

Development of the **HITEP_RCC-MRx** program for the support of elevated temperature design evaluation and defect assessment according to RCC-MRx

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KAERI

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1. Introduction

❖ Elevated Temperature Design (ETD) Codes

- ASME Section III Division 5 Subsection HB ('ASME-HB')
- RCC-MRx
- JSME D&C Code for Fast Reactors, BDS (Japan)
- KEPIC MNH (SFR, Korea)

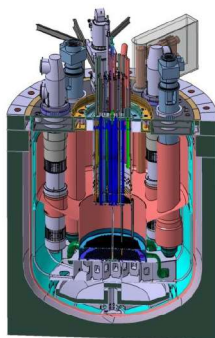
❖ ETD Code for EU Gen. IV

(ASTRID, MYRRHA, ALLEGRO)

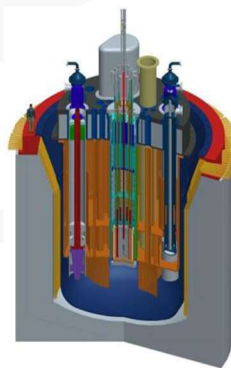
- RCC-MRx

❖ ETD Code for ITER

- RCC-MRx (Eurofer)
- ASME-HB



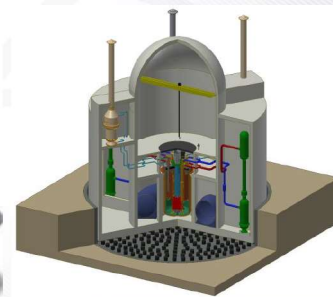
ASTRID



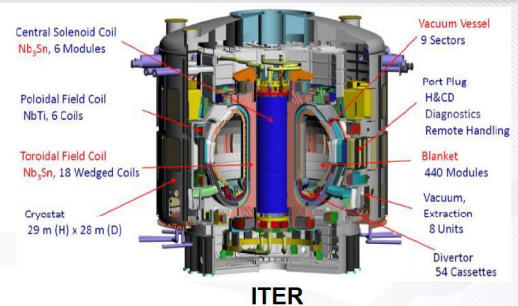
MYRRHA



ALLEGRO

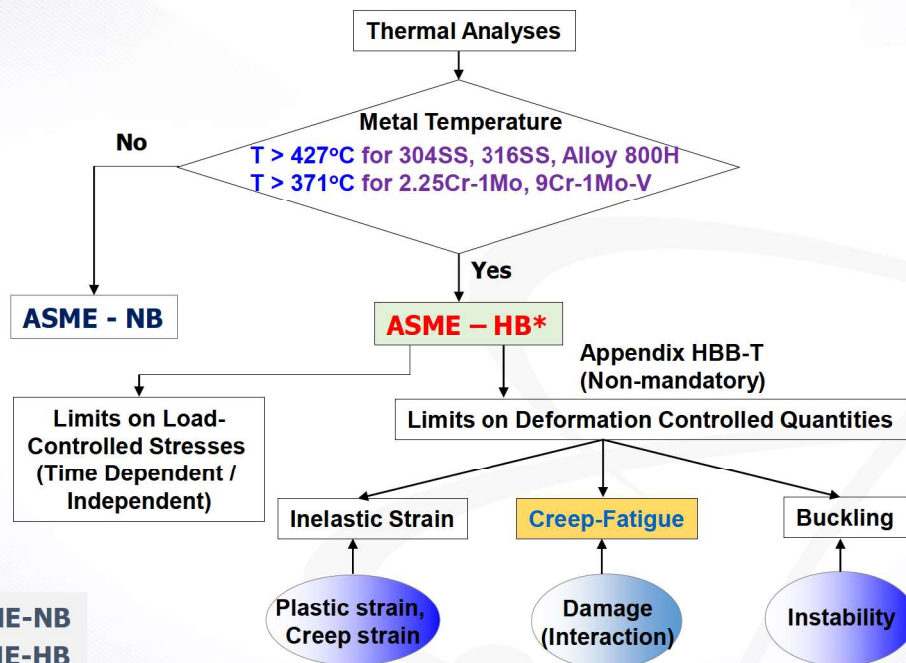


PGSRF (Korea)



ITER

2. Elevated Temperature Design rules : ASME-HB

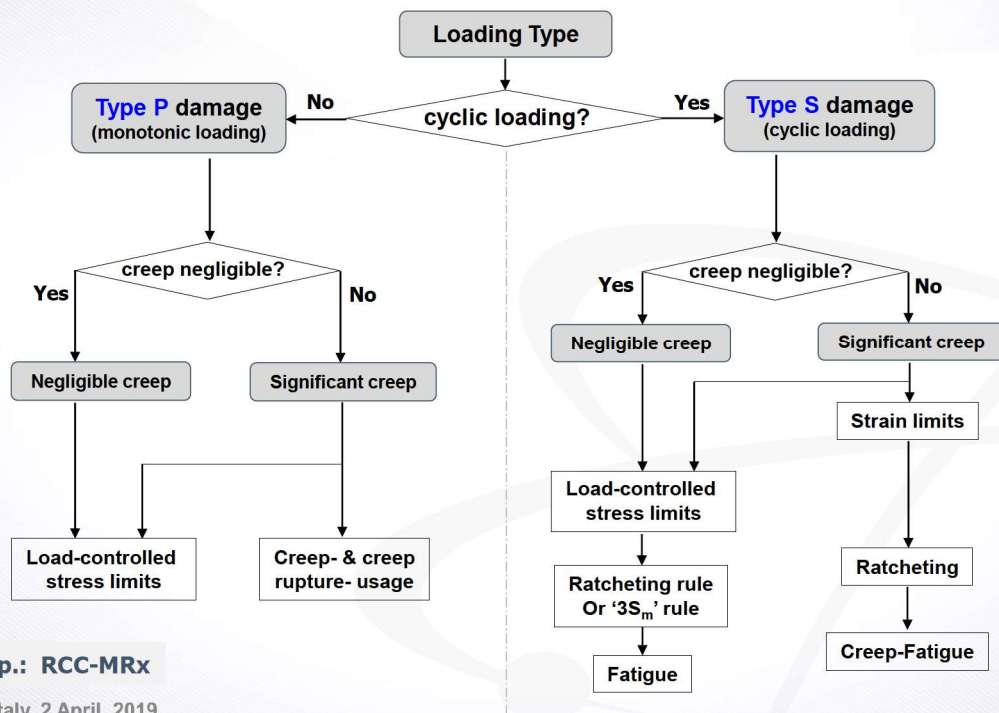


Low Temp.: ASME-NB
High Temp.: ASME-HB

Materials

- 304SS
- 316SS
- 2.25Cr-1Mo
- Mod.9Cr-1Mo
- Alloy 800H
- Alloy 718(Bolt)

2. Elevated Temperature Design rules : RCC-MRx



Low & High Temp.: RCC-MRx

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Materials

- 304
- 304L
- 316L
- 316L(N)
- 2.25Cr-1Mo
- Mod.9Cr-1Mo
- Alloy 800
- ...

2. Elevated Temperature Design rules : Comparison

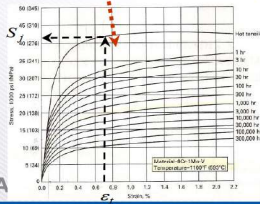
- strain based approach (strain results used)
- Equivalent strain range (peak strains should be excluded in elastic analysis approach)

$$\Delta \varepsilon_{equiv,i} = \frac{\sqrt{2}}{2(1+\nu^*)} \left[\frac{(\Delta \varepsilon_{x_i} - \Delta \varepsilon_{y_i})^2 + (\Delta \varepsilon_{y_i} - \Delta \varepsilon_{z_i})^2 + (\Delta \varepsilon_{z_i} - \Delta \varepsilon_{x_i})^2}{2} \right]^{\frac{1}{2}}$$

$$\varepsilon_t = K_v \Delta \varepsilon_{\text{mod}} + K \Delta \varepsilon_c$$

- Hand calculations required
- Data are given in curve form

- ✓ Isochronous curve based damage evaluation (both for creep & fatigue)



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

RCC-MRx

- strain from total S.I ($\overline{\Delta\sigma_{tot}}$) based approach (peak σ included : stress results used)

$$\overline{\Delta \mathcal{E}} = \overline{\Delta \mathcal{E}_{el+pl}} + \overline{\Delta \mathcal{E}_{cr}} \quad \overline{\Delta \mathcal{E}_{el+pl}} = \overline{\Delta \mathcal{E}_1} + \overline{\Delta \mathcal{E}_2} + \overline{\Delta \mathcal{E}_3} + \overline{\Delta \mathcal{E}_4}$$

$$\overline{\Delta \varepsilon_1} = \frac{2}{3}(1+\nu) \frac{\overline{\Delta \sigma_{tot}}}{E}$$

$$\overline{\Delta \varepsilon_2} = \dots$$

- ✓ Creep law is used for determining creep strain

$$\overline{\Delta \varepsilon_{cr}} \leftarrow \varepsilon_{cr} = C_1 t^{C_2} \sigma^{n_1}$$

- ✓ Cyclic σ - ϵ curve

Better Reproducibility

Better kept

Evaluation procedures more suitable for Programming

CC-MRx

HITeP_RCC-MRx

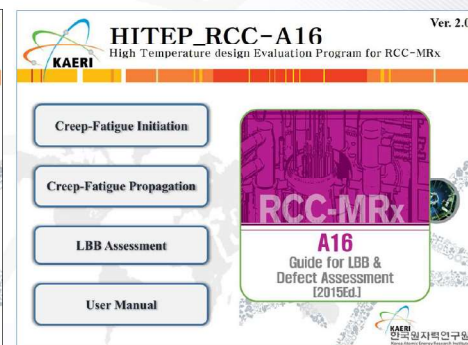
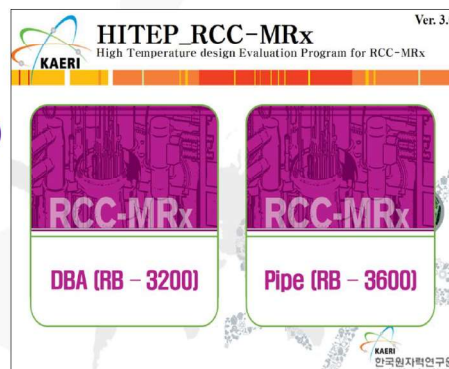
3. HITEP_RCC-MRx

- ❖ ‘Design evaluation & defect assessment program’ as per RCC-MRx (2018 Ed.).
- ❖ **HITEP** : **HI**gh **T**emperature design **E**valuation **P**rogram of RCC-MRx.
- ❖ **Language** : **PHP** (a server-side scripting language designed for web development)
HITEP_RCC-MRx is operating at SMART phone as well (web-based program)

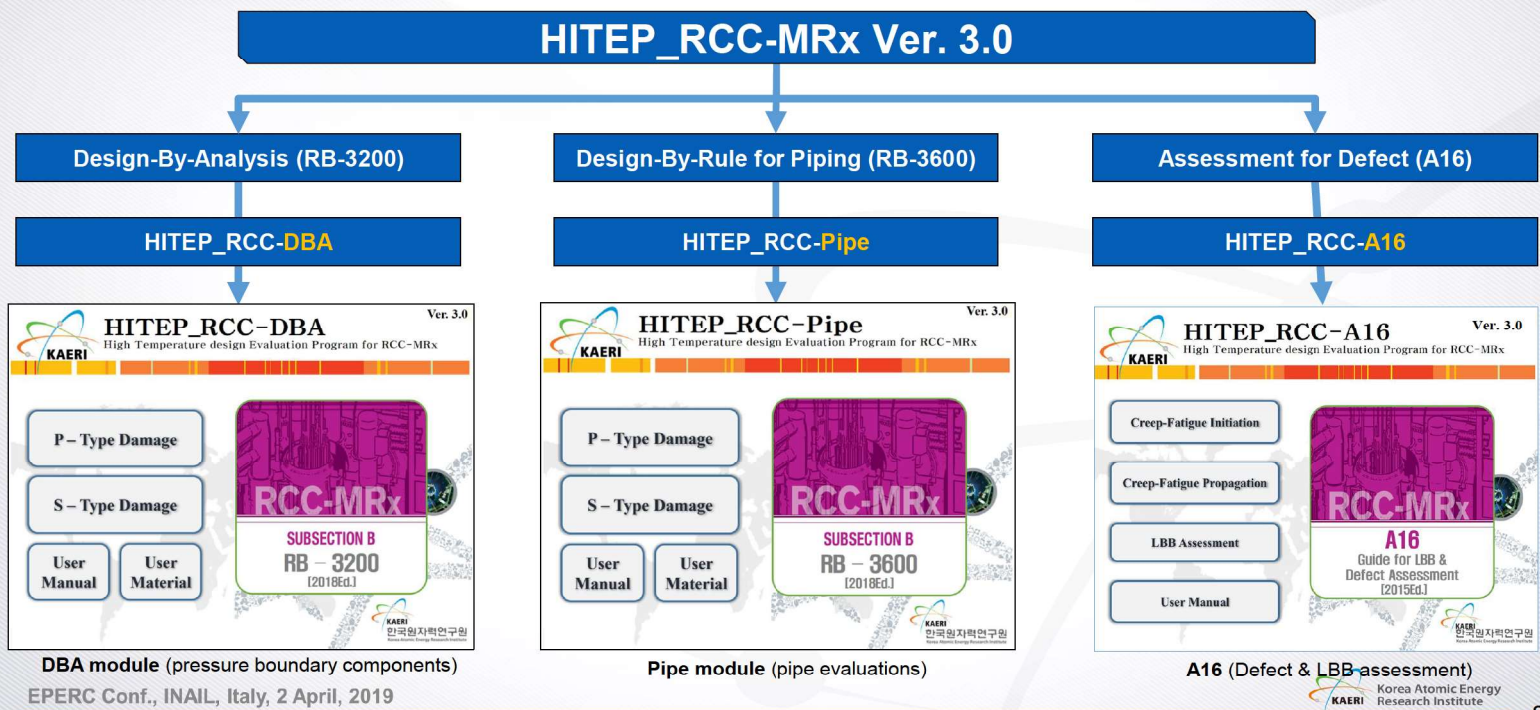
- ❖ **Three-module Program (3-pillar)**

- **DBA (Design-By-Analysis :RB-3200)**
- **Pipe** (RB-3600)
- **A16** (defect assessment)

- ❖ **Royalty License Agreement with CEA for DBA + Pipe module (9 Nov. 2017)**



3. HITEP_RCC-MRx : Program Structure



3.1 HITEP_RCC-DBA module

❖ RCC-MRx RB-3200(DBA) design evaluation module

- Design-By-Analysis module for pressure boundary comp. (pressure vessel, Heat exchangers etc.)
- Main material properties (316L(N), 316L, 304, 304L, Gr.91, Eurofer) embedded.
- Creep-Fatigue Damage evaluation and Verification (third-party verifications)

RCC-MRx RB-3200

P – Type Damage (RB-3250)

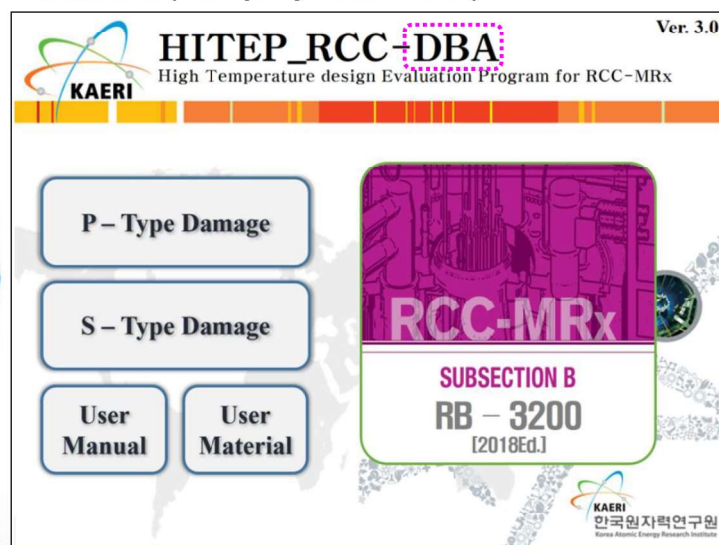
Negligible Creep (RB-3251)

Significant Creep (RB-3252)

S – Type Damage (RB-3260)

Negligible Creep (RB-3261)

Significant Creep (RB-3262)



3.1 HITEP_RCC-DBA module – Input & Output (1/3)

❖P-Type Damage

P - Type Damage

Material316L

Weld or BaseBase

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	1.001	2.491	1.196	0.2092	2.171	-1.436
L_m	0	0	0	0	0	0
P_b	1.532	1.489	2.781	1.456	-4.317	-1.586
F	0.5823	0.386	1.776	0.8864	-0.9726	-0.6109

[Reset]

Max. temp (°C)510J-integral350

Total Hold Time15000Cross-Section Coefficient(Φ)0.88

[OK] [Close]

[Save] [Reset All]

Input Window

P - Type Damage

P - Type Damage (Level A)

Material		316L		
Evaluation Items (Significant creep)		Calculated	Limit value	Remark
J-integral	$J_1 < J_{1c}$	0 kJ/m ²	500 kJ/m ²	OK!! [+]
P_m	$P_m < S_m$	5.4674 Mpa	79.4 Mpa	OK!! [+]
P_L	$P_L < 1.5S_m$	5.4674 Mpa	119.1 Mpa	OK!! [+]
$P_L + P_b$	$P_L + P_b < 1.5S_m$	7.9891 Mpa	119.1 Mpa	OK!! [+]
$U_A(\Omega P_m)$	$U_A(\Omega P_m) \leq 1$	4.6860E-18	1	OK!! [+]
$U_A(P_m + \Phi P_b)$	$U_A(P_m + \Phi P_b) \leq 1$	1.9919E-16	1	OK!! [+]
$W_A(1.35P_m)$	$W_A(1.35P_m) \leq 1$	5.9928E-10	1	OK!! [+]
$W_A(1.35(P_m + \Phi P_b))$	$W_A(1.35(P_m + \Phi P_b)) \leq 1$	3.5067E-9	1	OK!! [+]

[Back] [Next]

Output Window

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3.1 DBA module – Input & Output (2/3)

❖ S-Type Damage

S - Type Damage

Material316L

Weld or BaseBase

Overloadw/o Overload

Secondary membrane stress (Q_m)w/o Q_m

Max. temp. (°C)510

Hold Temperature (°C)510

Total Hold Time (h)15000

Design Number of Cycle(s)500

Cross-section Coefficient(φ)0.83

UNIT

☒ MPa

☐ Pa

[Primary stress Component (Max)]

σ ₁	σ ₂	σ ₃	σ _{xy}	σ _{yz}	σ _{zx}	
P _m	1.001	2.491	1.196	0.2092	2.171	1.436
L _m	0	0	0	0	0	0
P _s	1.532	1.489	2.781	1.456	-4.317	-1.585
F	0.5823	0.386	1.776	0.8864	-0.9726	-0.6109

[Reset]

[Primary stress Component (Min)]

σ ₁	σ ₂	σ ₃	σ _{xy}	σ _{yz}	σ _{zx}	
P _m	0	0	0	0	0	0
L _m	0	0	0	0	0	0
P _s	0	0	0	0	0	0
F	0	0	0	0	0	0

[Reset]

[Secondary stress Component (Max)]

Q _m	σ ₁	σ ₂	σ ₃	σ _{xy}	σ _{yz}	σ _{zx}
Q _h	19.74	-46.97	-9.751	-4.313	5.944	2.412
Q _h	-80.23	-210.3	-48.41	-24.4	37.43	-24.3
F	23.81	-18.18	36.97	8.013	-14.29	-12.77

[Reset]

[Secondary stress Component (Min)]

Q _m	σ ₁	σ ₂	σ ₃	σ _{xy}	σ _{yz}	σ _{zx}
Q _h	0	0	0	0	0	0
Q _h	0	0	0	0	0	0
F	0	0	0	0	0	0

[Reset]

[OK] [Close]

[Save] [Reset All]

S - Type Damage

S - Type Damage				
Material		316L		
Evaluation Items (Significant creep)		Calculated	Limit value	Remark
P ₁	P ₁ < 1.3 S _m	39.839 MPa	103.22 MPa	OK!! [+]
P ₂	P ₂ < 1.3 x 1.5 S _m	42.536 MPa	154.83 MPa	OK!! [+]
Max(P _m + P _b) + Max q _j / J		166.22 MPa	238.2 MPa	OK!! [+]
ε _{plastic} + ε _{creep} (1.25 P ₁)	ε _{plastic} + ε _{creep} (1.25 P ₁) < 1 %	0.0092 %	1 %	OK!! [+]
ε _{plastic} + ε _{creep} (1.25 P ₂)	ε _{plastic} + ε _{creep} (1.25 P ₂) < 2 %	0.0108 %	2 %	OK!! [+]
Creep-Fatigue Damage		Creep-Fatigue Envelope Show		
Fatigue damage		Negligible (Negligible)	1.4355E-5 (0.0008)	OK!! (OK!!) [+]
Creep damage		0.0454 (0.0007)	0.9999 (0.9980)	OK!! (OK!!) [+]

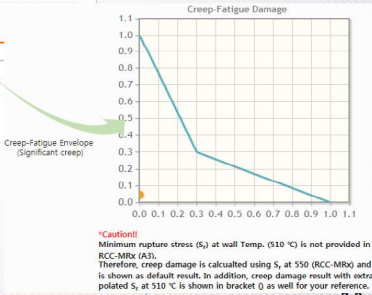
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[Export]

Output Window

click



EPERC Conf., INAIL, Italy, Input Window

3.1 DBA module – Input & Output (3/3)

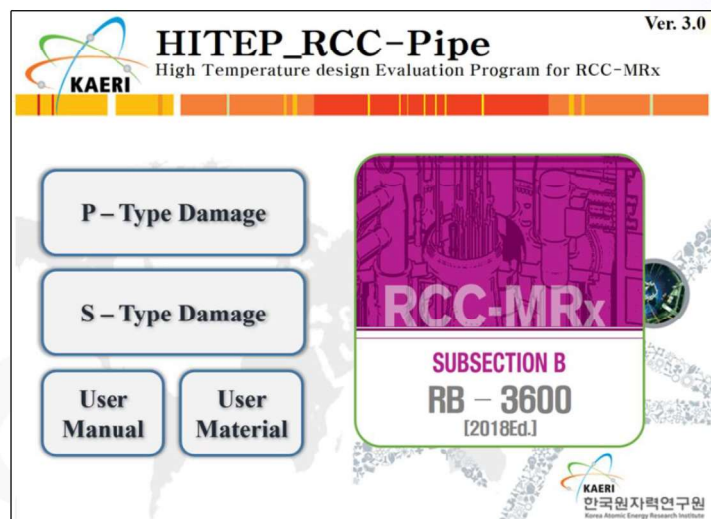
❖ Exporting total evaluation results in Excel form

HITEP_RCC-DBA					
Material		316L			
Service Level		Level A			
Max. Wall Temp.		300			
Total hold Time		8507			
Hold Temperature		545			
Evaluation Items			Calculated	Limit value	Remark
P Type Damage	Negligible Creep	$P_m < S_m$	31.118	102	OK!!
		$P_L < 1.5S_m$	31.118	153	OK!!
		$P_L + P_s < 1.5S_m$	43.891	153	OK!!
		J-integral	350	500	OK!!
	Significant Creep	$U(\sigma P_m)$	0.6607	1	OK!!
		$U(P_m+P_b)$	0.5519	1	OK!!
		$W(1.35P_m)$	4.7975E-16	1	OK!!
		$W[1.35(P_m+\Phi P_b)]$	6.0158E-14	1	OK!!
S Type Damage	Negligible Creep	$P_1 < 1.3 S_m$	38.062	132.6	OK!!
		$P_2 < 1.3 \times 1.5 S_m$	87.698	198.9	OK!!
		$Max(P_m + P_b) + Max q(i,j) < 3 S_m$	396.72	306	Fail
	Significant Creep	Fatigue Damage	0.0029	0.0099	OK!!
		$\epsilon_{plastic} + \epsilon_{creep} (1.25 P_1) < 1 \%$	1.8903E-5	1	OK!!
		$\epsilon_{plastic} + \epsilon_{creep} (1.25 P_3) < 2 \%$	0.0315	2	OK!!
		Fatigue Damage	0.0029	0.0099	OK!!
		Creep Damage	0.2933	0.9768	OK!!

3.2 HITEP_RCC-Pipe module

❖ RCC-MRx RB-3600(DBR) program

- Evaluations on P-Type & S-Type damage
- Web-based DBR (Design-By-Rule) evaluation module.



3.2 HITEP_RCC-DBA module – Input & Output (1/3)

HITEP_RCC-Pipe

Material

316L

Service Level

Level A/B

Level C

Level D

[Geometric Information]

Geometry

Straight Pipe

D_o (mm)

101.6

D_i (mm)

4

h (mm)

93.6

[Internal Pressure (Max)]

P_{max} (MPa)

0.5

P_{min} (MPa)

0

[Internal Pressure (Min)]

[Load controlled moments (Max)]

M_{1,max} (N-mm)

-514500

M_{2,max} (N-mm)

-46947

M_{3,max} (N-mm)

-12556

[Load controlled moments (Min)]

M_{1,min} (N-mm)

0

M_{2,min} (N-mm)

0

M_{3,min} (N-mm)

0

[Displacement controlled moments (Max)]

m_{1,max} (N-mm)

-2187200

m_{2,max} (N-mm)

-233420

m_{3,max} (N-mm)

1675800

[Displacement controlled moments (Min)]

m_{1,min} (N-mm)

0

m_{2,min} (N-mm)

0

m_{3,min} (N-mm)

0

[Wall mean temperature (Max)]

T_{max} (°C)

600

T_{linearMax} (°C)

0

T_{Non-LinearMax} (°C)

0

[Wall mean temperature (Min)]

T_{min} (°C)

25

T_{linearMin} (°C)

0

T_{Non-LinearMin} (°C)

0

Stress Factor

Use Default Value

[Cycle Information]

Hold Time of Total Cycle

15000

Design Number of Cycles (n)

30

Highest Temperature (°C)

600

[OK] [Close]

[Save] [Reset All]

HITEP_RCC-Pipe

P - Type Damage (Level A)

Material

316L

Geometry

Straight Pipe [+]

Evaluation Items (Significant creep)	Calculated	Limit value	Remark	
P _m	P _m ≤ S _m	0.0713 Mpa	74 Mpa	OK!! [+]
P _m + P _b	P _m + P _b ≤ 1.3 S _m	10.252 Mpa	404.64 Mpa	OK!! [+]
S _m + S _b	S _m + S _b ≤ S*	7.1830 Mpa	46.238 Mpa	OK!! [+]
U _A (P _m)	U _A (P _m) ≤ 1	1.1075E-11	1	OK!! [+]
U _A (P _m +ΦP _b)	U _A (P _m +ΦP _b) ≤ 1 - ΔU _A	0.0002	1	OK!! [+]
W _A (1.35P _m)	W _A (1.35P _m) ≤ 1	2.9713E-13	1	OK!! [+]
W _A (1.35(P _m +ΦP _b))	W _A (1.35(P _m +ΦP _b)) ≤ 1	5.0656E-5	1	OK!! [+]

[Back]

[Next]

Input Window
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Output Window

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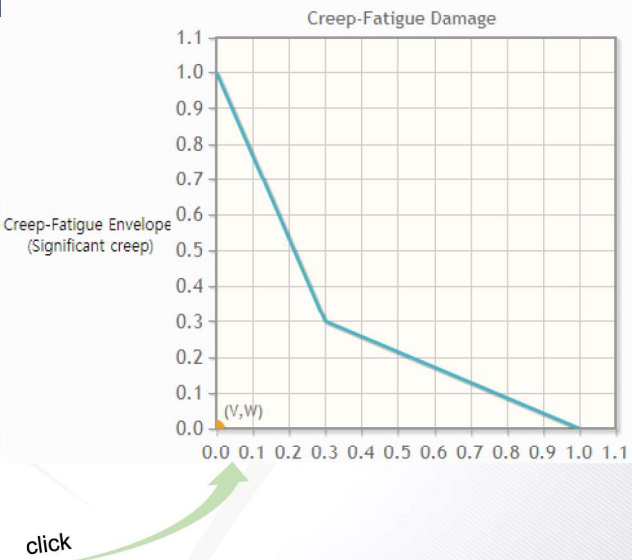
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3.2 Pipe module – Input & Output (2/3)

❖RCC-MRx RB-3600 (DBR*) based C-F damage evaluati

HITEP_RCC-Pipe

S - Type Damage (Level A)				
Material		316LN		
Geometry		Straight Pipe [-]		
Evaluation Items (Significant creep)		Calculated	Limit value	Remark
P_1	$P_1 < 1.3 S_m$	24.301 MPa	126.88 MPa	OK!! [-]
P_2	$P_2 < 1.69 S_m$	45.036 MPa	164.94 MPa	OK!! [-]
$\text{Max}(P_m + P_b) + \text{Max } q(j, j')$	$\text{Max}(P_m + P_b) + \text{Max } q(j, j') < 3 S_m$	117.15 Mpa	292.8 MPa	OK!! [-]
$\epsilon_{\text{plastic}} + \epsilon_{\text{creep}} (1.25 P_1)$	$\epsilon_{\text{plastic}} + \epsilon_{\text{creep}} (1.25 P_1) < 1 \%$	0.0002 %	1 %	OK!! [-]
$\epsilon_{\text{plastic}} + \epsilon_{\text{creep}} (1.25 P_3)$	$\epsilon_{\text{plastic}} + \epsilon_{\text{creep}} (1.25 P_3) < 2 \%$	0.0017 %	2 %	OK!! [-]
Creep-Fatigue Damage		Creep-Fatigue Envelope [Show]		
Fatigue damage		Negligible	4.8864E-9	OK!! [-]
Creep damage		0.0002	0.9999	OK!! [-]
[Back] [Close] [Export]				



3.2 Pipe module – Input & Output (3/3)

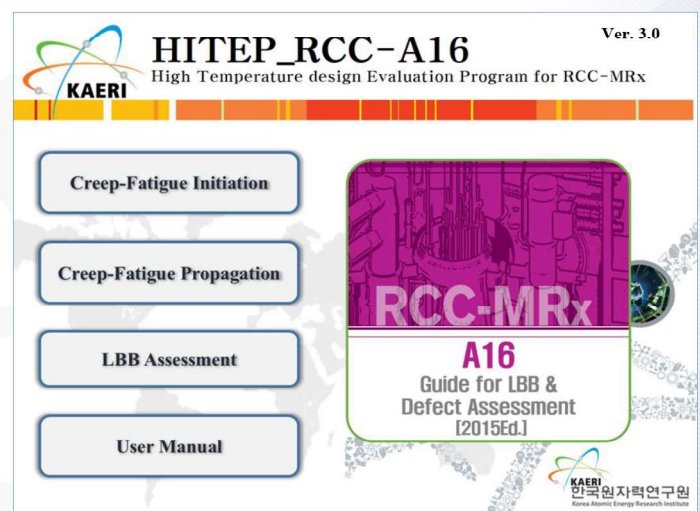
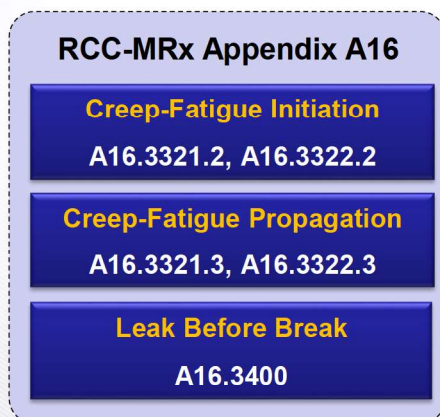
❖ Exporting total evaluation results in Excel form (for pipe design)

HITEP_RCC-Pipe					
Geometry		Straight Pipe			
Material		316L			
Service Level		Level A			
Max. Wall Temp.		300			
Total hold Time		8507			
Hold Temperature		545			
Evaluation Items			Calculated	Limit value	Remark
P Type Damage	Negligible Creep	$P_m < S_m$	31.118	153	OK!!
		$P_L < 1.5S_m$	43.891	153	OK!!
		$P_L + P_b < 1.5S_m$	0.6607	1	OK!!
	Significant Creep	$U(\Omega P_m)$	0.5519	1	OK!!
		$U(P_m+P_b)$	4.7975E-16	1	OK!!
		$W(1.35P_m)$	6.0158E-14	1	OK!!
		$W[1.35(P_m+\Phi P_b)]$	350	500	OK!!
S Type Damage	Neligible Creep	$P_1 < 1.3 S_m$	38.062	132.6	OK!!
		$P_2 < 1.3 \times 1.5 S_m$	87.698	198.9	OK!!
		$Max(P_m + P_b) + Max q(j,j') < 3 S_m$	396.72	306	Fail
		Fatigue Damage	0.0029	1	OK!!
	Significant Creep	$\epsilon_{plastic} + \epsilon_{creep} (1.25 P_1) < 1 \%$	1.8903E-5	1	OK!!
		$\epsilon_{plastic} + \epsilon_{creep} (1.25 P_3) < 2 \%$	0.0315	2	OK!!
		Fatigue Damage	0.0029	0.0099	OK!!
		Creep Damage	0.2933	0.9768	OK!!

3.3 HITEP_RCC-A16 module

❖ HITEP-RCC-A16

- ‘Creep-Fatigue crack initiation’, ‘C-F crack propagation’ and ‘LBB’ Evaluation Block.
- For verifications, direct calculations with Excel and MJSAM used.
- MJSAM example partly used for verification.



3.3 A16 module – Creep-Fatigue Initiation (1/2)

❖ Input window of C-F Crack Initiation evaluation

❖ Output window

Creep-Fatigue Initiation

Material: 316L

Geometry: Select
Pipe

[Cycle condition]

Number of cycle(n): 30 Total Hold Time

Temperature(°C): 600

[OK] [Close]

Initial screen of creep-fatigue initiation

Creep-Fatigue Initiation

Material: 316L

Geometry: Pipe

Crack Shape: Select
Circumferential Crack

Number of cycle(n):

Temperature(°C):

[OK] [Close]

Creep-Fatigue Initiation

Material: 316L

Geometry: Pipe

Crack Shape: L Through-Wall Crack

(Pipe Geometry)

(Crack Geometry)

$2\alpha = 2\beta$

[Geometry]

r_i (mm): 145.4727 h (mm): 33.327272

β (degree): 22.92894

[Loading Condition]

PMF(M): 5 N_0 (N): 50000

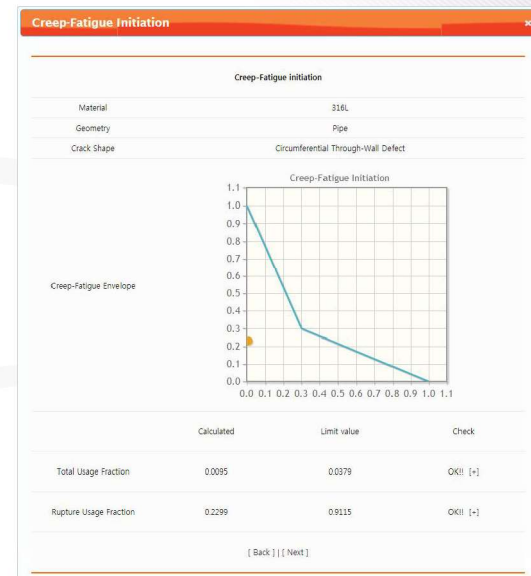
M_0 (N-mm): 0

[Cycle condition]

Number of cycle(n): 30 Total Hold Time: 15000

Temperature(°C): 600

[OK] [Close]



3.3 A16 module – Creep-Fatigue Propagation

❖ Input window

Creep-Fatigue Propagation

Material

316L

Geometry

Pipe

Crack Shape

L Through-Wall Crack

[Pipe Geometry]

[Crack Geometry]

[Geometry]

r_i(mm)

145.4727

h(mm)

32.327272

β(degree)

22.92994

[Loading Condition(Max)]

P_{max}(MPa)

5

N_{1,max}(N)

5000000

M_{2,max}(N-mm)

0

[Loading Condition(Min)]

P_{min}(MPa)

0.5

N_{1,min}(N)

500000

M_{2,min}(N-mm)

0

[Cycle condition]

Number of cycle(n)

30

Total Hold Time

15000

Temperature(°C)

600

[OK]

[Close]

❖ Output window

Creep-Fatigue Propagation

Material

316L

$$a_{resw} = C[(\Delta K_{eff})_i]^n + \int_{t_i}^{t_i+t_{mi}} A(C_i^*(t))^q dt$$

Evaluation Items;

Calculated

Evaluation Items

Calculated

Final Crack Length(a_{final})

309.66

Final Crack Angle

132.19 [°]

Number of Cycles to wall penetration

22 [°]

[Back]

[Next]

EPERC Conf., INAIL, Italy, 2 April, 2019

KAERI Korea Atomic Energy Research Institute

19

3.3 A16 module – Leak Before Break analysis (1/2)

❖ **Input window**

Leak-Before-Break Assessment

Material

316LN ▼

[Pipe Geometry]

[Crack Geometry]

[Geometry]

r_i (mm)

38.9636

h (mm)

5.4864

β (degree)

20

a (mm)

1

[Loading Condition]

P (MPa)

100

N_2 (N)

1000

M_2 (N-mm)

0

[Detectable Leak Flow (Min) & Temperature]

Q_{min} (gpm)

3

Temp (°C)

500

[OK] | [Close]

❖ Output window

Leak-Before-Break Assessment

Leak-Before-Break Assessment

Material

316LN

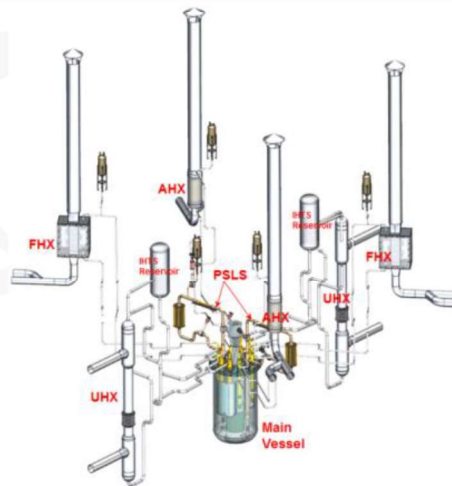
The diagram illustrates the Leak-Before-Break (LBB) assessment for a pipe. It shows a cross-section of a pipe with a semi-elliptical surface crack. Key parameters labeled include: $2C_L$ (detectable leak), $2C_i$ (initial), $2C_p = 3C_i + 0.5C_d$, $2C_d$ (detectable through-wall defect), $2C_{db} = 2C_{db} / \alpha$, and $2C_d$ (through-wall critical defect). The pipe thickness is denoted as h .

Evaluation Items		Calculated	Remark
Detectable Crack Length	C_L	4.1682 mm	[+]
Initial Crack Length	C_i	44.5 mm	[+]
Crack Length at Penetration	C_p	68.202 mm	[+]
Detectable Throughwall Crack Length	C_d	102 mm	[+]

[Back] [Next]

4. Verification of HITEP_RCC-MRx

- HITEP_RCC-DBA module
- HITEP_RCC-PIPE module
- HITEP_RCC-A16 module

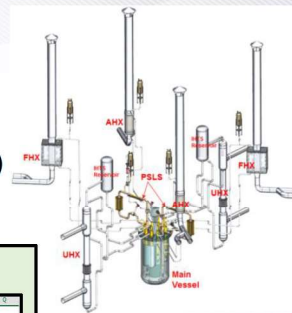


4.1 Verification of HITEP_RCC-DBA

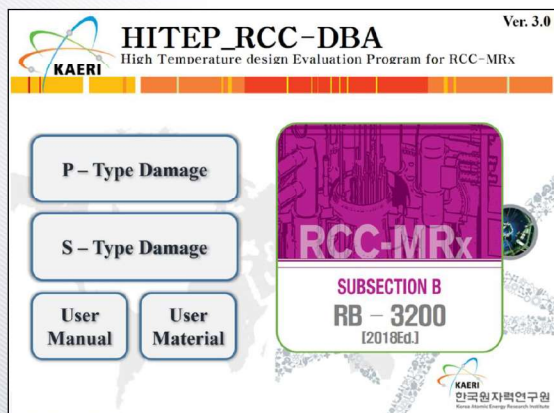
❖ Method : Comparison of calculation results (HITEP vs. Direct Calculation with Excel)

❖ Material (present verification)

- 316L : Main Vessel, Reservoir (Tank in ST-2*), AHX, FHX, UHX (HXs in ST-2), Exp. Tank (ST-1**)
- Gr.91 steel : DHX, IHX (STELLA-2)
- Eurofer : IHX (assumed material for IHX)



STELLA-2 Facility (KAERI)



Direct Calculation with Excel

Material	Temp
316L	320
R_p	S_p
247467517	87.6
R_m	S_m
247467517	156
$R_{p0.2}$	$S_{p0.2}$
157948105	148.4

Material	Temp
316L	320
R_p	S_p
138.545358	29.3

T	n	K	m	K_m
13942	0.3	722	6.3027	1.01412322

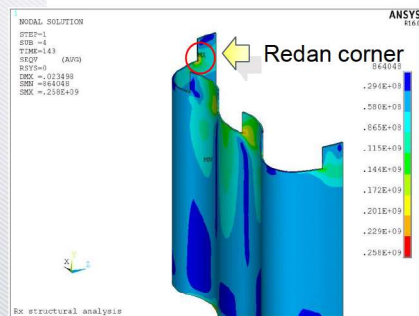
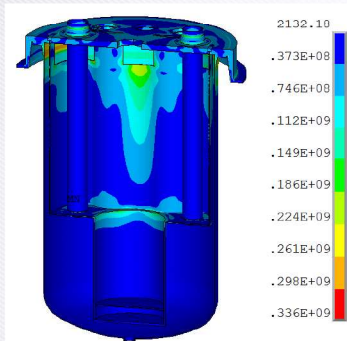
ΔS_p	ΔS_m	$\Delta S_{p0.2}$	$\Delta S_{m0.2}$
100.817399	4.00377588	100.817399	4.00377588
15.2830877	1.4375746	15.2830877	1.4375746
ΔS_p	ΔS_m	$\Delta S_{p0.2}$	$\Delta S_{m0.2}$
6.17528293	0.03851487	6.17528293	0.03851487
ΔS_p	ΔS_m	$\Delta S_{p0.2}$	$\Delta S_{m0.2}$
6.58E-06	0.0001139	6.58E-06	0.0001139

EPERC Conf., INAIL, Italy, 2 April, 2015

ST-2 : STELLA-2, **ST-1 : STELLA-1

4.1 Model Reactor Vessel of STELLA-2 (1/2)

❖ Material : 316L



➤ Comparison of the results

	HITEP	Excel
P_m	24.7	24.7
P_L	24.7	24.7
$P_L + P_B$	33.6	33.6
S_m	91.8	91.8
$1.5S_m$	137.7	137.7
$\text{Max}(P_L + P_B) + \Delta Q$	309.6	309.6
$3S_m$	245.16	245.16
$T_k(\sigma_k(0)/0.9)$	1855198	1856319
$T_k(\sigma_k(30)/0.9)$	2490919	2505228

❖ Temp, Hold time, Cycle

Temperature	Hold Time	Number of Cycle
470°C	30 h	500

❖ Creep Damage detailed results

Creep damage	0.0065	0.9996	OK!!
$W_k(\sigma_k) =$	$t_k / T_k(\sigma_k)$		
$\Delta \varepsilon_{II} =$	$\int_0^{T^*} \dot{\varepsilon}_{II}(\sigma_k) dt$	$\sigma_k(0) =$	$P_{max} + K_2 \Delta S^*$
$P_{max} =$	33.6 MPa	$K_2 =$	0.5765
$\Delta S^* =$	$\Delta \sigma^* - \Delta P =$	225.98 MPa	
$\Delta \sigma^* =$	225.98 MPa	$\Delta P =$	0 MPa
$\sigma_k(0) =$	163.89 MPa	$\sigma_k(30) =$	158.86 MPa
$T_k(\sigma_k(0)/0.9) =$	1855198 h	$T_k(\sigma_k(30)/0.9) =$	2490919 h

4.1 Model Reactor Vessel of STELLA-2 (2/2)

❖ Creep – Fatigue Damage



➤ Comparison of the results (316L)

	HITEP	Excel
Fatigue Damage	0.0001	0.0001
Creep Damage	0.0065	0.0064

Evaluation results of creep-fatigue damage

4.2 Verification of HITEP_RCC-PIPE

❖ RCC-MRx RB-3600(DBR) based program

➤ Verification of HITEP_RCC-Pipe

- Comparison of results (HITEP vs. direct calculation with Excel)



HITEP_RCC-PIPEIPIE

High Temperature design Evaluation Program for RCC-MRx

Ver. 2.0

P - Type Damage

S - Type Damage

User Manual



comparison

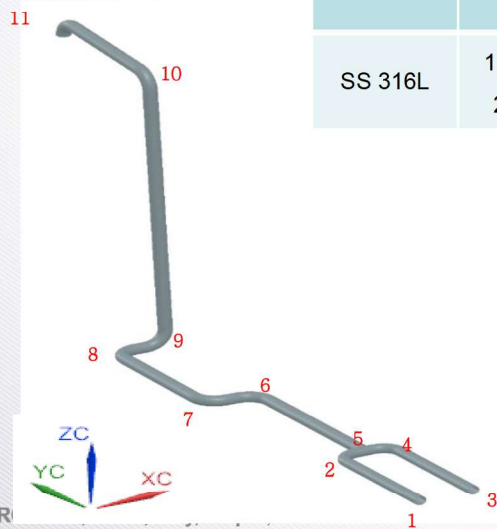
Direct calculation with Excel

4.2 Hot Leg Piping (1/2)

❖ Hot leg of IHTS* in STELLA-2 sodium test facility

❖ Material : 316L

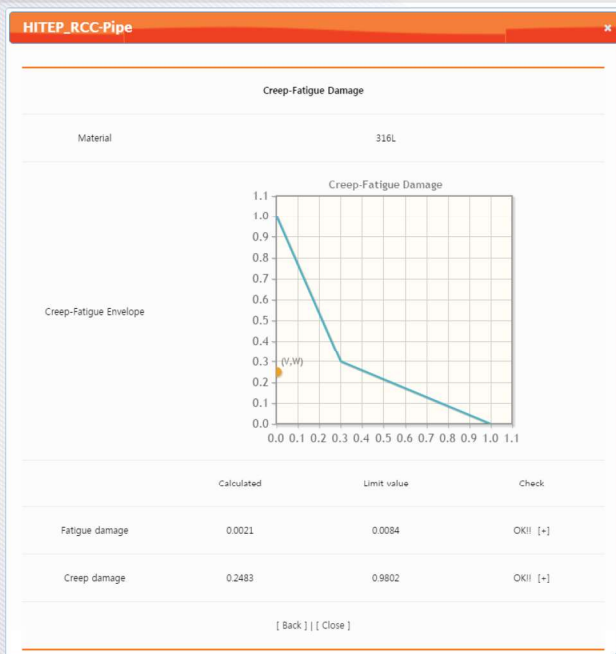
Material	R/D	Size, SCH	OD/WT (mm)	Rtemp. (°C)	Design Temp.(°C)	Design Pressure (Mpa)
SS 316L	1.5	3.5" SCH20S	101.6./4	25	600 (H/L)	0.5
	2	4" SCH20S	114.3/4			



Node conditions

- Node 1, 5, 11 : Built in
- Node 6, 7, 8, 9, 10 : R/D=2
- Node 2, 4 : R/D=1.5=LR
- Node 1~5 : 3.5" SCH20S
- Node 3~11 : 4" SCH20S
- Node 3 : Tee & Reducer 3.5" to 4"

4.2 Hot Leg Piping (2/2)

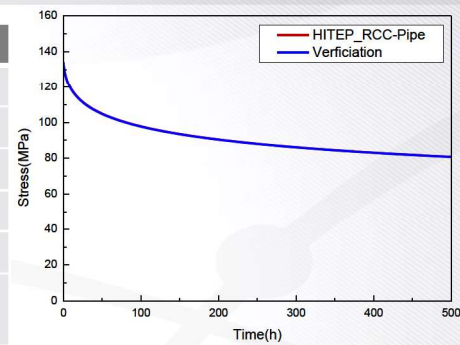


Creep-Fatigue Damage evaluation result

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	HITEP	Excel
$\Delta \epsilon$	0.2354	0.2354
$N_f(\Delta \epsilon)$	13972	13977
$\Delta \epsilon_{el+pl}$	0.1339	0.1339
$\Delta \epsilon_{II}$	0.1014	0.1014
$\Delta \epsilon_1$	0.1234	0.1234
$\Delta \epsilon_2$	1.5295E-5	1.5295E-5

	HITEP	Excel
Fatigue Damage	0.0021	0.0021
Creep Damage	0.2505	0.2483



Stress relaxation analysis result

4.3 Verification of HITEP_RCC-A16

❖ RCC-MRx A16 based program

➤ Verification of HITEP_RCC-A16

- Comparison of results (HITEP vs. direct calculation with Excel)



HITEP_RCC-A16

Ver. 2.0

HITEP_RCC-A16

High Temperature design Evaluation Program for RCC-MRx

한국원자력연구원
Korea Atomic Energy Research Institute

Creep-Fatigue Initiation

Creep-Fatigue Propagation

LBB Assessment

Usher Manual

RCC-MRx

A16

Guide for LBB &
Defect Assessment
[2015Ed.]



comparison

Direct calculation with excel

4.3 Creep-Fatigue Initiation (1/2)

❖ Assessment of Creep-Fatigue Crack Initiation with HITEP_RCC-A16

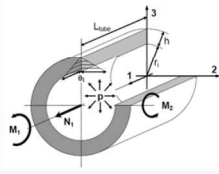
- Verification Ex. : Pipe with through-wall crack
- Verifications : Calculations from A16 module & direct calculations
- Specifications

	Specifications & Loading Conditions	
Pipe with semi-circular penetrated crack	Material	316 L
	r_i (mm)	145.4727
	h (mm)	32.3272
	β (mm)	22.93
Loading conditions	N_1 (N)	50,000
	M_2 (N-mm)	0
	P (MPa)	5
	Temperature (°C)	600
	Number of cycle	30
	Total hold time (h)	15,000

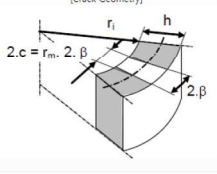
Creep-Fatigue Initiation

Material: 316L
 Geometry: Pipe
 Crack Shape: L Through-Wall Crack

[Pipe Geometry]



[Crack Geometry]



[Geometry]

r_i (mm): 145.4727 h (mm): 32.327272
 β (degree): 22.92994

[Loading Condition]

P(MPa): 5 N_1 (N): 50000
 M_2 (N-mm): 0

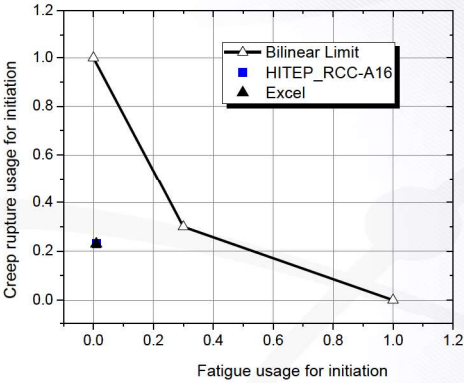
[Cycle condition]

Number of cycle(n): 30 Total Hold Time: 15000
 Temperature(°C): 600

[OK] [Close]

4.3 Creep-Fatigue Initiation (2/2)

❖ Output window



Assessment results on C-F crack initiation

Evaluation Items	HITEP	Excel
Total Usage Fraction	0.0095	0.0095
Rupture Usage Fraction	0.2299	0.2299

4.3 Creep-Fatigue Propagation (1/2)

❖ Assessment of Creep-Fatigue Crack Propagation with HITEP_RCC-A16

- Verification Ex. : pipe with through-wall crack
- Verifications : Calculations from A16 module & direct calculations
- Specifications

Specifications & Loading Conditions		
Pipe with semi-circular penetrated crack	Material	316 L
	r_i (mm)	145.4727
	h (mm)	32.3272
	β (mm)	22.93
Loading conditions	N_1 (N)	5,000,000 / 500,000
	M_2 (N-mm)	0
	P (MPa)	5 / 0.5
	Temperature (°C)	600
	Number of cycle	30
	Total hold time (h)	15,000

Creep-Fatigue Propagation

Material: 316L
 Geometry: Pipe
 Crack Shape: L Through-Wall Crack

[Pipe Geometry]
 r_i (mm): 145.4727
 h (mm): 32.3272
 β (degree): 22.92994

[Crack Geometry]
 $2.c = r_m, 2. \beta$

[Loading Condition(Max)]
 P_{max} (MPa): 5
 $N_{1,max}$ (N): 5000000
 $M_{2,max}$ (N-mm): 0

[Loading Condition(Min)]
 P_{min} (MPa): 0.5
 $N_{1,min}$ (N): 500000
 $M_{2,min}$ (N-mm): 0

[Cycle condition]
 Number of cycle(n): 30
 Total Hold Time: 15000
 Temperature(°C): 600

[OK] [Close]

4.3 Creep-Fatigue Propagation (2/2)

❖ Assessment results on C-F crack propagation

Evaluation Items	HITEP	Excel
Final Crack Length	309.66	309.66
Final Crack Angle	132.19	132.19
Number of Cycles to wall penetration	22	22

Creep-Fatigue Propagation

Creep-Fatigue Propagation

Material316L

$$a_{resw} = C[(\Delta K_{eff})_t]^n + \int_{t_i}^{t_i+t_{mi}} A(C_i^*(t))^q dt$$

Evaluation Items;	Calculated	Evaluation Items	Calculated
Final Crack Length(a _{final})	309.66	Final Crack Angle	132.19 [°]
Number of Cycles to wall penetration	22 [°]		

[Back] [Next]

4.3 Leak Before Break analysis (1/2)

❖ Input data

Input data		HITEP_RCC-A16
Geometrical	r_i (mm)	38.9636
	h (mm)	5.4864
	β (degree)	20
	a (mm)	1
Loading	P (MPa)	100
	N_1 (N)	1000
	M_2 (N-mm)	0
Q_{min} (gpm)		3
Temp (°C)		500

Leak-Before-Break Assessment ✕

Material 316LN

[Pipe Geometry]

[Crack Geometry]

[Geometry]

r_i (mm)	38.9636	h (mm)	5.4864
β (degree)	20	a (mm)	1

[Loading Condition]

P (MPa)	100	N_1 (N)	1000
M_2 (N-mm)	0		

[Detectable Leak Flow (Min) & Temperature]

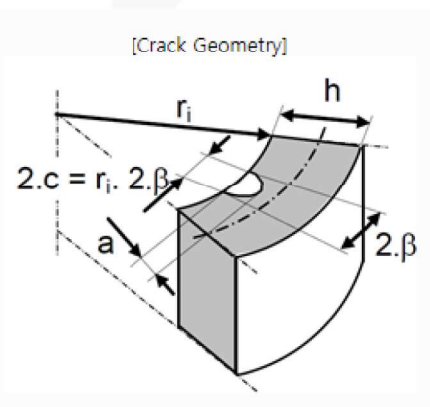
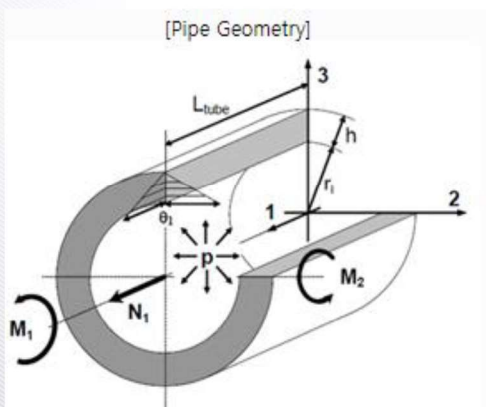
Q_{min} (gpm)	3	Temp (°C)	500
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[OK] [Close]

4.3 Leak Before Break analysis (2/2)

❖ Comparison of assessment results on crack lengths

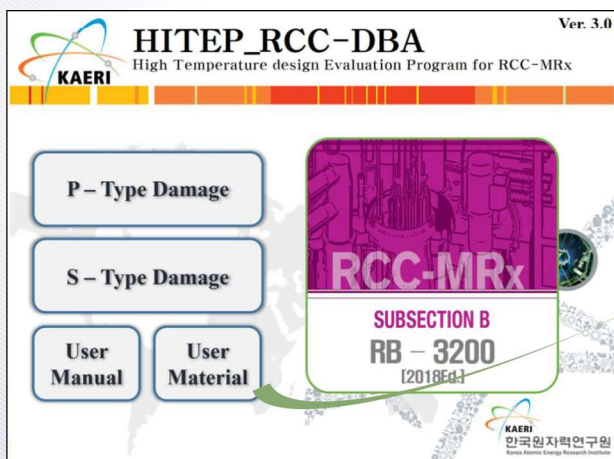
Evaluation Items	HITEP_RCC-A16	Excel
Crack length at penetration	7.8270 mm	7.8270 mm
Detectable through-wall crack length	38.052 mm	38.052 mm



4.4 User Material (e.g. ARAA) option in HITEP (1/2)

❖ User materials

- User can use a new material not registered in A3.
- Excel file should be uploaded as shown below.



click

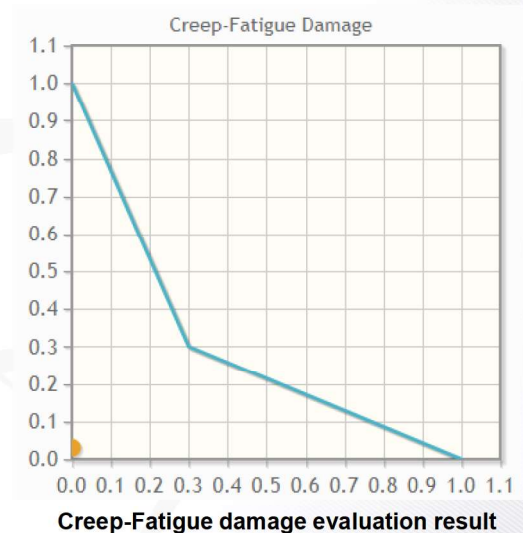
Young's modulus	Temp. (°C)	E (MPa)

Loading of new material properties

4.4 User Material (e.g. ARAA) option in HITEP (2/2)

❖ Eurofer (IHX) (Evaluation results as per RCC-MRx 2018Ed.)

Evaluation Items		HITEP	Excel
P-Type Damage	P_m (MPa)	9.9749	9.9749
	$P_m + P_b$ (MPa)	12.905	12.905
	$U_A(P_m)$	2.3356E-10	2.3356E-10
	$U_A(P_m + \Phi P_b)$	2.0458E-9	2.0458E-9
	$W_A(1.35P_m)$	3.3429E-11	3.3429E-11
	$W_A[1.35(P_m + \Phi P_b)]$	3.2145E-10	3.2145E-10
S-Type Damage	P_1 (MPa)	34.887	34.887
	P_2 (MPa)	39.683	39.683
	$(P_m + P_b) + q(j,j')$ (MPa)	134.92	134.92
	$\epsilon_{\text{plastic}} + \epsilon_{\text{creep}} (1.25P_1)$	0.0006 %	0.0006 %
	$\epsilon_{\text{plastic}} + \epsilon_{\text{creep}} (1.25P_3)$	0.0013 %	0.0013 %
Creep-Fatigue Damage	Fatigue Damage	0.0001	0.0001
	Creep Damage	0.0033	0.0033

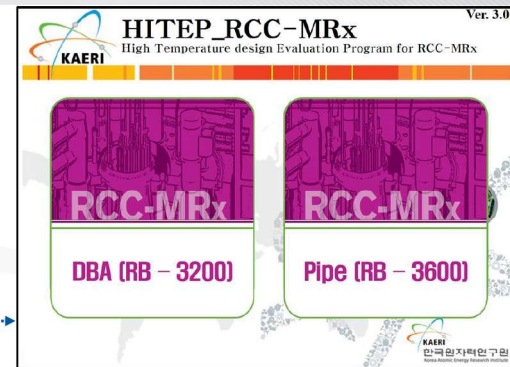


■ ‘HITEP’ Platform

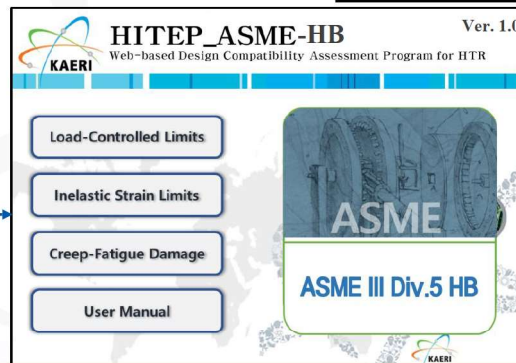
*ETD : Elevated Temperature Design

❖ HITEP platform for comprehensive ETD* evaluations.

- RCC-MRx : [HITEP_RCC-MRx](#)
- ASME Section III Div.5 sub HB : [HITEP_ASME-HB](#) (Draft developed)



click



click

5. Summary

- ❖ Web-based program of HITEP_RCC-MRx (Ver. 3.0) for design evaluation & defect assessment as per RCC-MRx has been developed. (2018Ed.)
 - **HITEP_RCC-DBA (Design-By-Analysis : Pressure boundary components)**
 - **HITEP_RCC-Pipe (pipe design)**
 - **HITEP_RCC-A16 (defect assessment)**
- Eurofer Material Properties incorporated in Ver. 3.0
- 'User Material' option added, new material (e.g. ARAA) can be used for design evaluations (sensitivity analysis before Codification of the new material).
- HITEP program can be used for reliable & efficient design evaluations and defect assessments as per RCC-MRx. (verifications were conducted.)

THANK YOU

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