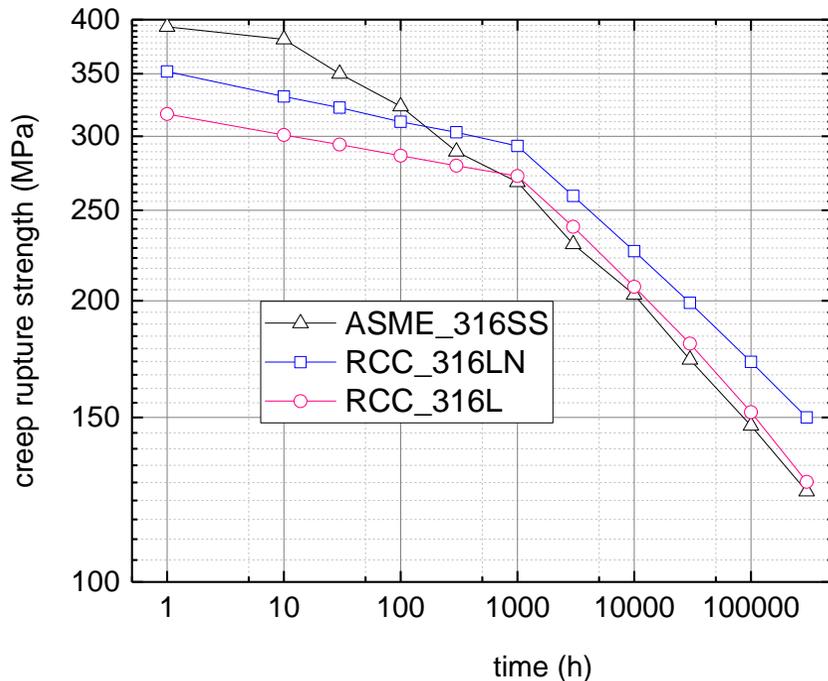

Fatigue strength (**316** @550°C)
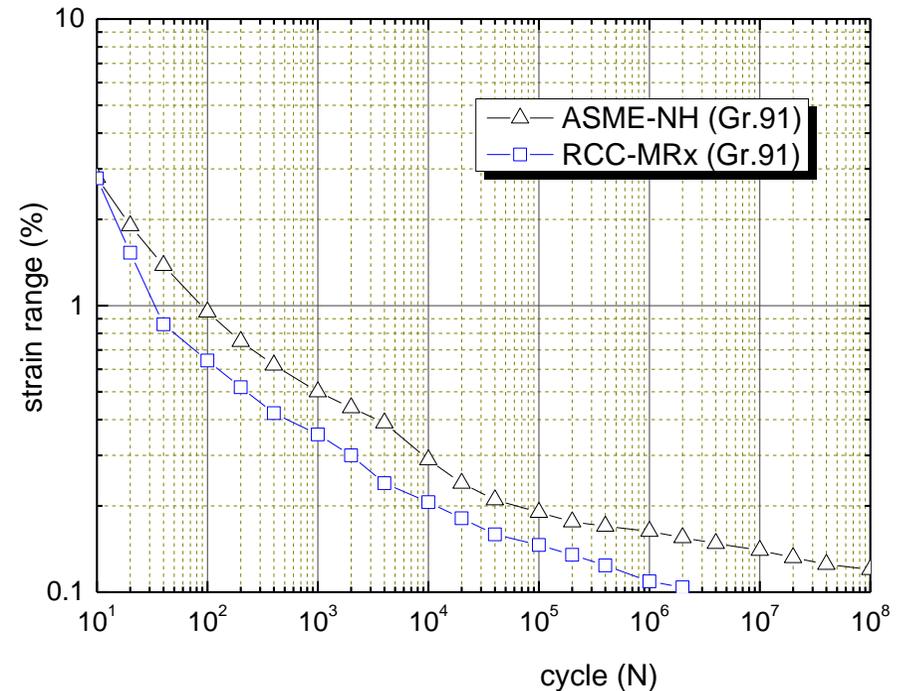
Fatigue strength (**Gr.91**)

(RCC-MRx @550°C, ASME-NH @540°C)

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III.3 Comparison of Properties : Creep

❑ **Creep rupture strength : RCC-MRx(316L,316LN) values are higher for 316 (CRS > 270MPa), and lower for Gr.91 steel (than ASME-NH).**

❖ **ASME-NH : Creep data of 500,000h provided for Alloy 800H (from 2013Ed.)**

  "Creep data of **500,000h to be provided for 316SS, P91,** P22, 304SS **from 2017Ed.***"

Creep rupture strength (**316** @550°C)
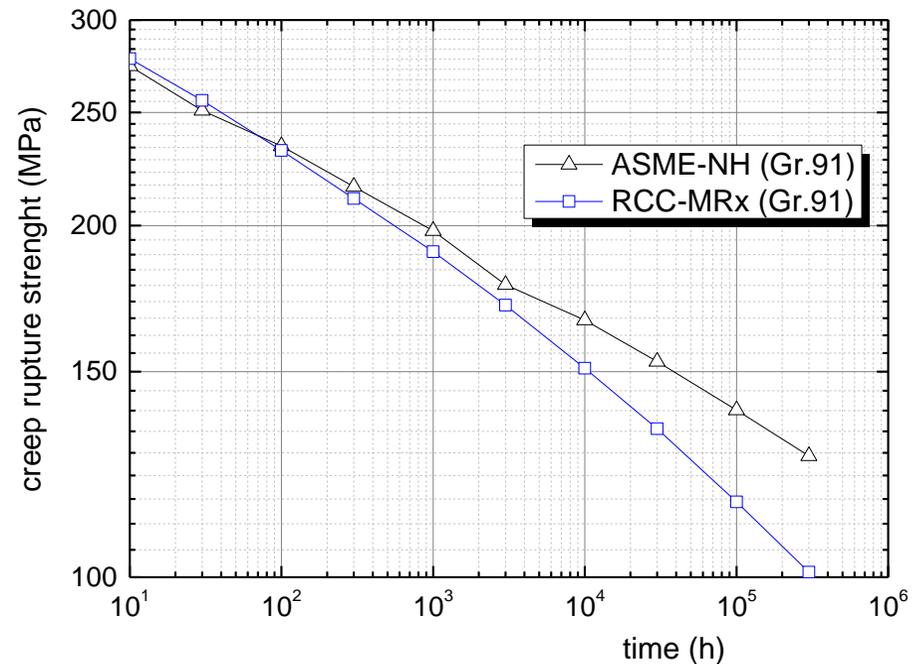
Creep rupture strength (**Gr.91** @550°C)

*Ref. : G.H.Koo (ASME)

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III.4 Thermal Aging in RCC-MRx

❖ **316L(N)** : TA considered in J-R curve

❖ **Gr.91** : TA Not considered in TS, YS & S_m

A9.J1S.812c: J-R curves at 550°C
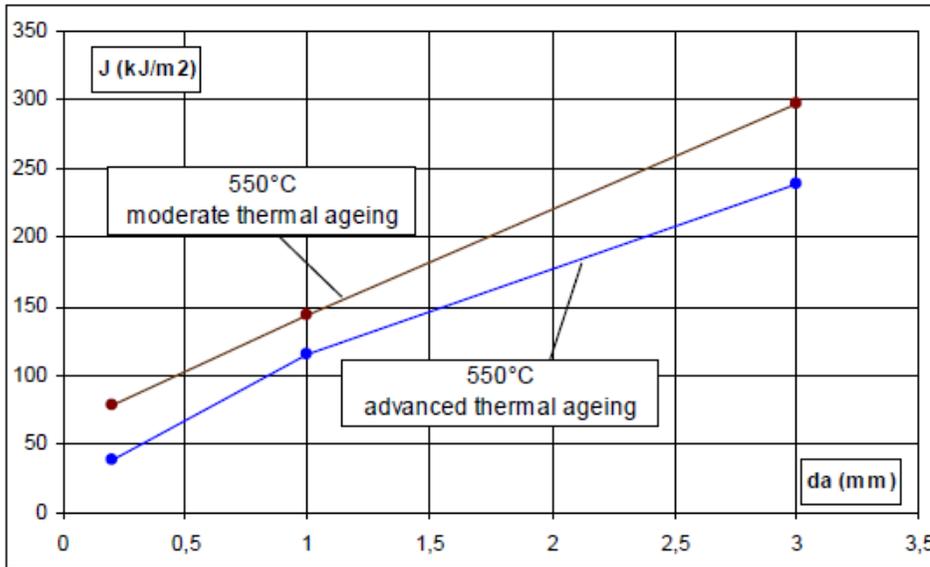
	500 °C	525 °C	550 °C	600 °C	650 °C
moderate thermal ageing	175 000 h	64 000 h	25 000h	4 000 h	950 h
advanced ageing		280 000 h	110 000 h	19 000 h	4 000 h

Figure A3.18AS.41: values of $R^t_{p0.2}$, R_m, S_m and S - RM 242-2 and RM 243-1 X10CrMoVNb9-1
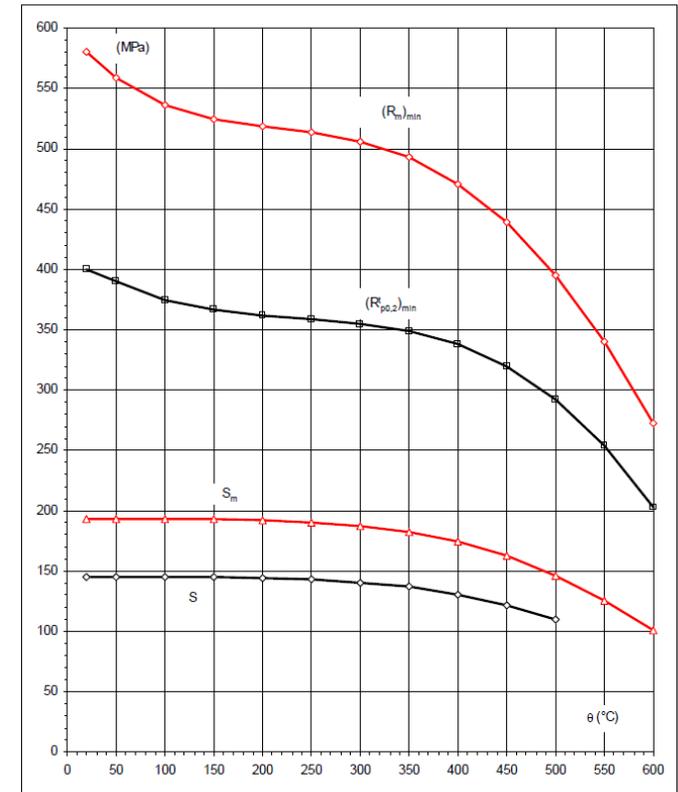
A3.1S.51   *THERMAL AGEING COEFFICIENT (NOT SUPPLIED)*

(In case of 316LN @600C : $F_v(T_m)$ = 30,000 hrs.)

RCC-MRx (2013 Addm.)

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III.5 Thermal Aging in ASME-NH

Table NH-3225-2
Tensile and Yield Strength Reduction Factor Due to Long Time Prior Elevated Temperature Service

Material	Service Temp., °F (°C)	YS Reduction Factor	TS Reduction Factor
304SS	≥ 900 (480)	1.00	0.80
316SS	≥ 900 (480)	1.00	0.80
800H	≥ 1,350 (730)	0.90	0.90
2¼ Cr-1Mo	≥ 800 (425)	[Note (1)]	[Note (1)]
9Cr-1Mo-V	≥ 900 (480)	1.0	[Note (2)]

GENERAL NOTE: No reduction factor required for service below the indicated temperature.

NOTES:
(1) See Tables NH-3225-3A and NH-3225-3B are selected to correspond to the maximum wall-averaged temperature achieved during any Levels A, B, or C Service Loading.
(2) See Table NH-3225-4.

- **Started consideration of TA effect from 2013 Ed.**
- **"No 'long-time service effect @ET*' on YS for Gr.91 & 316SS (T ≥ 480°C)"**
- **"It may be necessary to adjust S_m** values (NH-3221)"**
- **Validation of the Table NH-3225-2 may be necessary (study underway @KAERI)**

(*) Elevated Temperature
(**) Design Stress Intensity (lesser of (1/3 UTS, 2/3 YS))

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III.6 Comparison of Design Rules

	RCC-MRx	ASME-NH
Calculation of total strain range and creep damage	**Creep laws** directly used.	**Isochronous curves** used.
Elastic Follow-up	Explicitly considered (q=3, default)	Implicitly considered
Strain limits	**1%** (membrane), **2%**(bending)	**1%** (membrane), **2%**(bending), **5%**(peak)
Peak terms in strain calculation	Contained in total S.I (convenient)	Should be decomposed in elastic approach
Ratcheting rule	Efficiency diagram method (Gr.91 pending)	Mod. Bree diagram (O'Donnel Porowski)
Environmental effects	Explicitly to be considered (irradiation, thermal ageing etc.) (@ beginning stage)	No guideline (except thermal aging, designer's duty)

❒ RCC-MRx provides (that ASME-NH does not provide)

➢ Guide for LBB and defect assessment (A16)
➢ Heat Exchangers (RB-3900)
➢ Box Structure (RB-3800) etc.

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III.7 C-F Damage for Weldment

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

❖ ASME-NH

1. Fatigue Damage

$$N_d(\text{HAZ})^{(*)} = \tfrac{1}{2}\, N_d(\text{base})$$

2. Creep Damage

T_d determined from $S_r \times R$ (Weld SRF)

❖ RCC-MRx
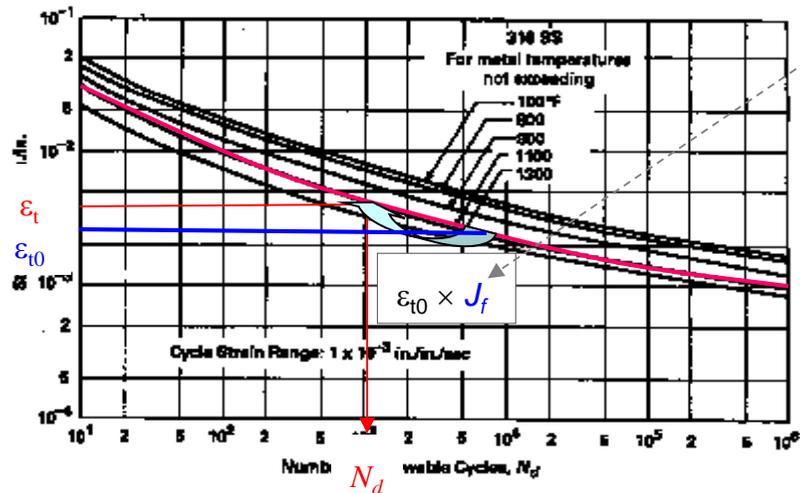
1. Fatigue Damage

$$\overline{\Delta\sigma}_{weld} = \text{FSRF} \times \overline{\Delta\sigma}_{base}$$

$$\varepsilon_t(\text{HAZ}) = J_f * \varepsilon_{t0}(\text{base})$$

2. Creep Damage

T_d determined from $\boxed{S_r \times J_r}$
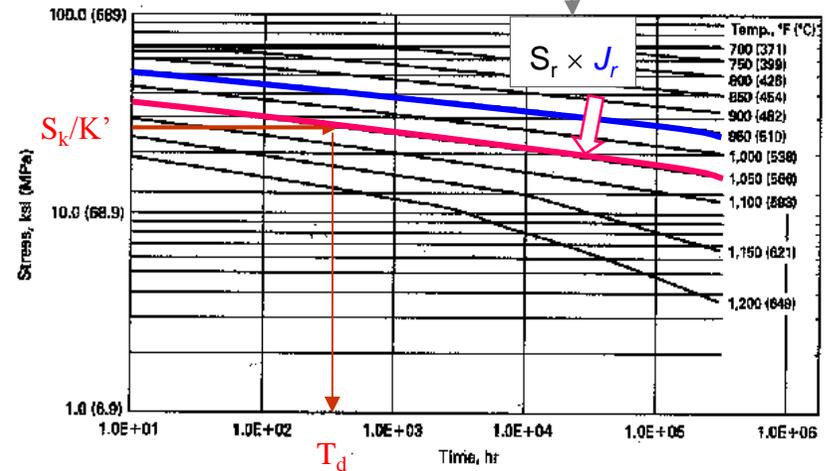
FIG. I-14.6F   9Cr-1Mo-V — EXPECTED MINIMUM STRESS-TO-RUPTURE, ksi (MPa)

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❖ **Linear Damage Summation Rule (LDSR)**

- Severud (1970s)

- Based on cavity growth of Austenitic S.S at tensile hold

$$\sum_{j=1}^{P}\left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q}\left(\frac{\Delta t}{T_d}\right)_k \leq D$$
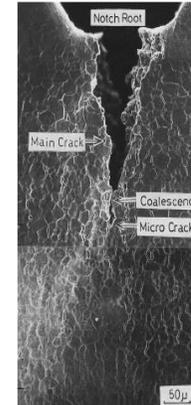
Fig. 11. Scanning electron micrograph of microcrack and creep damage around a main crack under creep condition (SUS 304 stainless steel, 650°C, σ₀ = 191 MPa).
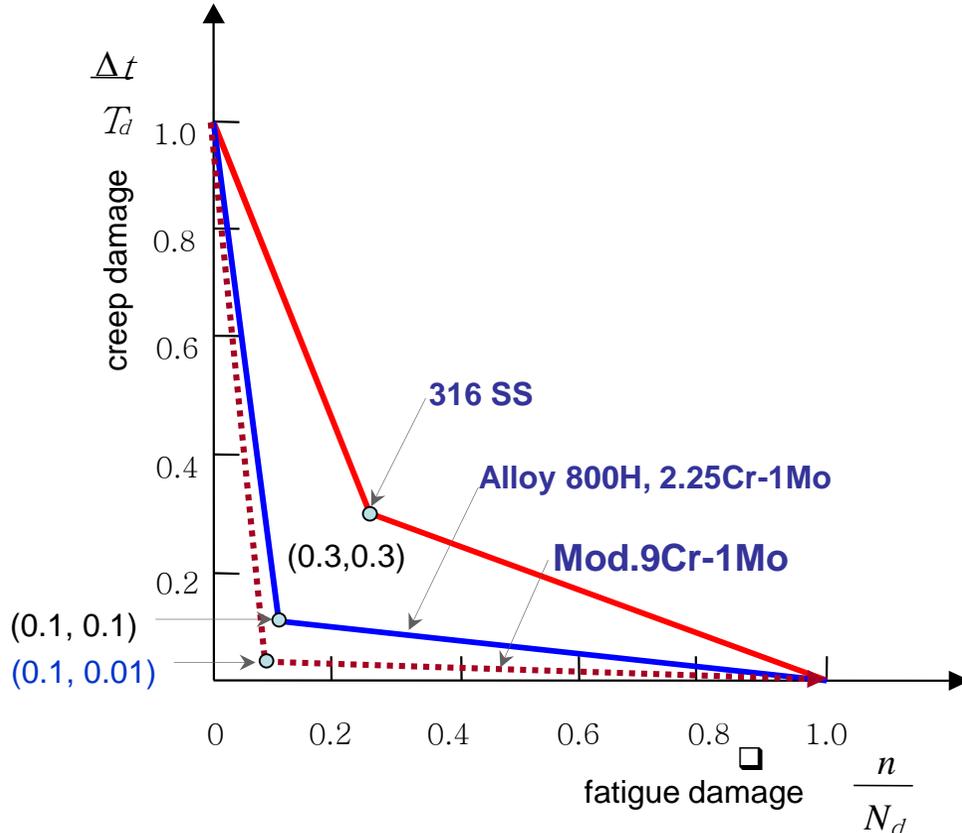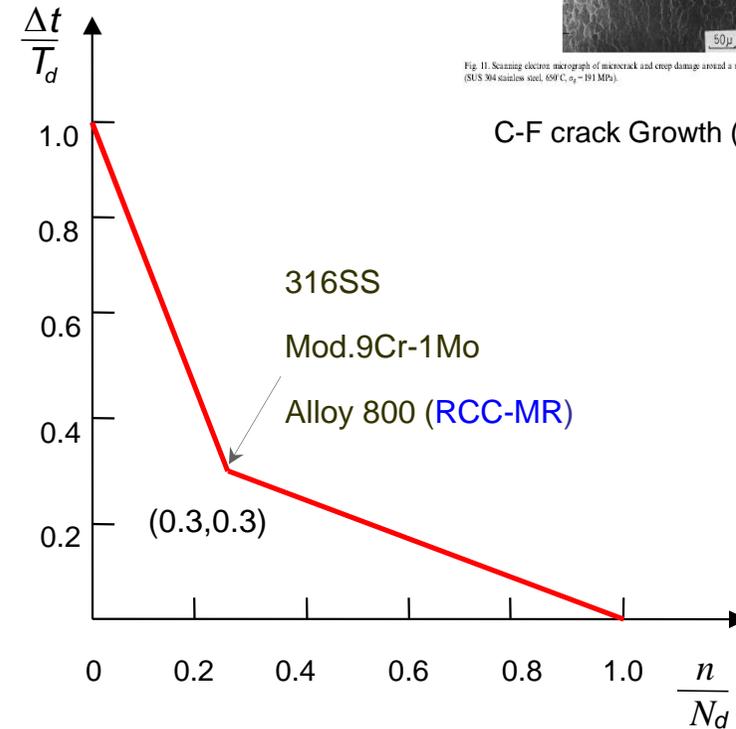
C-F crack Growth (304SS, 650°C)

❖**ASME-NH**

❖**RCC-MRx**

(*) Creep-Fatigue

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❖ **Procedures of CC N-812 applicable (Gr.91)**

- **Elastic Analysis of ASME-NH (T-1430)**

- **Isochronous Curves (T-1433(a) Step 5(2))**

ASME-NH

(0.1, 0.01)

Code Case N-812

(0.3, 0.3)
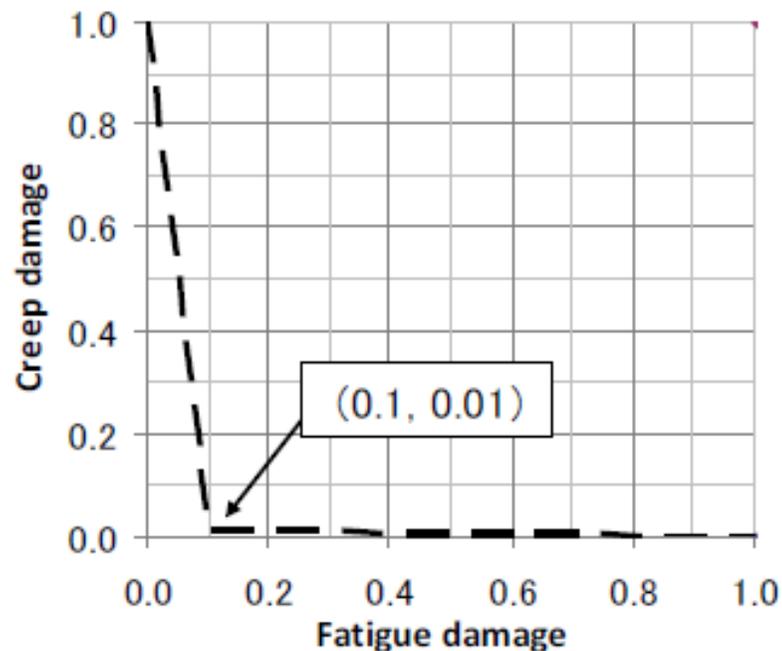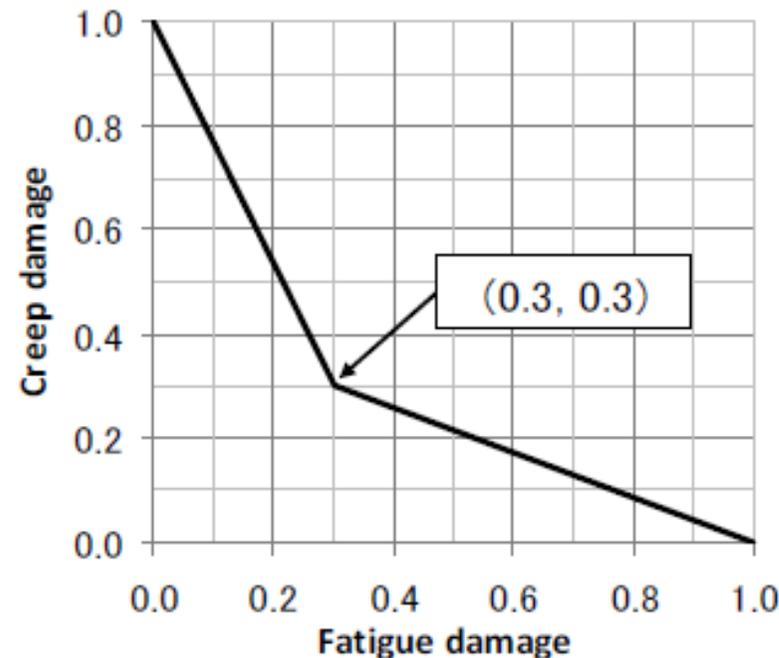
(Alternative C-F Damage Envelope for 9Cr-1Mo-V for use with T-1433(a) Step 5(2))

Ref. Asayama, 2010, EPRI C-F Workshop

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Application of the ETD rules to sodium test facilities

STELLA-1

STELLA-2

AHX

FHX

IHTS Reservoir

IHTS Reservoir

PSLS

FHX

UHX

AHX

UHX

Main Vessel
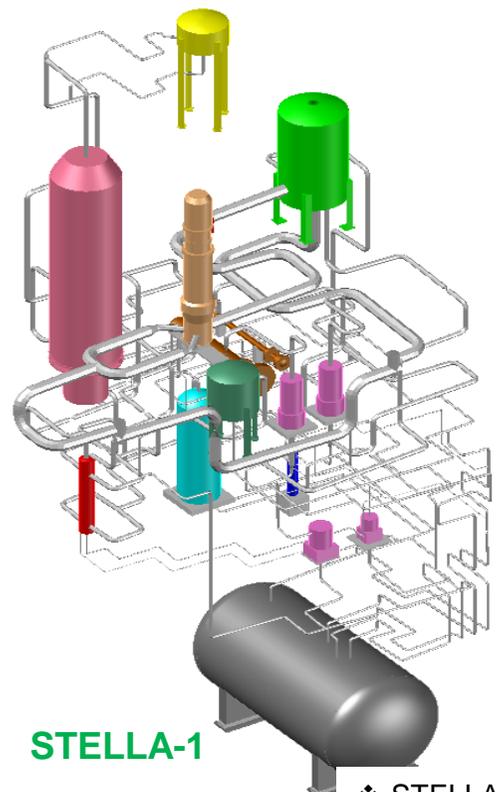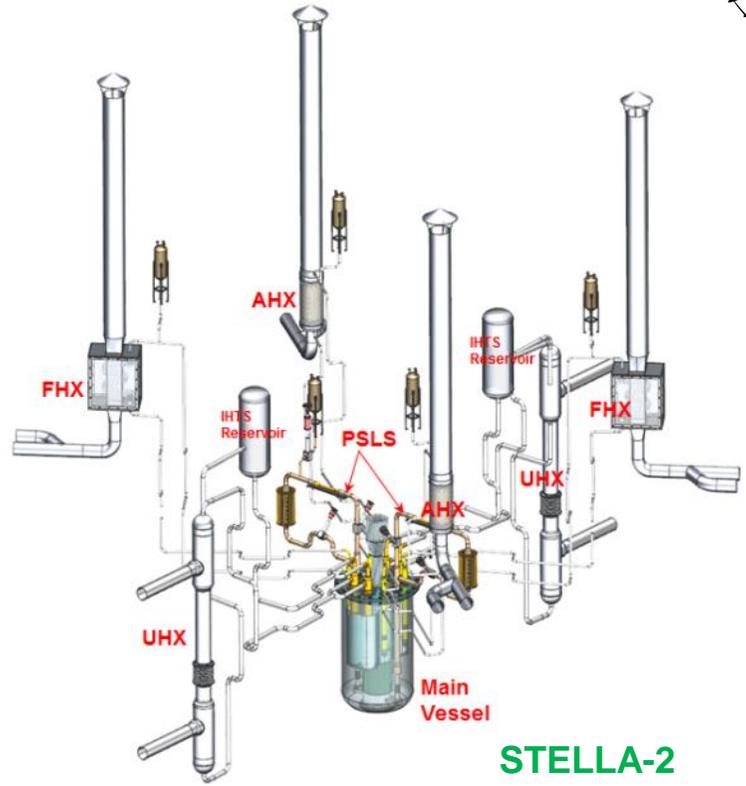
❖ STELLA : Sodium integral effect TEst Loop for safety simuLation and Assessment
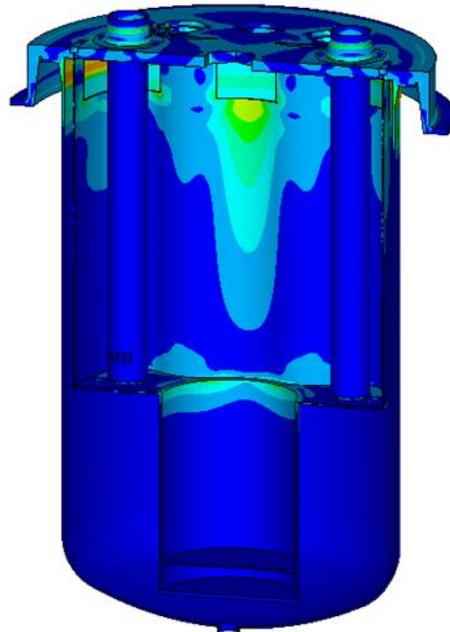❖ SELFA : Sodium thermal-hydraulic Experiment Loop for Finned-tube sodium-to-Air heat exchanger

DHX

AHX
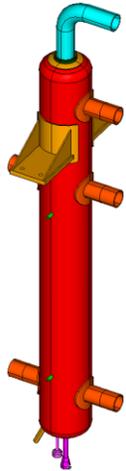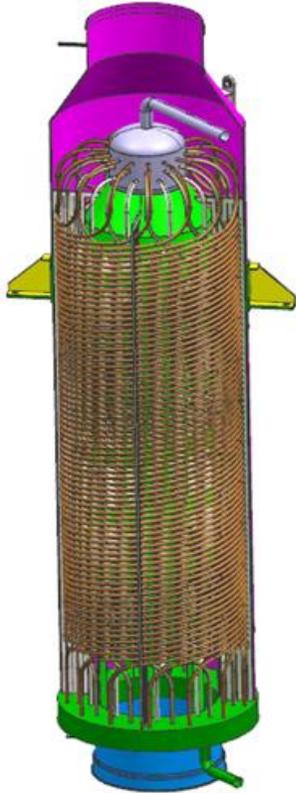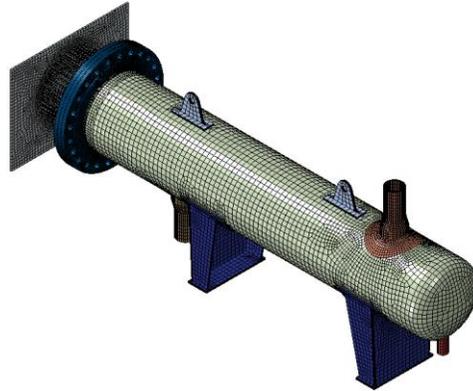
Expansion tank

Loop heater vessel

Reactor Vessel (ST-2)

STELLA-1 test facility

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- **3D CAD Model based FE Model. (ABAQUS)**

- **225,511 3D Brick Elements**

- **290,790 nodes**
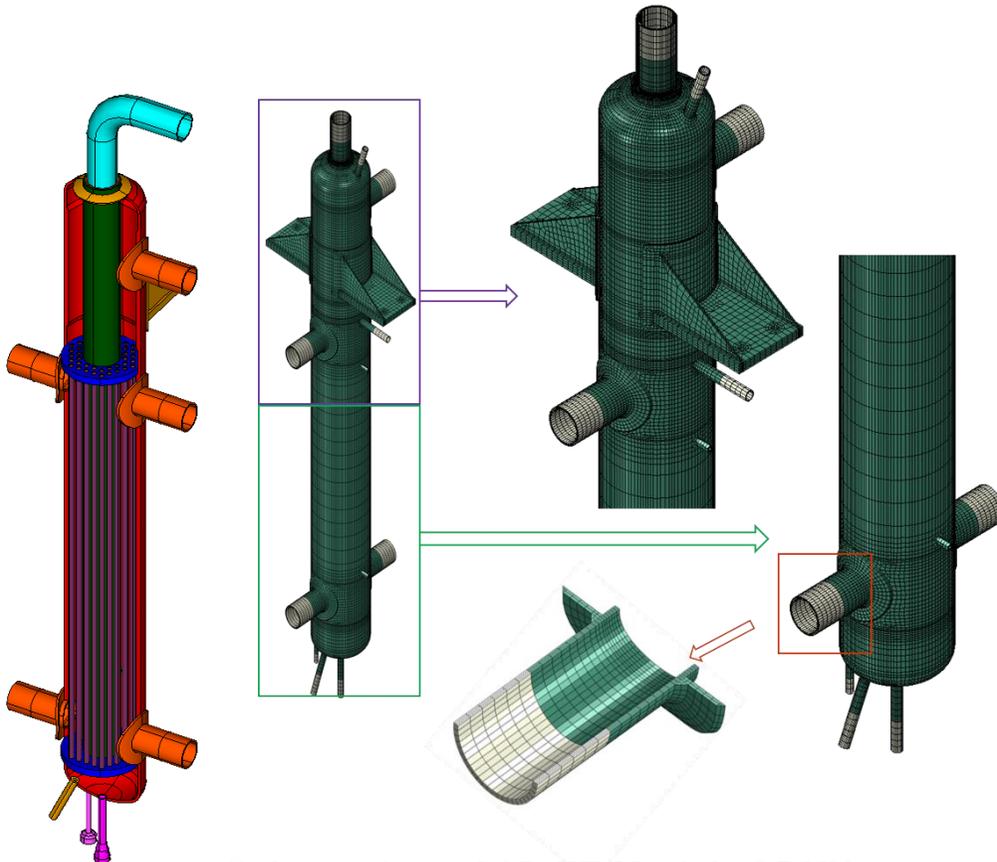
Schematic and 3D FE Model of DHX
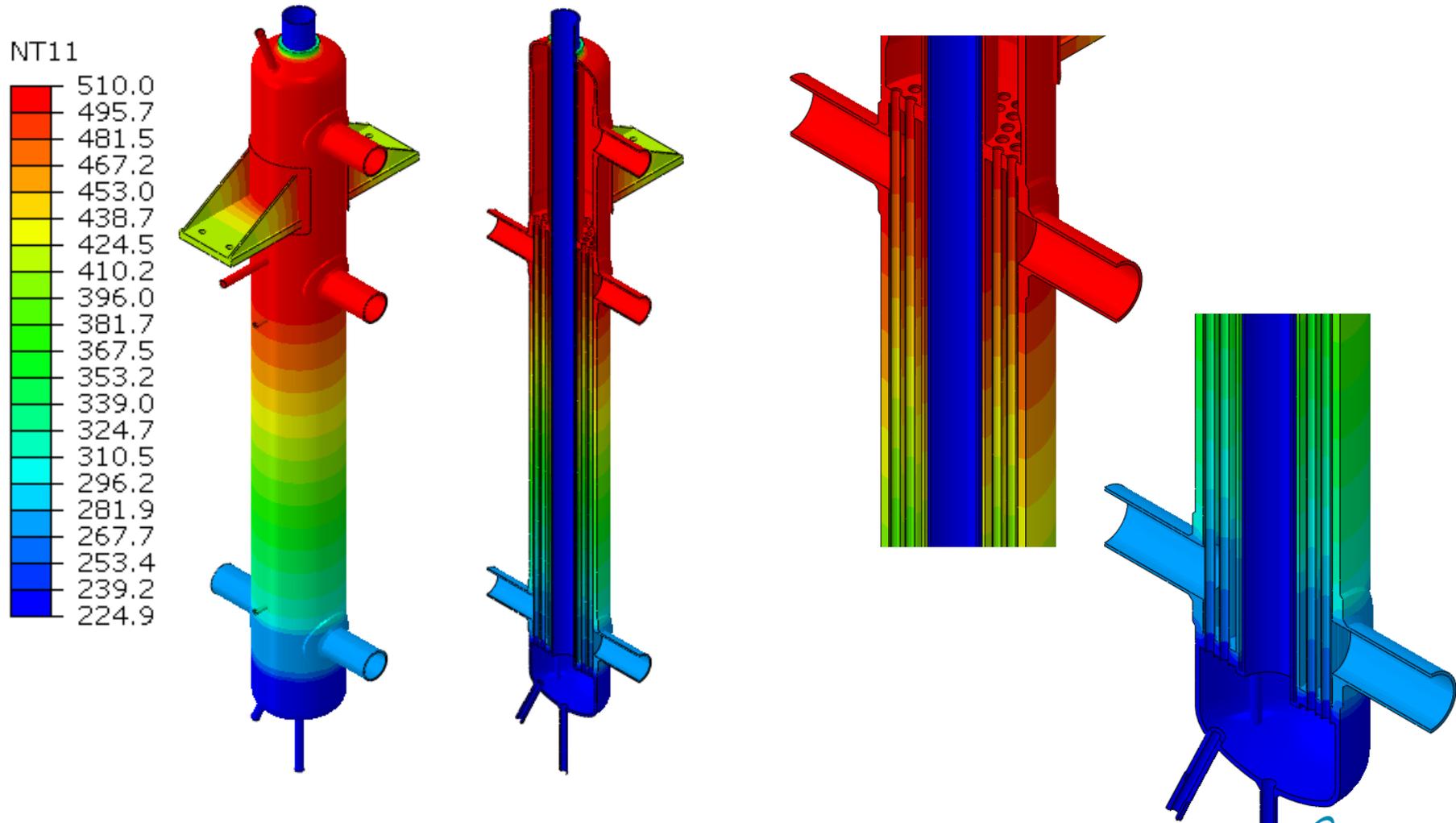
❑ **Primary side**

72 hr 510°C 72 hr

100°C/hr

100°C/hr

200°C

3.1 hr   3.1 hr

time (hr)

❑ **Secondary side**

72 hr 500 °C 72 hr

100°C/hr

100°C/hr

200°C

3 hr   3 hr

time (hr)
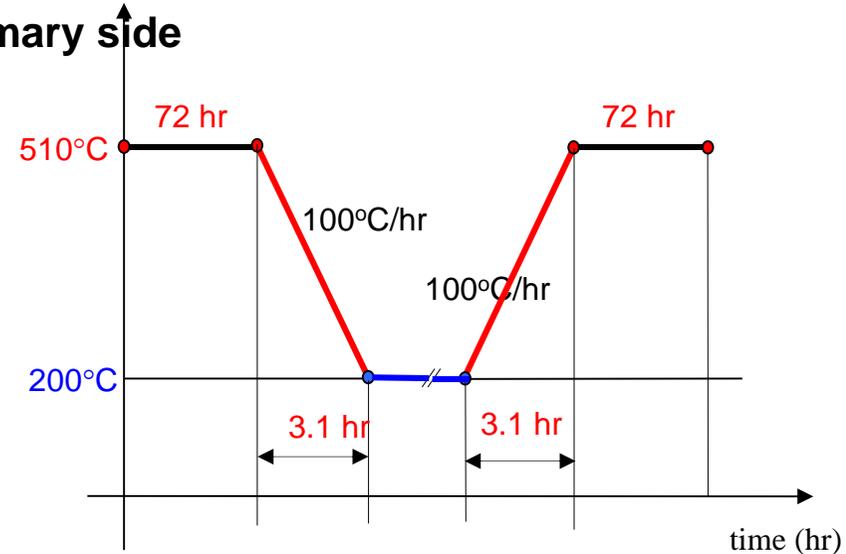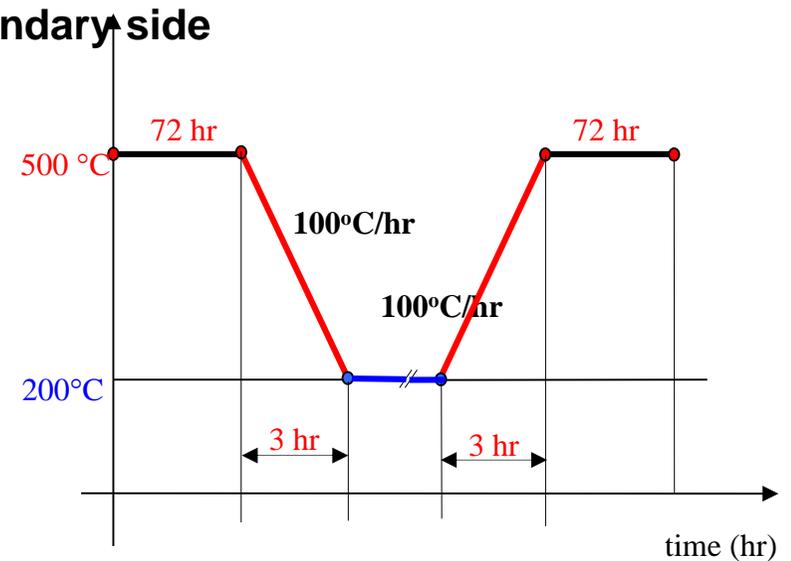
- **No. of cycles = 500.**
- **Hold Time / C-F cycle = 30 hr**

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❖ **Temperature Contour of Step 4 (410 → 510 ℃ Transient)**

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KAERI

❖ **Stress Contour of DHX**

max

S, Mises
(Avg: 75%)

- 67.15
- 63.79
- 60.44
- 57.08
- 53.72
- 50.36
- 47.01
- 43.65
- 40.29
- 36.93
- 33.58
- 30.22
- 26.86
- 23.50
- 20.15
- 16.79
- 13.43
- 10.07
- 6.72
- 3.36
- 0.00

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❖ **Stress Contour of DHX (at the end of Heat Up)**

Max
(Top Support Ring)

N4A Nozzle

➤ **tubesheet stress level : low**

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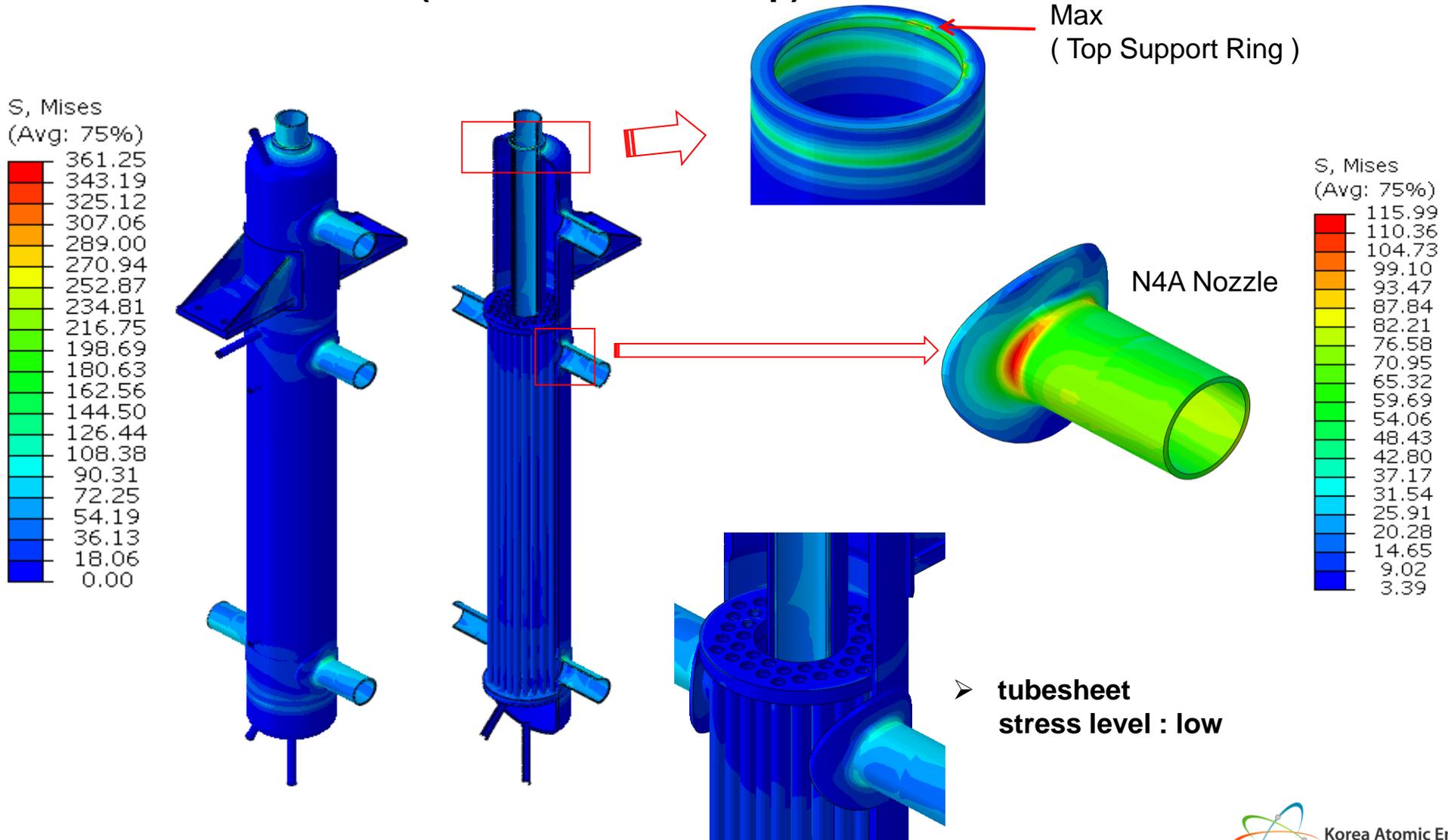
IV.6 Creep-Fatigue Damage (DHX)

❖ **DHX (Gr.91)**   @ **nozzle pt. 3**

❖ **C-F damage** @ nozzle pt.3

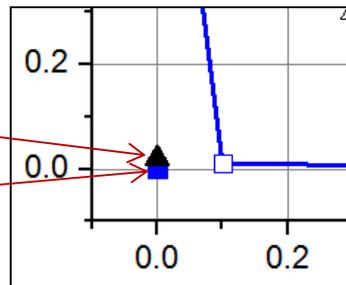| DHX	ASME-NH	RCC-MRx
D_f	0.00005	0.00005
D_c	0.02051	0.00023
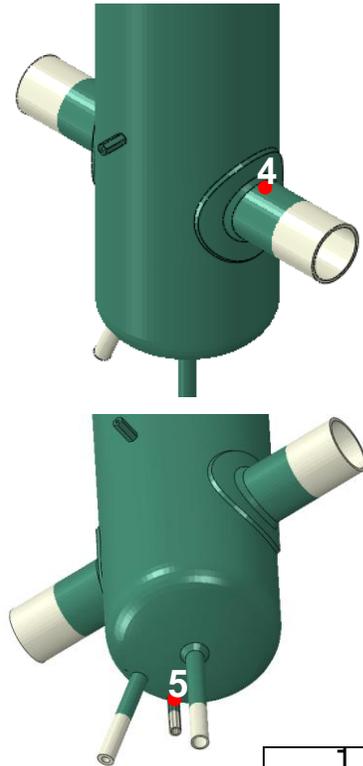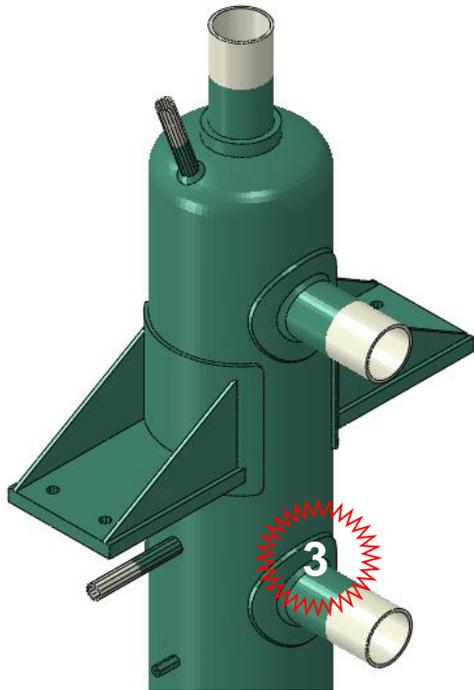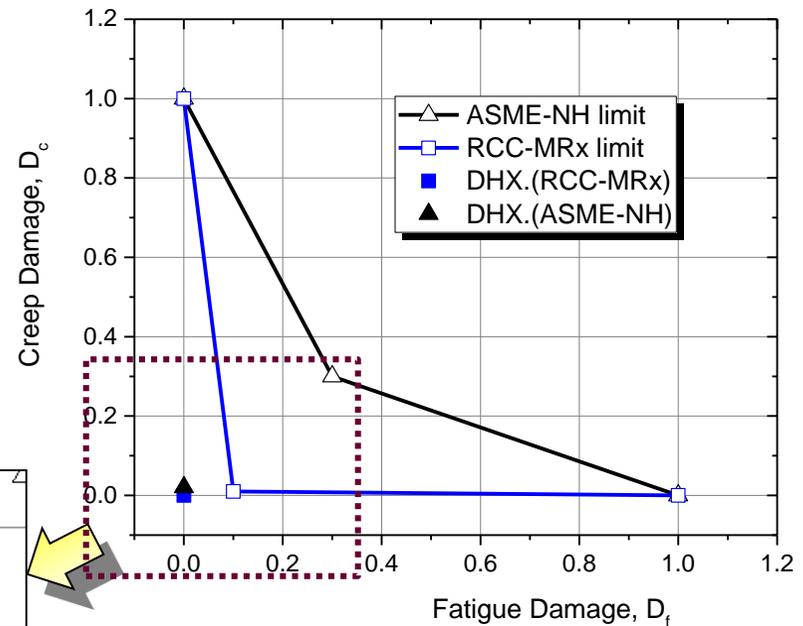
$$\sum_{j=1}^{p}\left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q}\left(\frac{\Delta t}{T_d}\right)_j \leq D$$

DHX (ASME-NH)
DHX (RCC-MRx)
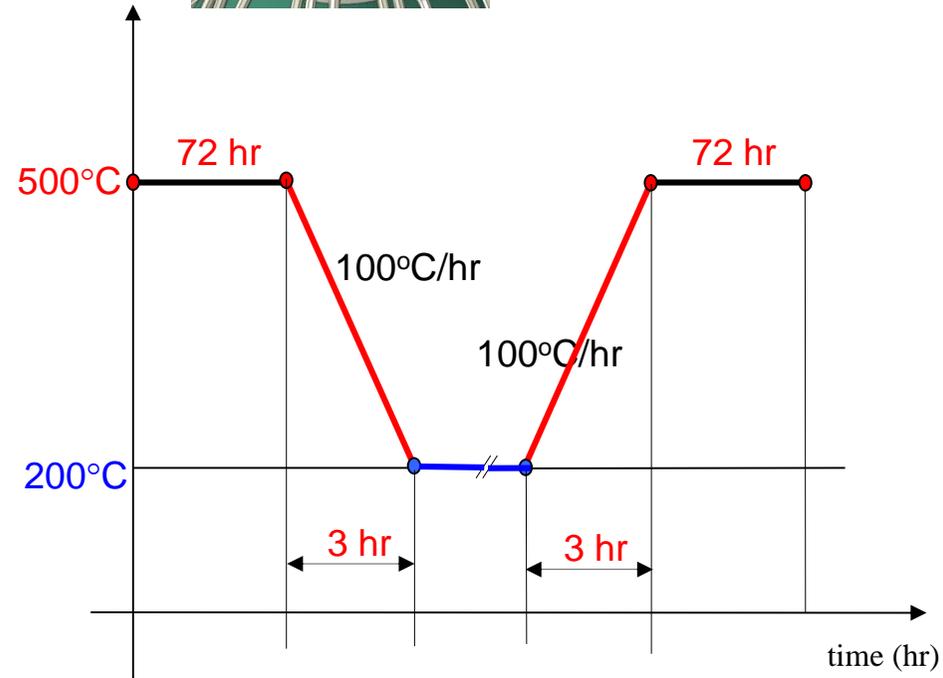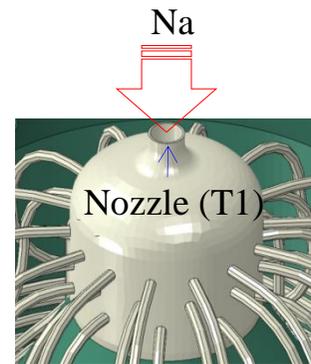
❖ **Conservatism (Gr.91) : RCC-MRx < ASME-NH**

- **3D CAD Model based FE Model. (ABAQUS)**
- **523,752 3D Brick Elements**
- **803,199 nodes**

Primary Inlet (Na)

Na

Nozzle (T1)

AHX (sodium-to-air HX)

500°C   72 hr   72 hr

100°C/hr

100°C/hr

200°C

3 hr   3 hr

time (hr)
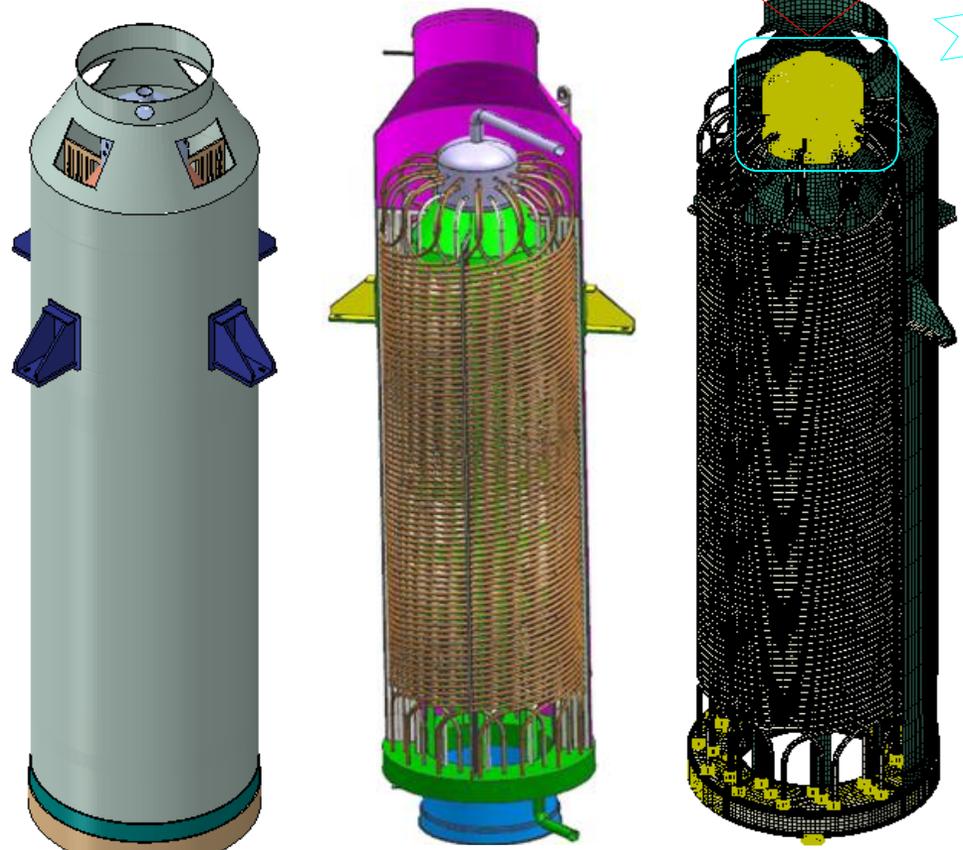
Sodium temp. at Inlet nozzle

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IV.8 Heat Transfer Analysis

❖ **Temperature Contour of Step 4 (400 → 500 ℃ Transient (Heat Up End))**

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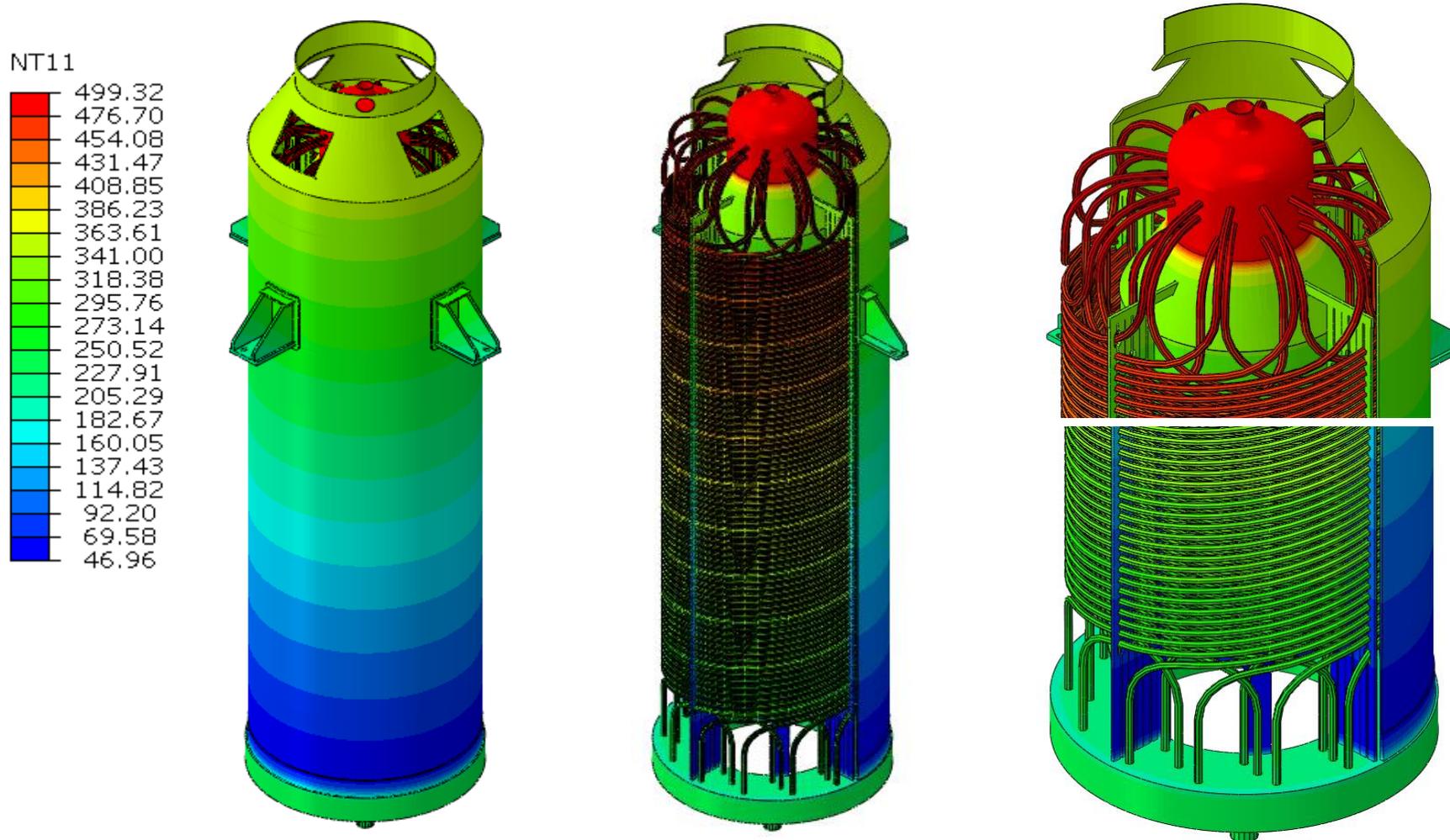
IV.9 Stress Analysis : Secondary Load

❖ **Stress Contour of AHX (at the end of Heat Up)**
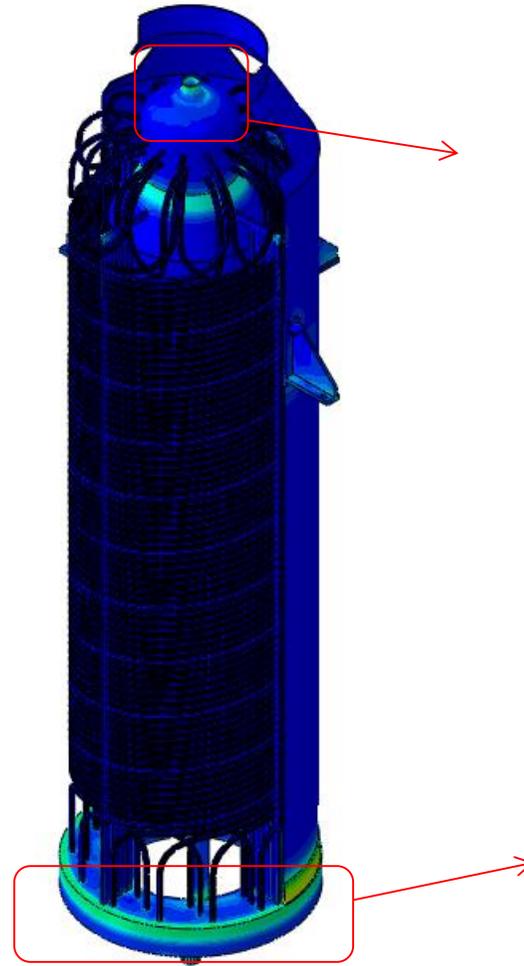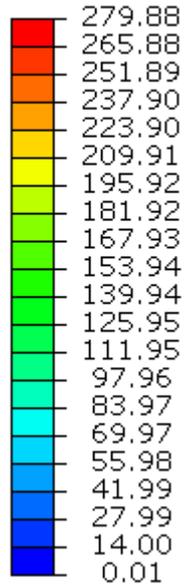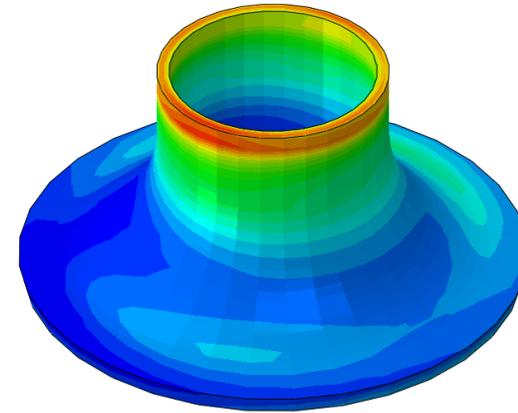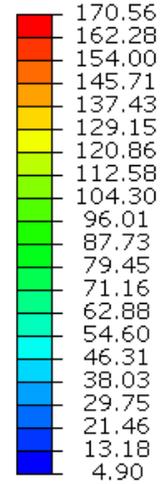
T1 Nozzle

Tube Sheet
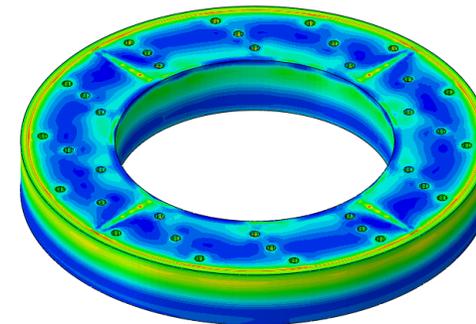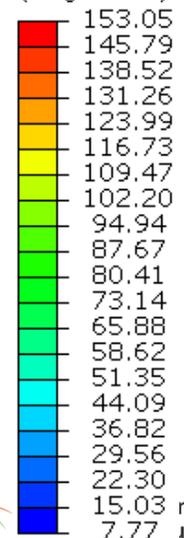
IV.10 Creep-Fatigue Damage (AHX)

❖ **AHX (316L)**

Point 1. T1 Nozzle

(498℃)

Point 2. Inner Shell (190℃)

Point 3. Outer Shell /

Stiffener Ring (~190℃)
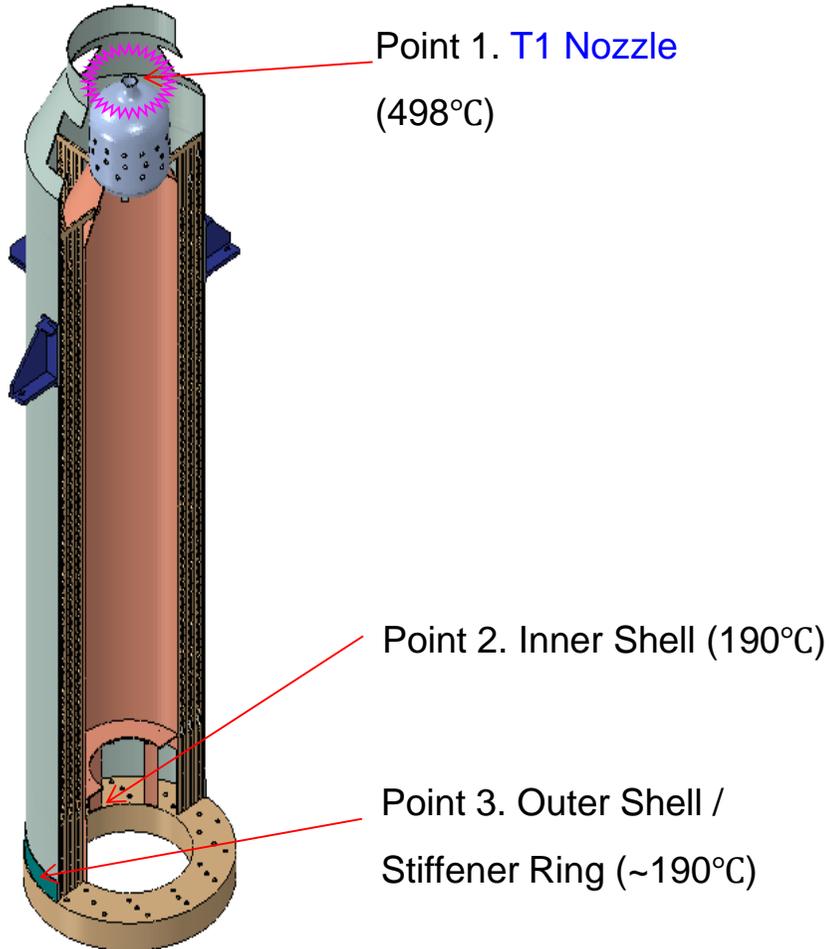
❖ **C-F damage** @ T1 Nozzle
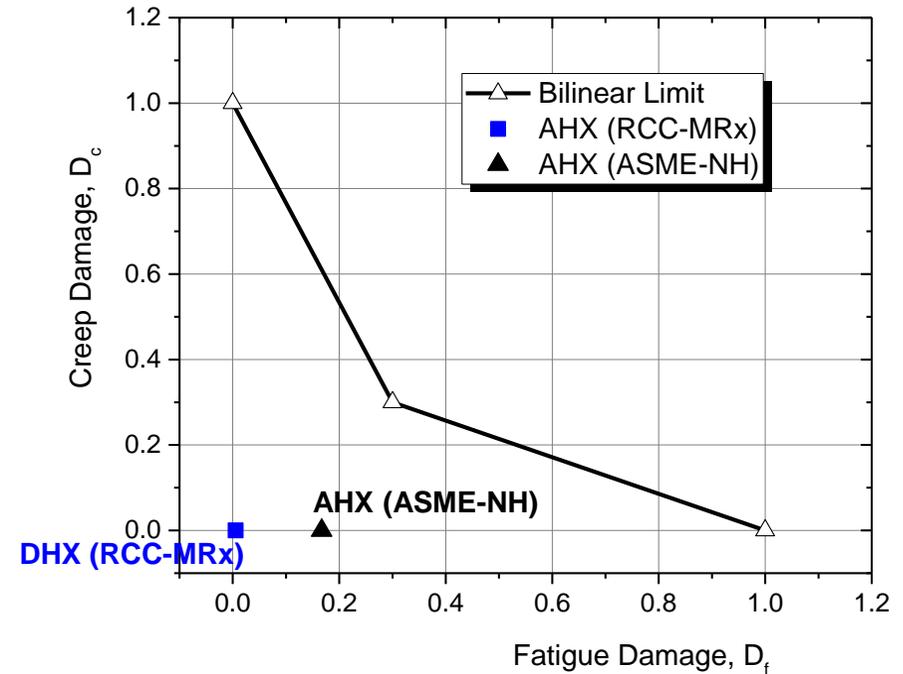
AHX	ASME-NH	RCC-MRx
D_f	0.16706	0.00540
D_c	0.00023	0.00010

❖ **Conservatism (Gr.91) : RCC-MRx < ASME-NH**

❖ **Distribution of temperature**

Rx thermal analysis

Rx thermal analysis
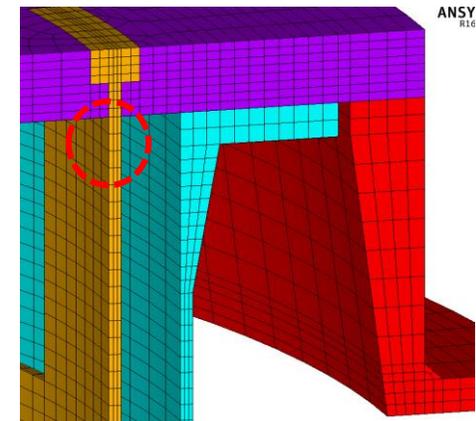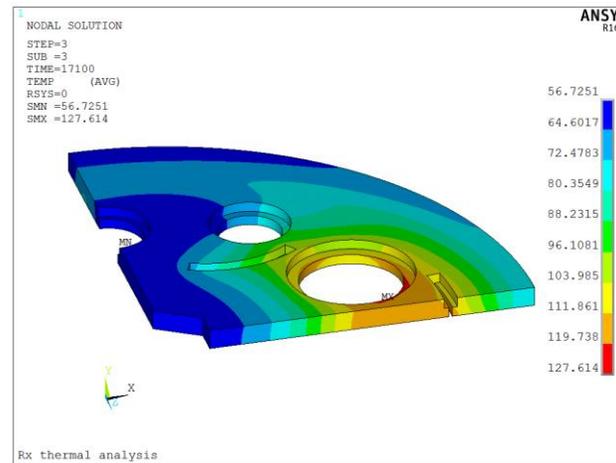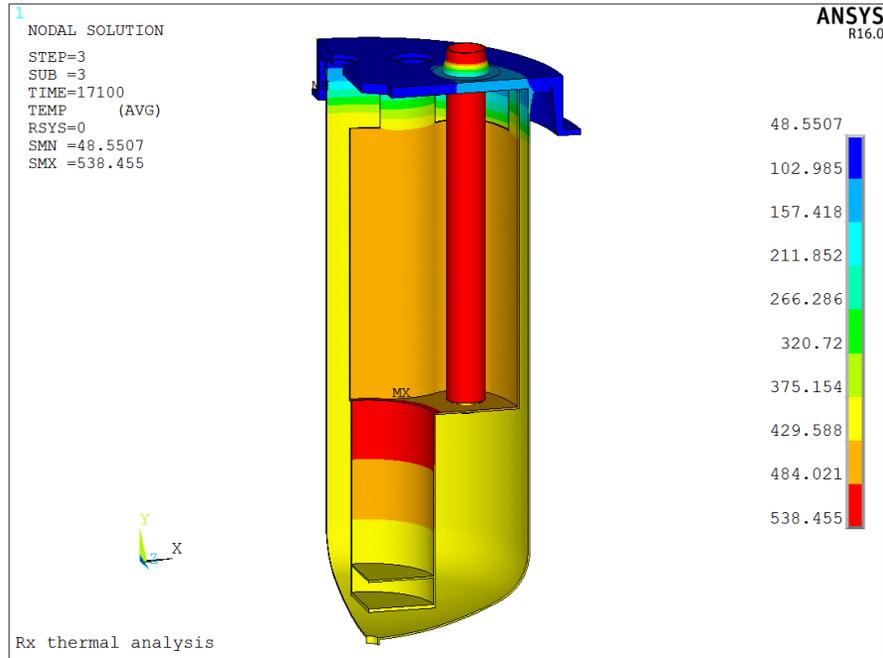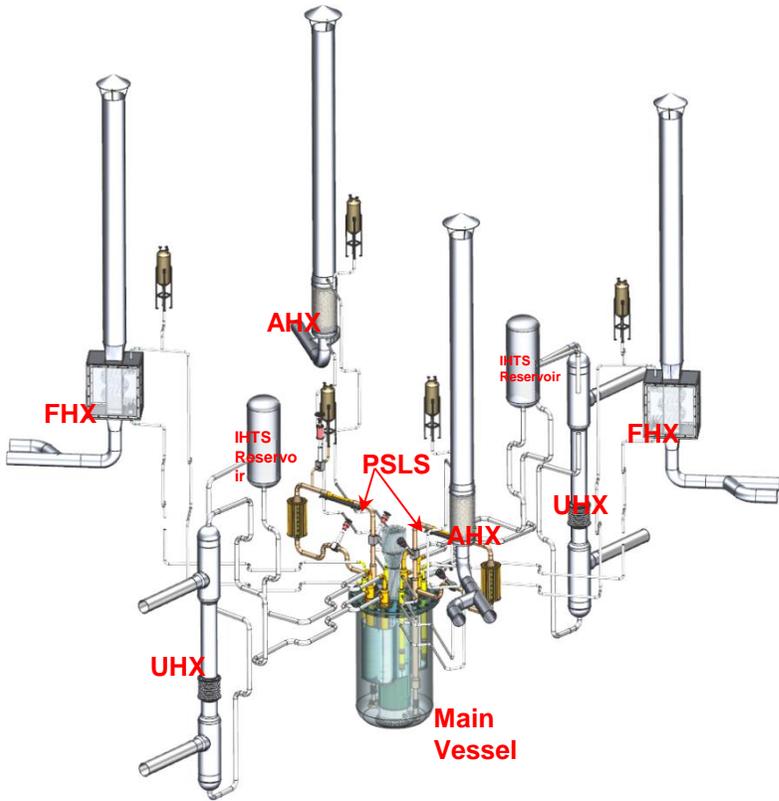
Temp. distribution @4.25h after Heat-up started

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IV.12 Stress Analysis & C-F Damage (STELLA-2)

❖ **Stress distributions under thermal loads**
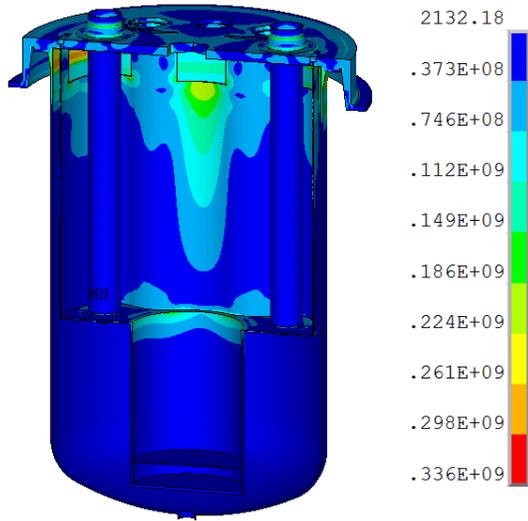
Stress intensities after Heat-up (4.25h)
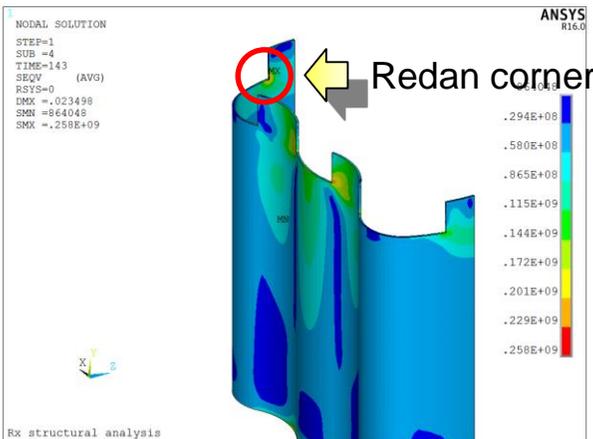
Redan corner

❖ **C-F damage** @ Redan corner

- Bilinear Limit
- ■ Redan (RCC-MRx)
- ▲ Redan (ASME-NH)
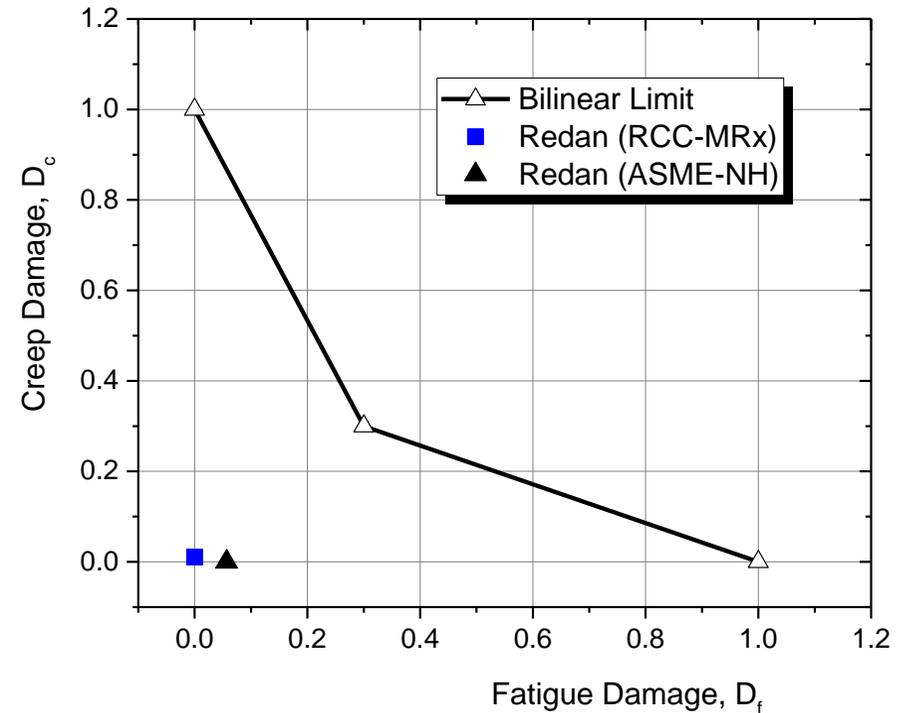
Redan	ASME-NH	RCC-MRx
D_f	0.05690	0.00017
D_c	0.00010	0.01020

❖ **Conservatism : RCC-MRx < ASME-NH for fatigue**
RCC-MRx > ASME-NH for creep

V

Design evaluation program, HITEP_RCC-MRx

(*) Elevated Temperature Design

❖ **Web-based calculation program of RCC-MRx** (language : php)

➢ RB-3200 (Design by analysis) programming completed.

➢ FY2016 : RB-3600(DBR) to be programmed.
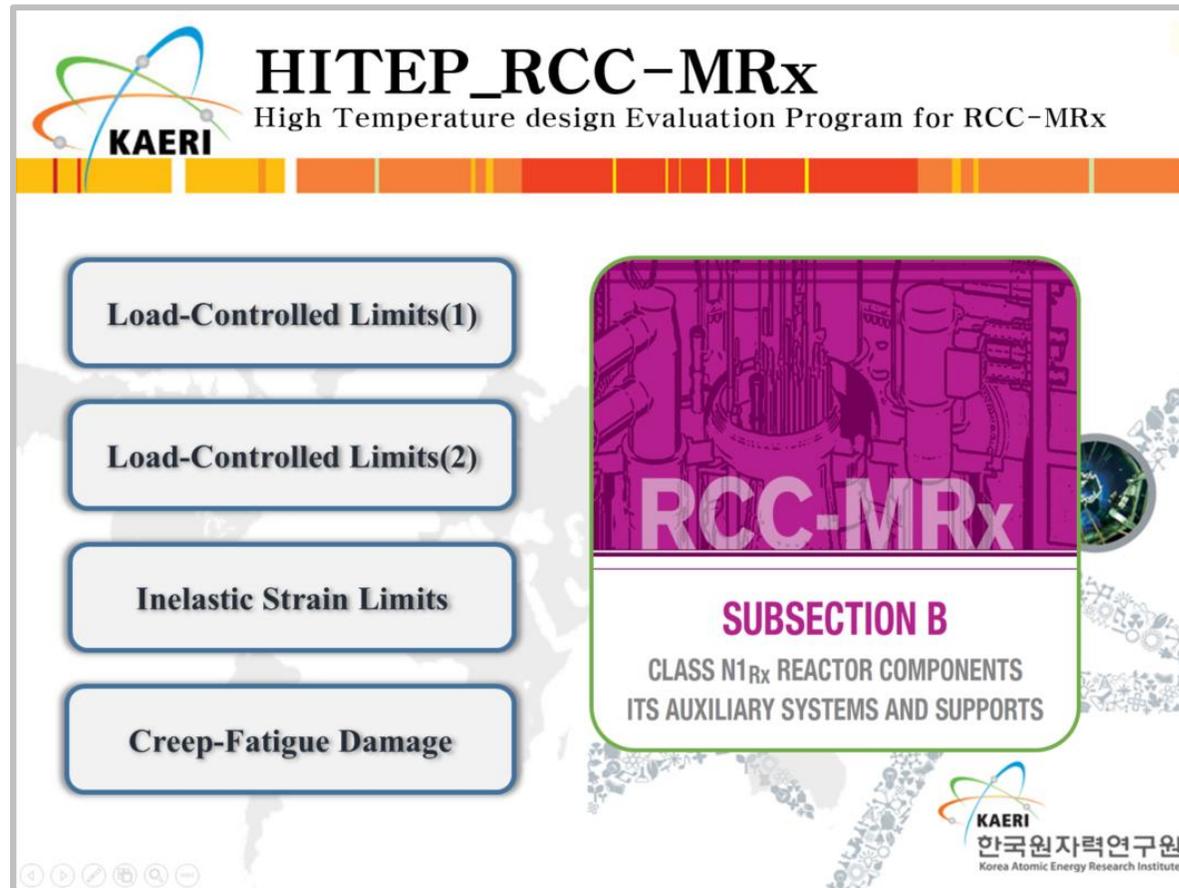
[HITEP_RCC-MRx program cover screen]

- **HITEP_RCC-MRx verification (1)**
  - Load Controlled Limits(1) – Input window
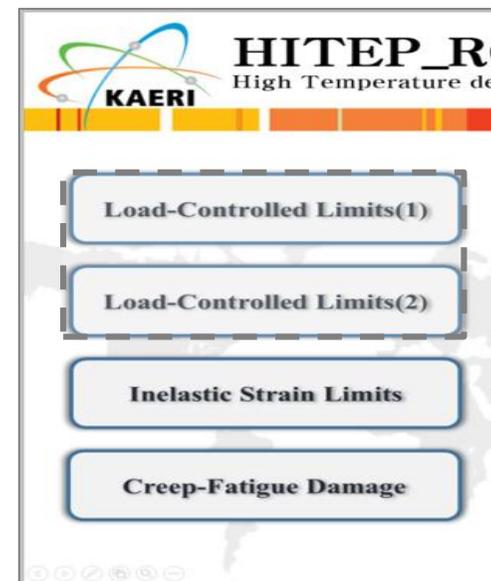
Load Controlled Limits (2)

Material	316LN ▼
Service Level	○ Level A ○ Level C ○ Level D
UNIT	○ MPa ○ Pa

[Primary Stress Component (Max)]

	σ_x	σ_y	σ_z	σ_{xy}	σ_{yz}	σ_{zx}
P_m (MPa)	0.01015	24.75	4.16	-0.1056	0	0
L_m (MPa)	0	0	0	0	0	0
P_b (MPa)	-0.02637	11.23	3.401	0	0	0
F (MPa)	-1.819E-18	0.02109	0.01483	0.02226	0	0

[Secondary Stress Component (Max)]

	σ_x	σ_y	σ_z	σ_{xy}	σ_{yz}	σ_{zx}
Q_m (MPa)	-0.1128	-0.0002557	-10.83	3.658	0	0
Q_b (MPa)	0.2093	-140.9	-37.99			
F (MPa)	0	0.7269	0.8799			

[Secondary Stress Component (M...]

	σ_x	σ_y	σ_z
Q_m (MPa)	-0.1961	-0.0000885	-77.25
Q_b (MPa)	0.1042	-173.1	-65.25
F (MPa)	4.366E-17	-1.359	-2.581

| Max. temp (°C) | 510 | J-integral |

[OK] | [Close]

[Load–Controlled Limits(2) evaluation m...

Load Controlled Limits (2)

Load-Controlled Limits(2)(Level A)

| Material | | | 316L | |

Evaluation Items		Calculated	Limit value	Remark
Max(P_L + P_b)+ΔQ	Max(P_L + P_b)+ΔQ < $3S_m$	130.54 Mpa	292.8 Mpa	OK!!

[Back] | [Next]

HITEP_RC
High Temperature des...

- Load-Controlled Limits(1)
- Load-Controlled Limits(2)
- Inelastic Strain Limits
- Creep-Fatigue Damage

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- **HITEP_RCC-MRx verification**
  - Creep-Fatigue Damage - window

Creep-Fatigue Damage

Material	316LN ▼	
Total Hold Time	617	hour
Hold Temperature	510	°C
Design Number of Cycles(n)	851	
UNIT	○ MPa	○ Pa

[Primary Stress Component (Max)]

	σ_x	σ_y	σ_z	σ_{xy}	σ_{yz}	σ_{zx}
P_m	0.01015	24.75	4.16	-0.1056	0	0
L_m	0	0	0	0	0	0
P_b	-0.02637	11.23	3.401	0	0	0
F	-1.819E-18	0.02109	0.01483	0.02226	0	0

[Primary Stress Component (Min)]

	σ_x	σ_y	σ_z	σ_{xy}	σ_{yz}	σ_{zx}
P_m	0	0	0	0	0	0
L_m	0	0	0	0	0	0
P_b	0	0	0	0	0	0
F	0	0	0	0	0	0

[Secondary Stress Component (Max)]

	σ_x	σ_y	σ_z	σ_{xy}	σ_{yz}	σ_{zx}
Q_m	-0.1128	-0.000255?	-10.83	3.658	0	0
Q_b	0.2093	-140.9	-37.99	0	0	0
F	0	0.7269	0.8799	-0.7823	0	0

[Secondary Stress Component (Min)]

	σ_x	σ_y	σ_z	σ_{xy}	σ_{yz}	σ_{zx}
Q_m	-0.1961	-0.000088?	-77.25	-2.266	0	0
Q_b	0.1042	-173.1	-65.25	0	0	0
F	4.366E-17	-1.359	-2.581	0.4839	0	0

[OK] | [Close]
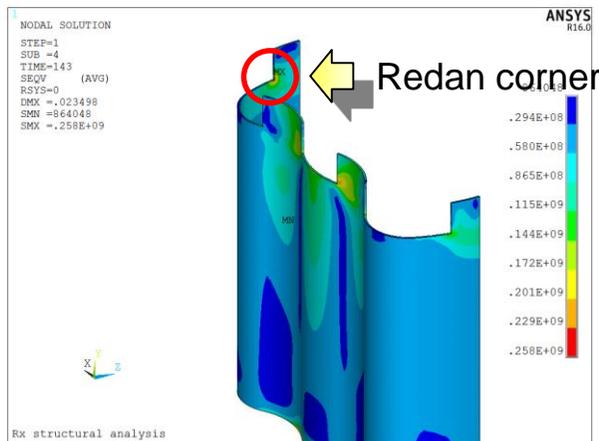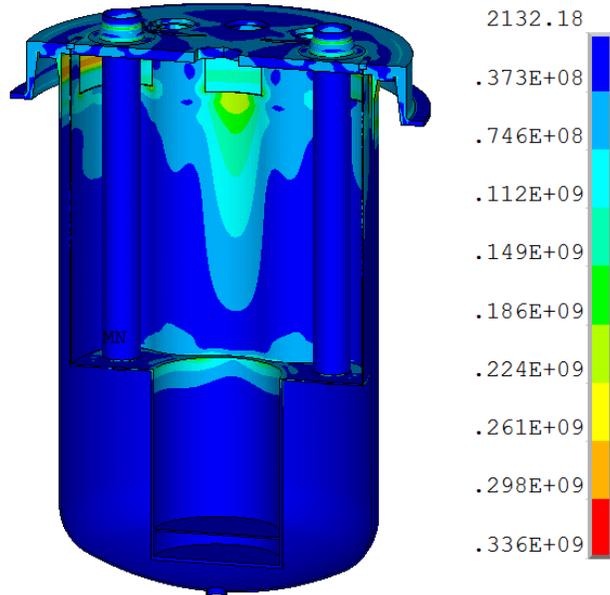
Creep-Fatigue Damage

Creep-Fatigue Damage

Material

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

	Calculated	Limit value	Check
Fatigue damage	9.2199E-12		OK!!
Creep damage	0.0081		OK!!

[Back] | [Next]

※ [Creep-Fatigue Damage evaluation module (sample) – Input Window]

Verification of the program (STELLA-2)

Contents	Calculated	Limit value	Remark
Primary Stress Limit			
P_m	24.7 MPa	91.8 MPa	OK
P_L	24.7 Mpa	137.7 MPa	OK
$P_L + P_B$	33.6 MPa	137.7 MPa	OK
Creep-Fatigue Damage			
Fatigue Damage	0.000172	0.9996	OK
Creep Damage	0.01020	1	OK

[Summary of Results]
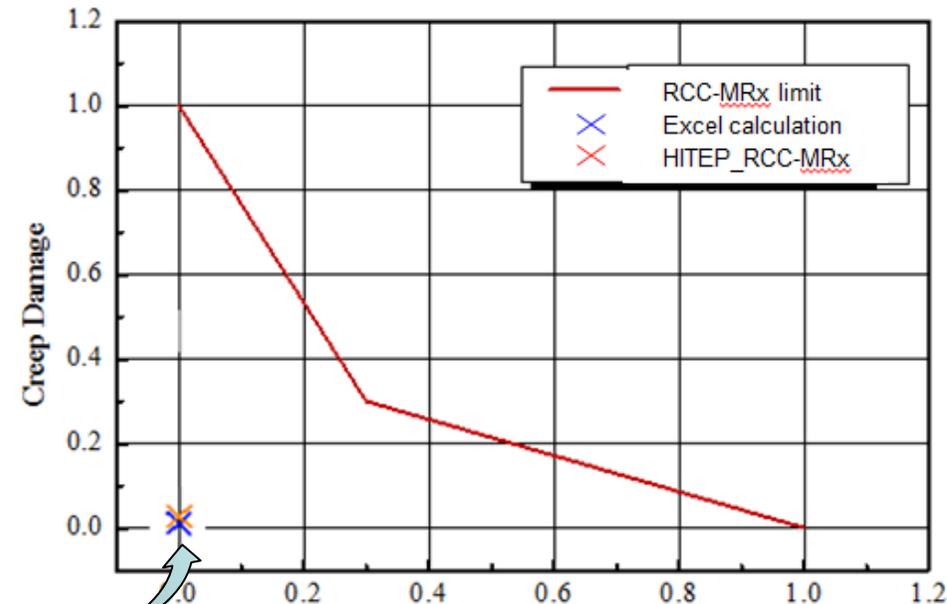
Redan corner

[Creep-fatigue damage evaluation]

Verification of the program (PGSFR)

Contents	Calculated	Limit value	Remark
Primary Stress Limit			
P_m	24.75 MPa	105.6 MPa	OK
$P_L + P_B$	24.51 MPa	159.7 MPa	OK
$P_L + P_B / K_t$	24.56 MPa	138.4 MPa	OK
Creep-Fatigue Damage			
Fatigue Damage	2.4E-04	0.2360	OK
Creep Damage	0.4492	1	OK

[Summary of Results]
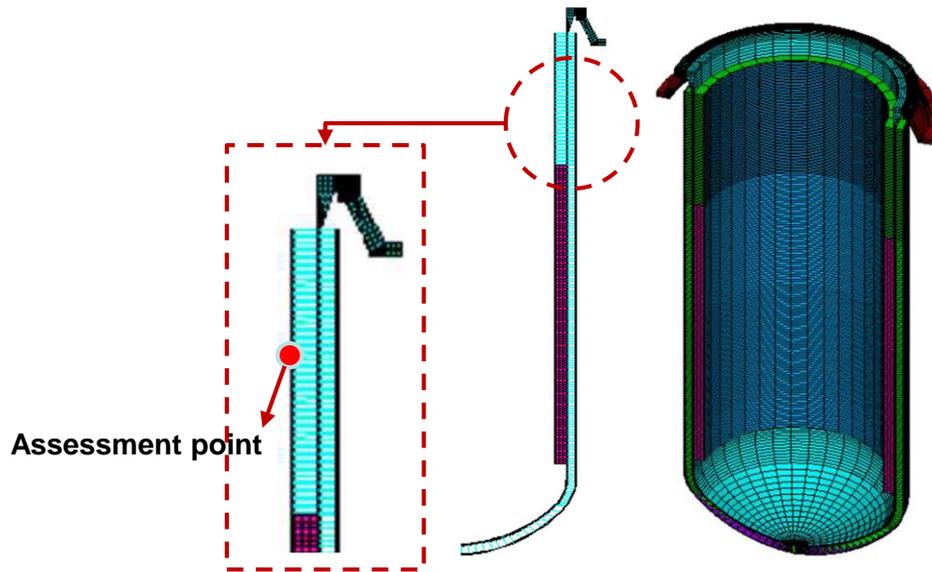
[2D Axisymmetric FE model of Reactor Vessel]

Assessment point

[Creep-fatigue damage evaluation]

VI NRC Licensing Concerns on ETD rules (for CRBR)
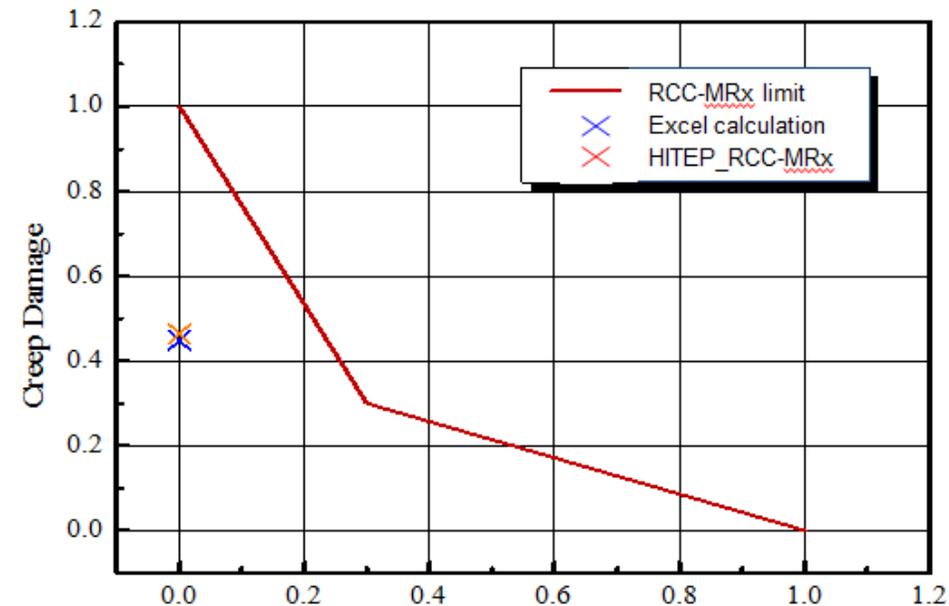
❑ **List of Elevated Temperature Structural Integrity Issues (25 items) : 1983**

1. **Transition joints**
2. **Weld residual stresses**
3. Design loading combinations
4. Creep-rupture and fatigue damage
5. Simplified bounds for creep ratcheting
6. Thermal striping
7. Creep-fatigue analysis of class 2 and 3 piping
8. Are limits of Case N-253 for elevated temperature class 2 and 3 components met?
9. Creep buckling under axial compression – design margins
10. Identify areas where Appendix T rules are not met
11. Rules for component supports at elevated temperature
12. Strain and deformation limits at elevated-temperature
13. **Evaluation of weldments**
14. Material acceptance criteria for elevated temperature
15. Creep-rupture damage due to forming and **welding**
16. Mass transfer effects
17. Environmental effects
18. Fracture toughness criteria
19. Thermal aging effects
20. Irradiation effects
21. Use of simplified bounding rules at discontinuities
22. Elastic follow-up
23. **Design criteria for elevated-temperature core support structures and welds**
24. Elevated-temperature data base for mechanical properties
25. Basis for leak-before-break at elevated temperatures

* : Regulatory Safety Issues on ASME-NH

Issues on

- weldments   : 5EA
- Creep / fatigue : 5EA
- Environ. effects : 3EA
- LBB : 1EA
- Frac. Toughness: 1EA.

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VII. Summary

❖ **Comparison of ETD rules, RCC-MRx & ASME-NH has been conducted and application of the rules to the STELLA-1&2 and SELFA was conducted.**

❖ **Full 3D FEA conducted for the components and C-F damage was evaluated according to RCC-MRx and ASME-NH for**

 + Heat Exchangers (DHX, AHX, FHX) & RI (Redan) : within C-F design limits

 ⇒ **Conservatism depends on the problems although generally it tends to be ; RCC-MRx < ASME-NH.**

 ⇒ **Conservatism of material properties depends although RCC-MRx properties such as YS, Fatigue strength, creep rupture strength etc.)**

❖ **Computer program of HITEP_RCC-MRx for evaluation as per RCC-MRx has been developed.**

 + RB-3200 (DBA*) programming completed

 + RB-3600 (DBR) to be developed in FY2016.**

* : Design By Analysis, ** : Design By Rule

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VI.1

Thank You!

Hyeong-Yeon Lee (KAERI)

hylee@kaeri.re.kr