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

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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
Introduction
I.1 Gen.IV Reactors & Design Rules (1/2)

- 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

(*) ETD : Elevated Temperature Design
I.1 Gen.IV Reactors & Design Rules (2/2)

- **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.

  - 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
I.2 Two major materials in PGSFR

- 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)
ETD Rules

- RCC-MRx
- ASME Section III Div.1 Subsection NH
  Section IIII Div.5

(*) Elevated Temperature Design
II.1 Elevated Temperature Design Codes

- ASME Section III Subsection NH (2015 Ed.) ⇒ merge to Div.5 (2017)
- ASME Section III Div. 5 (High Temp. Reactors, 2015 Ed.)
  - 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)
- KEPIIC MNH (SFR, Korea)
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

Subsection HC — Class B Metallic Pressure Boundary Components
  Subpart A — Low Temperature Service
  Subpart B — Elevated Temperature Service

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

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
II.3 RCC-MRx Procedures: strains

- **Total strain**
  - Determined from total stress range (peak included)
  
  \[ \Delta \sigma_{tot} = \Delta (P + Q + F) \]

  \[ \Delta \varepsilon_{el+pl} = \Delta \varepsilon_1 + \Delta \varepsilon_2 + \Delta \varepsilon_3 + \Delta \varepsilon_4 \]

  \[ \Delta \varepsilon = \Delta \varepsilon_{el+pl} + \Delta \varepsilon_{cr} \]

- **Total strain**

  \[ \Delta \varepsilon_1 = \frac{2}{3} (1 + \nu) \frac{\Delta \sigma_{tot}}{E} \]
II.4 RCC-MRx Procedures : C-F Damage

Fatigue damage

\[ V(\Delta \varepsilon) = \sum \frac{n_i}{N_{ai}} \]

Creep damage

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

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

Limits on Deformation Controlled Quantities

Inelastic Strain
- Plastic, Creep, Ratcheting Effects
- Fatigue

Creep-Fatigue
- Interaction Effects

Buckling
- Instability Effects

By Appendix T (Non-mandatory)

Materials
- 304SS
- 316SS
- 2.25Cr-1Mo
- Mod.9Cr-1Mo
- Alloy 800H
- Alloy 718
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
Comparison of ETD* Codes

- Material Properties (chem. Composition incl.)
- Design evaluation procedures
### 316 Stainless steel

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

### Grade 91

<table>
<thead>
<tr>
<th>Code/Test</th>
<th>Grade</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>N</th>
<th>Nb</th>
<th>other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ASME</strong></td>
<td>Gr.91</td>
<td>0.06-0.15</td>
<td>0.25-0.66</td>
<td>0.025</td>
<td>0.012</td>
<td>0.18-0.56</td>
<td>7.90-9.60</td>
<td>0.43</td>
<td>0.80-1.10</td>
<td>0.025-0.080</td>
<td>...</td>
<td>Al. 0.02</td>
</tr>
<tr>
<td><strong>RCC-MRx</strong></td>
<td>X10CrMoVNb9-1 (Gr.91)</td>
<td>0.080-0.120</td>
<td>0.30-0.60</td>
<td>≤0.020</td>
<td>≤0.005</td>
<td>0.20-0.50</td>
<td>8.00-9.50</td>
<td>≤0.20</td>
<td>0.85-1.05</td>
<td>0.03-0.07</td>
<td>0.06-0.10</td>
<td>Al. ≤0.040</td>
</tr>
</tbody>
</table>
III.2 Comparison of Properties: \( \text{YS, TS, } S_m \)

- **Yield strength, Tensile strength & Design stress intensity of Gr.91 steel**
  - RCC-MRx properties are more conservative.

- **Design stress intensity, \( S_m \) of Gr.91**

\[ \text{YS (Gr.91)} \]
\[ \text{TS (Gr.91)} \]
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)
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)](image1)

![Creep rupture strength (Gr.91 @550°C)](image2)

*Ref. : G.H.Koo (ASME)
III.4 Thermal Aging in RCC-MRx

- **316L(N)**: TA considered in J-R curve
- **Gr.91**: TA Not considered in TS, YS & $S_m$

**A3.1S.51**  **THERMAL AGEING COEFFICIENT (NOT SUPPLIED)**

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

Ref.: RCC-MRx 2012 Addendum
### III.5 Thermal Aging in ASME-NH

#### Table NH-3225-2

<table>
<thead>
<tr>
<th>Material</th>
<th>Service Temp., °F (°C)</th>
<th>YS Reduction Factor</th>
<th>TS Reduction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>304SS</td>
<td>≥ 900 (480)</td>
<td>1.00</td>
<td>0.80</td>
</tr>
<tr>
<td>316SS</td>
<td>≥ 900 (480)</td>
<td>1.00</td>
<td>0.80</td>
</tr>
<tr>
<td>800H</td>
<td>≥ 1,350 (730)</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>2 1/4 Cr-1Mo</td>
<td>≥ 800 (425)</td>
<td>[Note (1)]</td>
<td>[Note (1)]</td>
</tr>
<tr>
<td>9Cr-1Mo-V</td>
<td>≥ 900 (480)</td>
<td>1.0</td>
<td>[Note (2)]</td>
</tr>
</tbody>
</table>

**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))
### III.6 Comparison of Design Rules

<table>
<thead>
<tr>
<th>Calculation of total strain range and creep damage</th>
<th><strong>RCC-MRx</strong></th>
<th><strong>ASME-NH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Creep laws directly used.</td>
<td>Isochronous curves used.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elastic Follow-up</th>
<th><strong>RCC-MRx</strong></th>
<th><strong>ASME-NH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explicitly considered (q=3, default)</td>
<td>Implicitly considered</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain limits</th>
<th><strong>RCC-MRx</strong></th>
<th><strong>ASME-NH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1% (membrane), 2% (bending)</td>
<td>1% (membrane), 2% (bending), 5% (peak)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak terms in strain calculation</th>
<th><strong>RCC-MRx</strong></th>
<th><strong>ASME-NH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Contained in total S.I (convenient)</td>
<td>Should be decomposed in elastic approach</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratcheting rule</th>
<th><strong>RCC-MRx</strong></th>
<th><strong>ASME-NH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency diagram method (Gr.91 pending)</td>
<td>Mod. Bree diagram (O’Donnel Porowski)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental effects</th>
<th><strong>RCC-MRx</strong></th>
<th><strong>ASME-NH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explicitly to be considered (irradiation, thermal ageing etc.) (@ beginning stage)</td>
<td>No guideline (except thermal aging, designer’s duty)</td>
<td></td>
</tr>
</tbody>
</table>

- 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.
III.7 C-F Damage for Weldment

**ASME-NH**

1. Fatigue Damage

\[ N_d \text{(HAZ)}^{(*)} = \frac{1}{2} N_d \text{(base)} \]

2. Creep Damage

\[ T_d \text{ determined from } S_r \times R \text{ (Weld SRF)} \]

**RCC-MRx**

1. Fatigue Damage

\[ \Delta \sigma_{\text{weld}} = \text{FSRF} \times \Delta \sigma_{\text{base}} \]

\[ \varepsilon_t \text{(HAZ)} = J_f \times \varepsilon_{t0} \text{(base)} \]

2. Creep Damage

\[ T_d \text{ determined from } (S_r \times J_r) \]
III.8 C-F* Damage Envelope

- **Linear Damage Summation Rule (LDSR)**
  - Severud (1970s)
  - Based on cavity growth of Austenitic S.S at tensile hold

- **ASME-NH**

- **RCC-MRx**

(*) Creep-Fatigue

![Graph showing damage envelope for ASME-NH and RCC-MRx](image-url)
III.9 Code Case **N-812** ; Gr.91 Alternative C-F Rule

- 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**

**Code Case N-812**

(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
Application of the ETD rules to sodium test facilities

STELLA-1

STELLA-2

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
IV.1 Main components in STELLA-1 & 2

- **DHX**: Expansion tank
- **AHX**: Loop heater vessel
- **Reactors Vessel (ST-2)**

STELLA-1 test facility
IV.2 FE Model & thermal load condition

- 3D CAD Model based FE Model. (ABAQUS)
- 225,511 3D Brick Elements
- 290,790 nodes

![Schematic and 3D FE Model of DHX]

**Primary side**
- 510°C
- 100°C/hr
- 72 hr

**Secondary side**
- 500°C
- 100°C/hr
- 72 hr

- No. of cycles = 500.
- Hold Time / C-F cycle = 30 hr
IV.3 Heat Transfer Analysis

- Temperature Contour of Step 4 (410 → 510 °C Transient)
IV.4 Stress Analysis : Primary Load

- Stress Contour of DHX

| 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 |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
IV.5 Stress Analysis : Secondary Load

- Stress Contour of DHX (at the end of Heat Up)

- Max (Top Support Ring)

- N4A Nozzle

- Tubesheet stress level: low
IV.6 Creep-Fatigue Damage (DHX)

- **DHX (Gr.91)**

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

\[\text{DHX (ASME-NH)}\]
\[\text{DHX (RCC-MRx)}\]

- **C-F damage @ nozzle pt. 3**

\[
D_f \leq \frac{\Delta}{\Delta_{\text{C-F damage}}} @ \text{nozzle pt. 3}
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{DHX} & \text{ASME-NH} & \text{RCC-MRx} \\
\hline
D_f & 0.00005 & 0.00005 \\
D_c & 0.02051 & 0.00023 \\
\hline
\end{array}
\]

- **Conservatism (Gr.91): RCC-MRx < ASME-NH**
IV.7 FE Model & thermal load condition for AHX

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

Sodium temp. at Inlet nozzle

- 500°C
- 100°C/hr for 72 hr
- 200°C
- 100°C/hr for 72 hr
- 3°C/hr for 3 hr

AHX (sodium-to-air HX)

Primary Inlet (Na)
III.8 Heat Transfer Analysis

- Temperature Contour of Step 4 (400 → 500 °C Transient (Heat Up End))
IV.9 Stress Analysis: Secondary Load

Stress Contour of AHX (at the end of Heat Up)
IV.10 Creep-Fatigue Damage (AHX)

- **AHX (316L)**
  - Point 1. T1 Nozzle (498°C)
  - Point 2. Inner Shell (190°C)
  - Point 3. Outer Shell / Stiffener Ring (~190°C)

- **C-F damage @ T1 Nozzle**

![](image)

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

<table>
<thead>
<tr>
<th></th>
<th>AHX</th>
<th>ASME-NH</th>
<th>RCC-MRx</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_f$</td>
<td>0.16706</td>
<td>0.00540</td>
<td></td>
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<tr>
<td>$D_c$</td>
<td>0.00023</td>
<td>0.00010</td>
<td></td>
</tr>
</tbody>
</table>
Distribution of temperature

IV.11 Temperature Analysis : STELLA-2

Temp. distribution @4.25h after Heat-up started
IV.12 Stress Analysis & C-F Damage (STELLA-2)

- **Stress distributions under thermal loads**

- **C-F damage @ Redan corner**

- **Conservatism: RCC-MRx < ASME-NH for fatigue**
  RCC-MRx > ASME-NH for creep
Design evaluation program, HITEP_RCC-MRx

(*) Elevated Temperature Design
V.1 Programming of RCC-MRx (1/3)

- Web-based calculation program of RCC-MRx (language : php)
  - RB-3200 (Design by analysis) programming completed.
  - FY2016 : RB-3600(DBR) to be programmed.
V.1 Programming of RCC-MRx (2/3)

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

[Load–Controlled Limits(2) evaluation module]
V.1 Programming of RCC-MRx (3/3)

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

![Creep-Fatigue Damage](image)

![Creep-Fatigue Damage](image)

![Creep-Fatigue Damage](image)
V.2 Verification of HITEP_RCC-MRx (1/2)

- Verification of the program (**STELLA-2**)

### Contents

<table>
<thead>
<tr>
<th>Contents</th>
<th>Calculated</th>
<th>Limit value</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Stress Limit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_m$</td>
<td>24.7 MPa</td>
<td>91.8 MPa</td>
<td>OK</td>
</tr>
<tr>
<td>$P_L$</td>
<td>24.7 Mpa</td>
<td>137.7 MPa</td>
<td>OK</td>
</tr>
<tr>
<td>$P_L + P_B$</td>
<td>33.6 MPa</td>
<td>137.7 MPa</td>
<td>OK</td>
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<tr>
<td>Creep-Fatigue Damage</td>
<td></td>
<td></td>
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<tr>
<td>Fatigue Damage</td>
<td>0.000172</td>
<td>0.9996</td>
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</tr>
<tr>
<td>Creep Damage</td>
<td>0.01020</td>
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</tr>
</tbody>
</table>

### Summary of Results

- Verification of the program (**STELLA-2**)
- Verification of HITEP_RCC-MRx (1/2)
- Creep-fatigue damage evaluation

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Redan corner

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[Summary of Results]
### V.3 Programming of HITEP_RCC-MRx (2/2)

- **Verification of the program (PGSFR)**

  ![2D Axisymmetric FE model of Reactor Vessel]

<table>
<thead>
<tr>
<th>Contents</th>
<th>Calculated</th>
<th>Limit value</th>
<th>Remark</th>
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</thead>
<tbody>
<tr>
<td><strong>Primary Stress Limit</strong></td>
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<tr>
<td>$P_m$</td>
<td>24.75 MPa</td>
<td>105.6 MPa</td>
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<tr>
<td>$P_L + P_B$</td>
<td>24.51 MPa</td>
<td>159.7 MPa</td>
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<tr>
<td>$P_L + P_B / K_t$</td>
<td>24.56 MPa</td>
<td>138.4 MPa</td>
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<tr>
<td><strong>Creep-Fatigue Damage</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue Damage</td>
<td>2.4E-04</td>
<td>0.2360</td>
<td>OK</td>
</tr>
<tr>
<td>Creep Damage</td>
<td>0.4492</td>
<td>1</td>
<td>OK</td>
</tr>
</tbody>
</table>

[Summary of Results]

![Creep-fatigue damage evaluation]
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.
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.
Thank You!

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