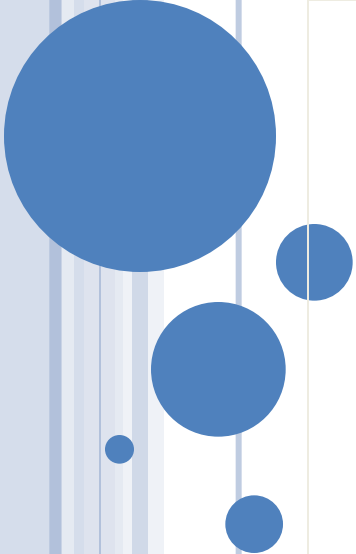




ELASTO-PLASTIC-CREEP MODELING FOR THE FIRST WALL WITH W ARMOR

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ARIES-Pathways Project Meeting

Bethesda, Washington DC

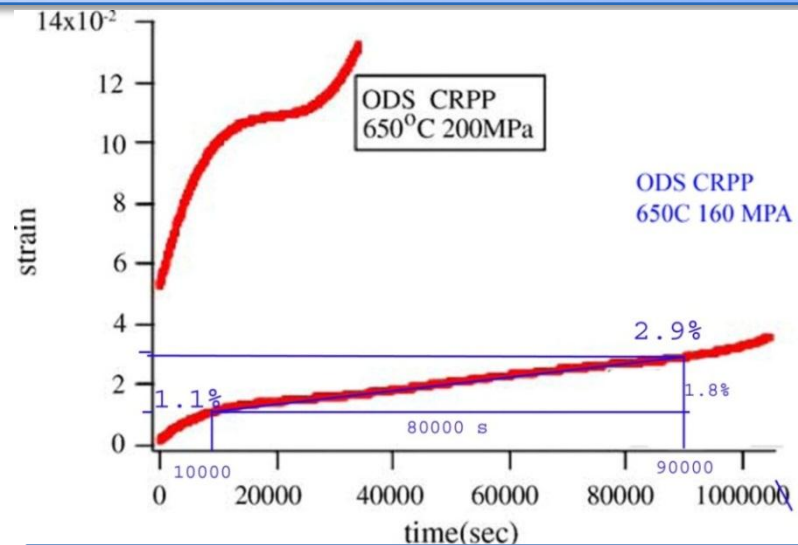
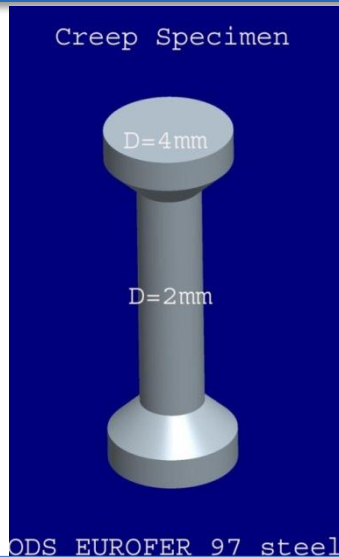
April 4-5, 2011

OUTLINE

- A simple thermal creep model for comparing the ANSYS results to experimental creep data
- Structural criteria in time-dependent elasto-plastic-creep analysis
- Creep rupture data and Norton Law parameter for Euorfer 97 steel
- Elastic-plastic-creep modeling of the first wall with W armor



THERMAL CREEP TEST FOR ODS EUORFER 97 STEEL*



- Applied constant stress: 160-200 MPa
- Applied temperature: 650 °C
- Corresponding creep strain rate associated with the steady stage: ~2.25E-7 1/s at applied stress of 160 MPa
- Creep strain in primary stage: 1.1%
- Creep strain in secondary stage: 1.8%

- Norton Creep Law :

$$d\epsilon_{cr}/dt = C_1 \sigma^{C_2} e^{-C_3/T}$$

- ✓ C₁, C₂, C₃ are temperature-dependent creep constants, σ is applied stress, T is temperature
- ✓ C₃=0
- ✓ **Creep exponent C₂: 4.9-5.5**
- ✓ Assuming C₂=5.1, the creep constant C₁=3.245E-49

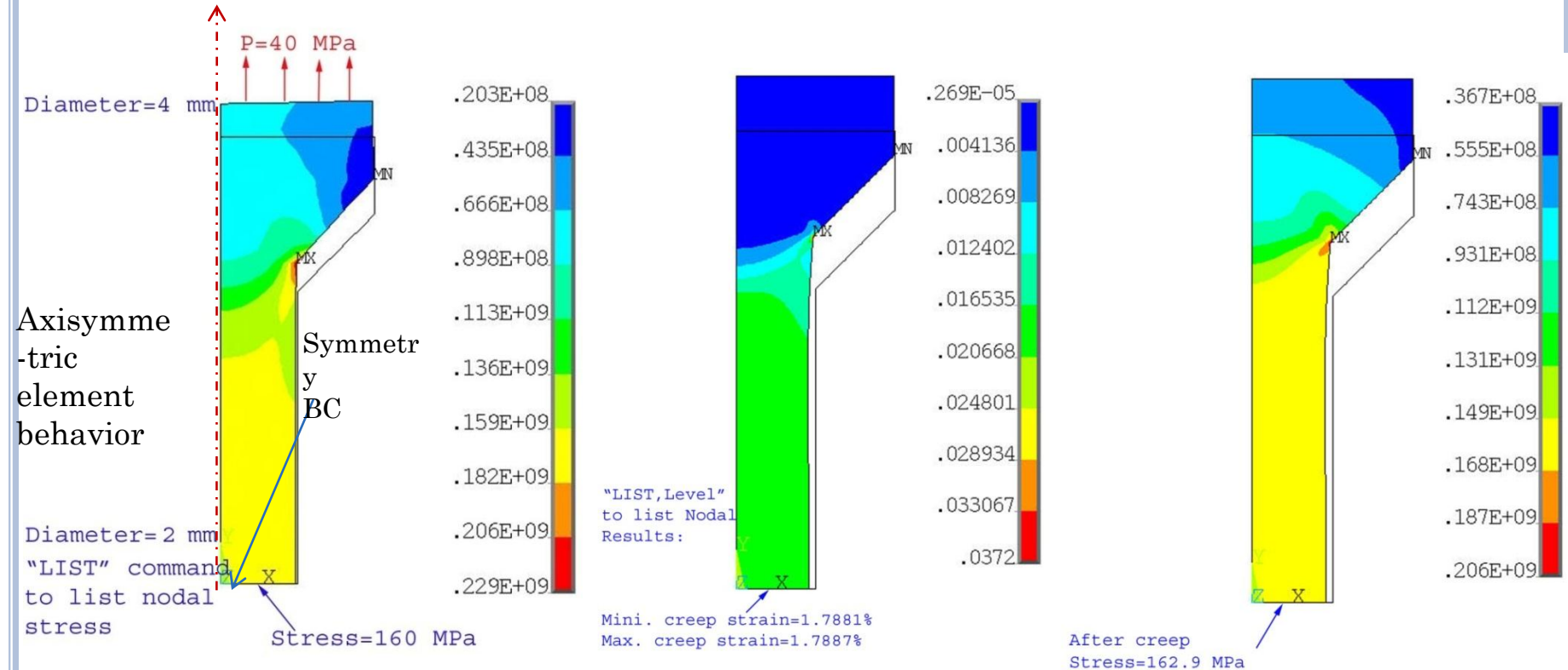
*G. Yu et al, *Fusion Engineering and Design*, 75-79, 1071(2002)

COMPARISON OF ANSYS CREEP RESULTS TO CREEP TESTED DATA

Stress Model (1/4 Specimen)

Creep strain after 80000 s

Stress after 80000 s

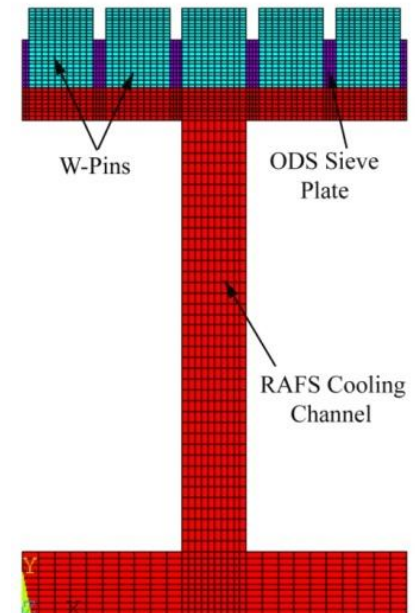


ANSYS modeling, $\epsilon_{cr} \sim 1.788\%$
Hand calculation, $\epsilon_{cr} \sim 1.8\%$
Exp. Data (Creep-time curve), $\epsilon_{cr} \sim 1.8\%$

Deformed shape was exaggerated by a factor of 10

THERMAL CREEP MODELING OF THE FW ARMOR

- Temperature of the W-pins is $\sim 680^\circ\text{C}$, therefore, thermal creep is not important as a deformation mechanism. W thermal creep begins to become significant around 1500°C and above.
- As there is not enough creep coefficients for ODS steel (12YWT), and the thermal creep of the ODS steel is not included. (Yu's creep data only at $T=650^\circ\text{C}$ and $\sigma=160\text{ MPa}$)
- Only F82H material will be considered in the creep model, and the creep data of Eourfer 97 steel will be used in analysis.
- Norton model is used in ANSYS, and primary stage is not included.
- **Irradiation induced creep** is not considered at present because of difficulty to find the irradiation induced creep data (**Arnold Lumsdaine** is helping us to collect the creep data.)

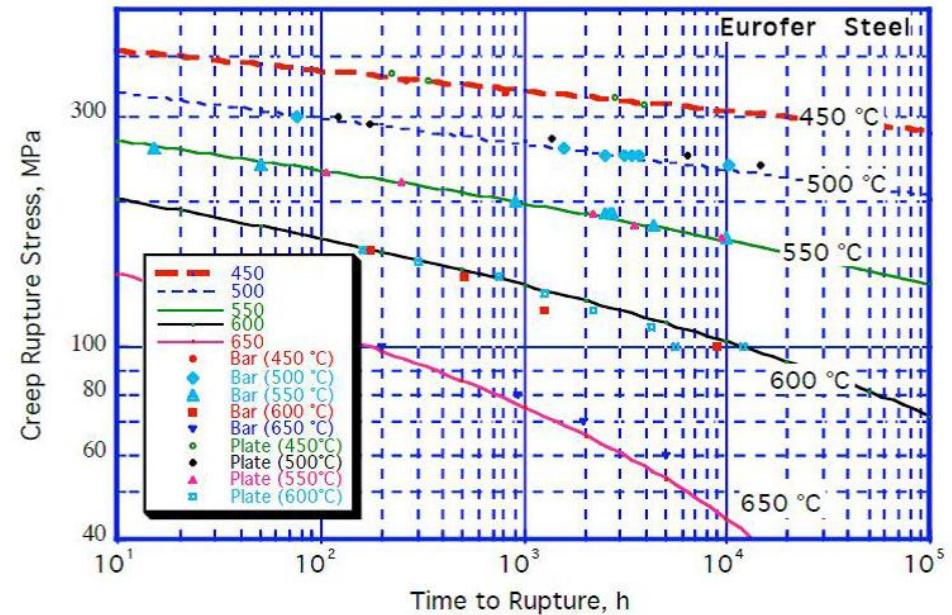


STRUCTURAL CRITERIA IN TIME-DEPENDENT ELASTO-PLASTIC-CREEP ANALYSIS

- **Structural strain limits:** At elevated temperatures where creep occurs, it is generally impossible to avoid strain accumulation. However, it is necessary to limit strain accumulation to avoid excessive structural distortion and fracture.
 - ❑ The calculated maximum accumulated positive **principal inelastic (plastic plus creep)** strain at the end of life must meet the three limits:
 1. *Membrane (strain averaged through the thickness) $\leq 1\%$*
 2. *Local (maximum strain anywhere) $\leq 5\%$*
 3. *Membrane + bending $\leq 2\%$*
 - ❑ The criteria were used in the design of metallic **HTR**-components with high application temperature of 750 °C ~1000 °C (INCONEL 617)
- **Need experts' opinion on this structural criteria**
- **Need to study ITER SDC-IC (Structural Design Criteria In-vessel Components) and make a comparison**

*Alfred Snow, "US Elevated Temperature Structural Design Standards: Current Status and Future Direction," Westinghouse Electric Corporation, 1976.

CREEP RUPTURE CURVES OF EUROFER STEEL(FZK, CIEMAT DATA)*



Creep Rupture Stress, S_r

FW	450 °C	500 °C	550 °C
S_r , MPa at 1000 h	328	254	185
S_r , MPa at 10000 h	295	221	152

*F. Tavassoli, DEMO Interim Structural Design Criteria, Appendix: A Material Design Limit Data, CEA/DEN/SAC/DMN, Dec. 2002.

*M. Rieth, et. al, "EUROFER 97 Tensile, Charpy, Creep and Structural Tests" FZKA 6911, Oct. 2003.

CREEP COEFFICIENTS OF EUOFER STEEL(FZK, CIEMAT DATA)*

- Only the secondary stage is considered.
- The creep is ignored at temperature less than 425 °C.
- Norton creep equation is expressed by:

$$d\varepsilon_{cr}/dt = C_1 \sigma^{C_2} e^{-C_3/T}$$

(creep rate in 10⁻⁶/h, σ in MPa in fig.)

Allowable creep rate (1/h)
corresponding to 1% creep
limit (Structural Criteria #1)

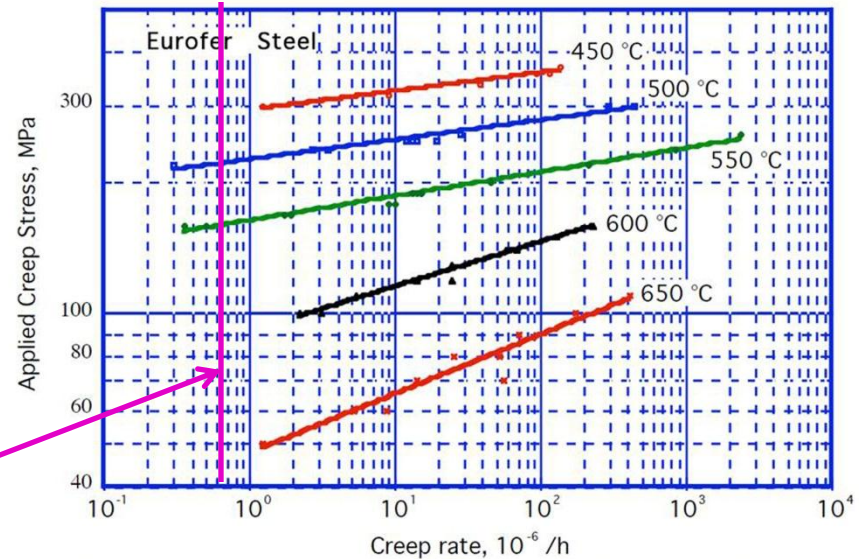


Figure A3.S18E.6.3.2.1. Stress versus minimum creep rate (CIEMAT, FZK data).

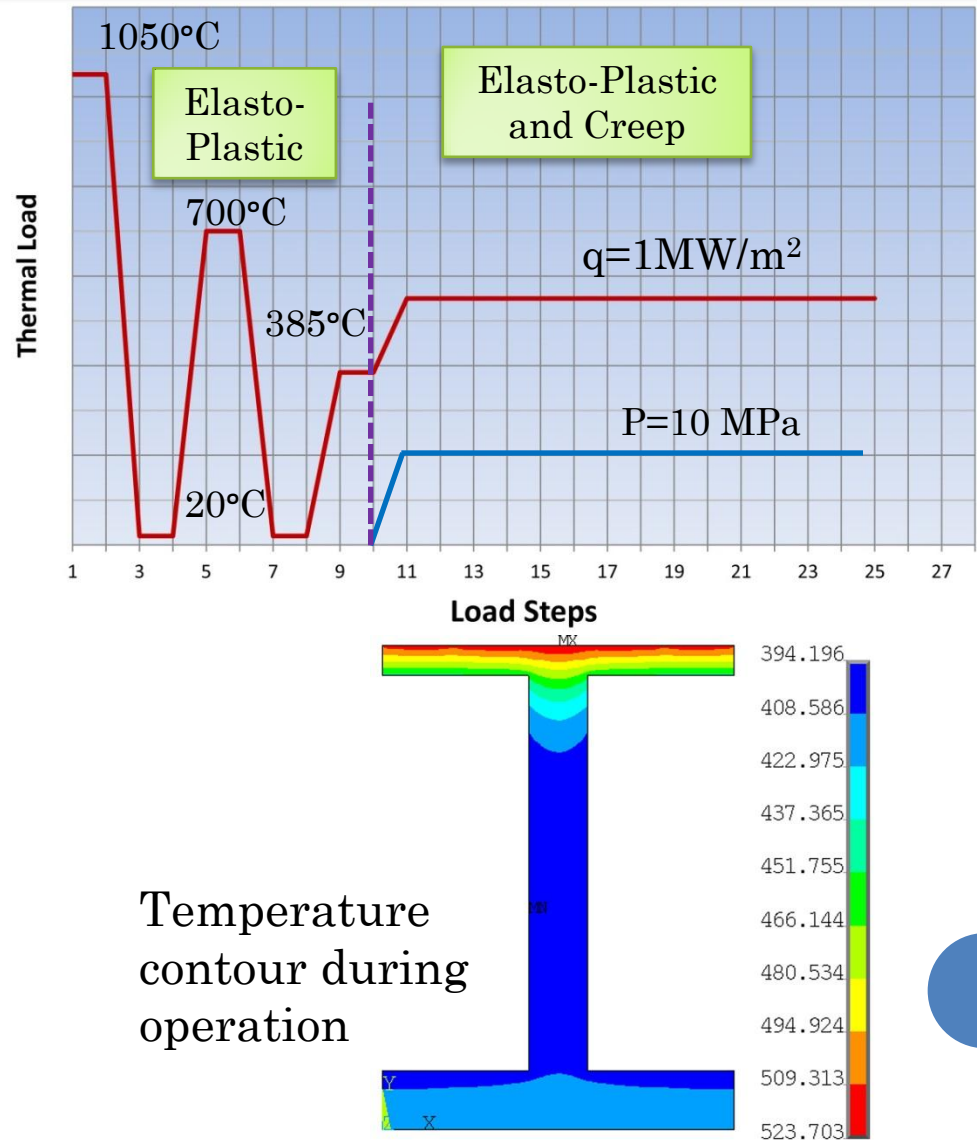
Norton law parameters for Eurofer Steel

- Only C1, C2 and C3 are inputted into ANSYS.

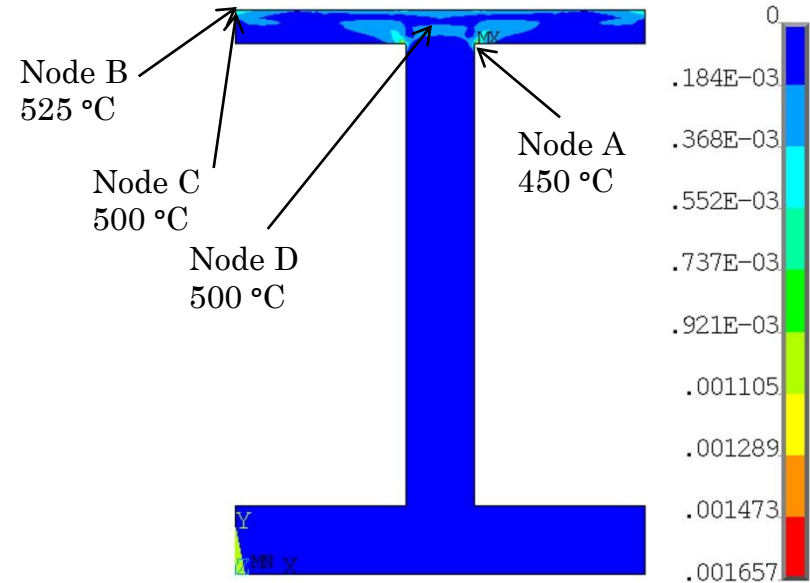
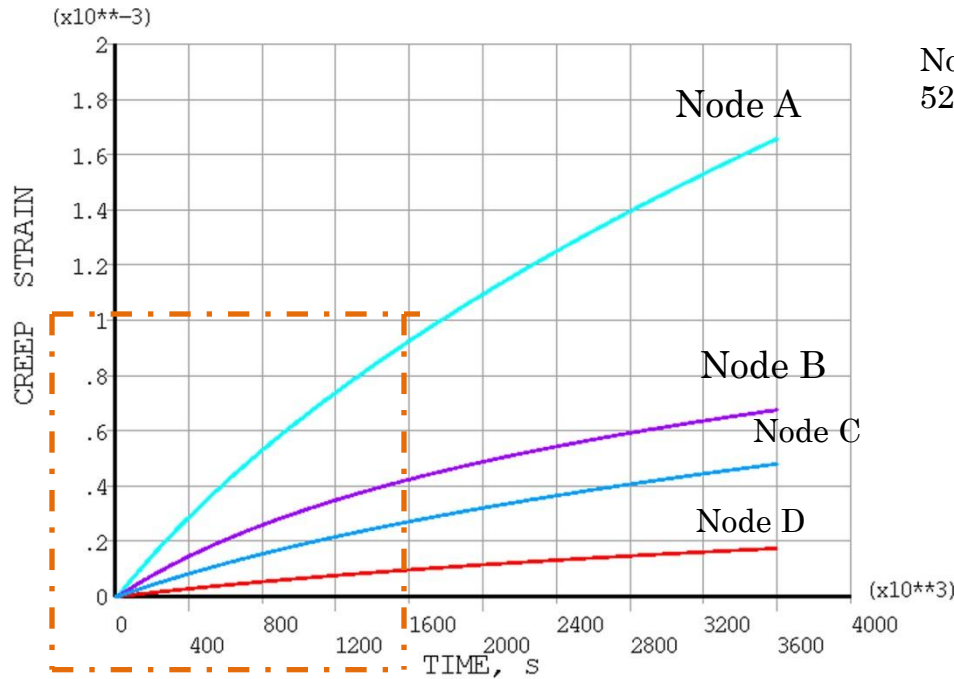
T	C1	C2	C3	Stress, MPa	Creep rate, 1/h
450 °C	8.352E-57	22.718	0.0	300	1.574E-6
500 °C	1.376E-50	21.19	0.0	220	5.950E-7
550 °C	4.566E-40	17.769	0.0	160	6.676E-7
600 °C	2.490E-19	9.5095	0.0	100	2.601E-6
650 °C	6.217E-12	6.7473	0.0	50	1.807E-6

THERMAL LOADS FOR THE ELASTO-PLASTIC-THERMAL CREEP MODEL

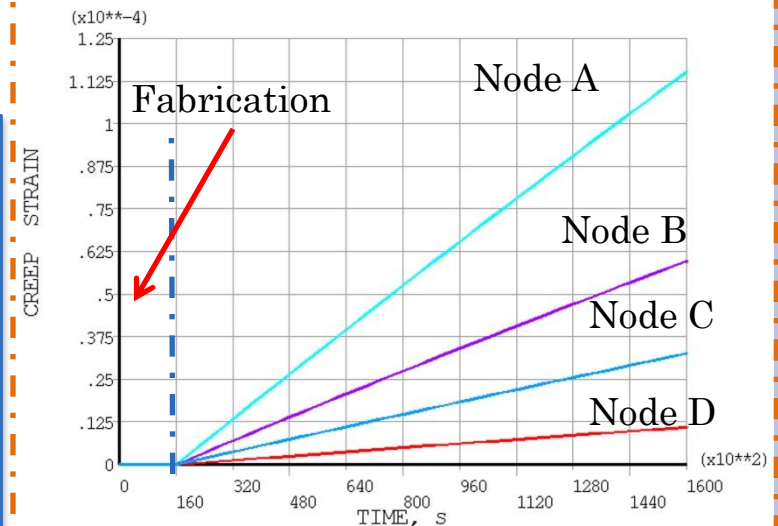
- Nonlinear structural behaviors of the FW are simulated by a combined elastic, plastic and creep models.
- Processes of the fabrication, heat treatment, reactor start-up and normal operation are included in plastic model.
- There are no stress, no plastic strain and creep strain during the FW brazing process.
- The FW is in the plastic range during braze cool-down.
- At this moment, the creep strains are ignored during the heat treatment because of such a short time.



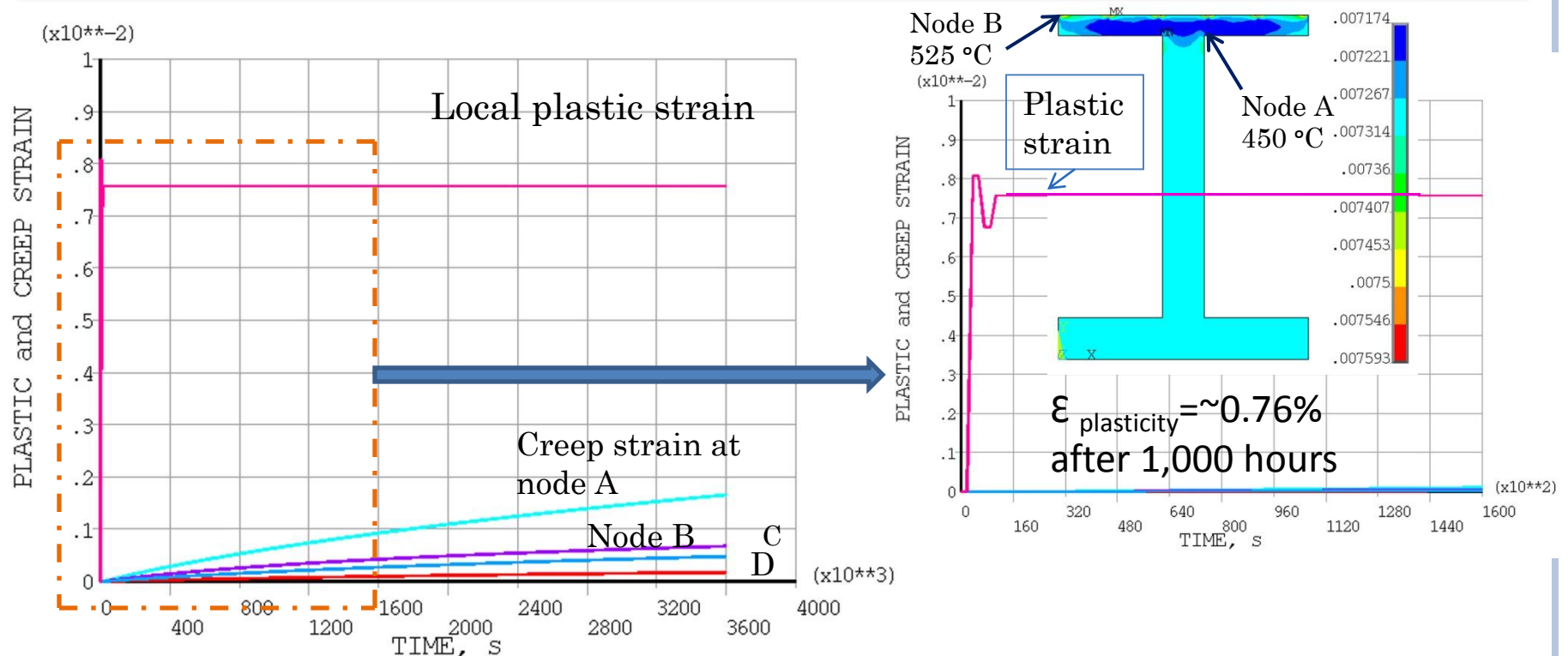
LOCAL CREEP STRAIN OF THE F82H



- The maximum local creep strain of the F82H plate at 1000 hours is ~ 0.17% at the Node A where the local stress occurs caused by sharp corner at the temperature of 450 °C.
- $\epsilon_{cr} \sim 0.07\%$ at the Node B with maximum temperature of 525 °C.
- $\epsilon_{cr} \sim 0.05\%$ at the Node C with temperature of 500 °C

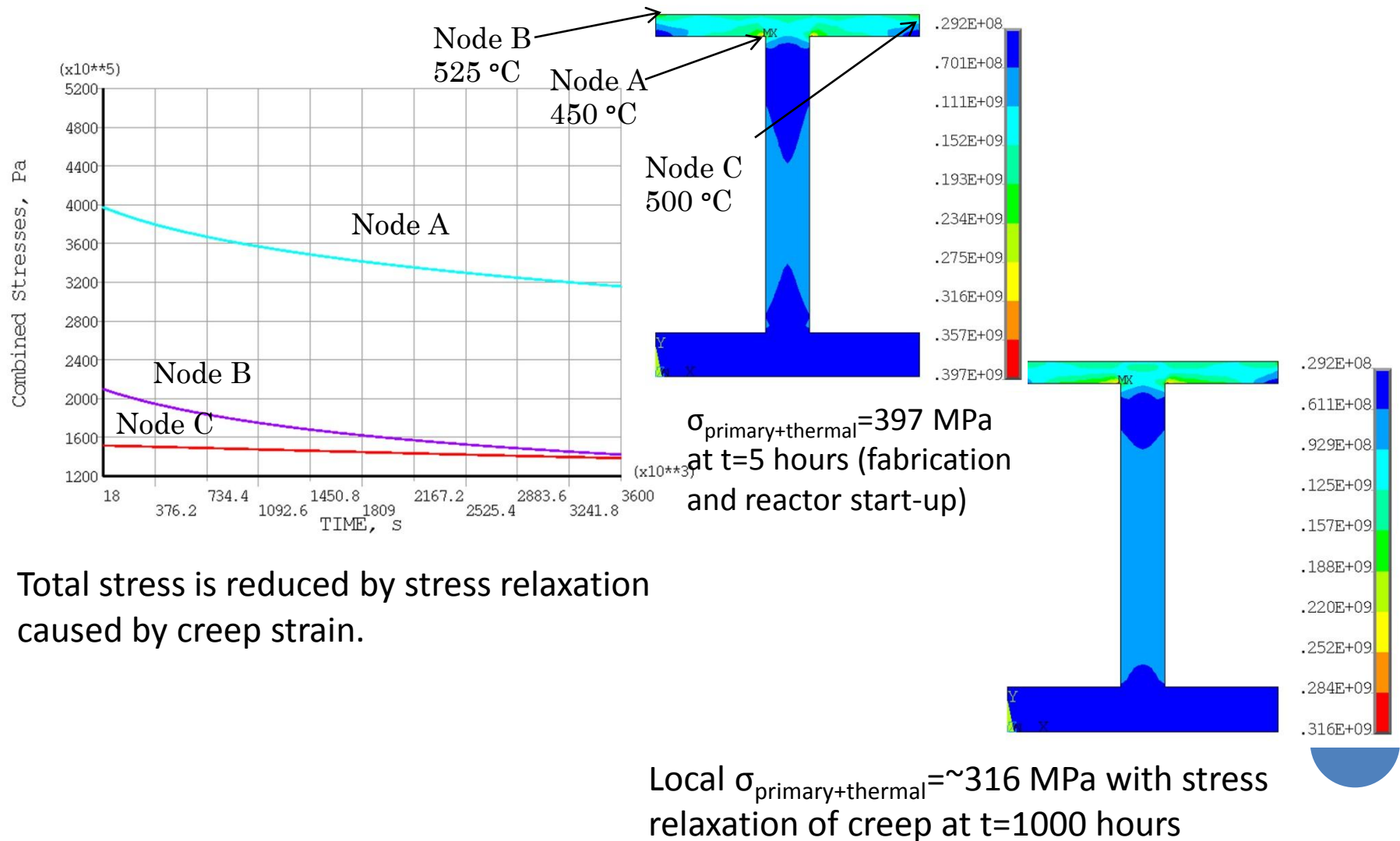


PLASTIC STRAINS AFTER 1000 HOURS



- The total local strain (plastic + creep) at node A is $\sim 0.9\%$, and $\sim 0.8\%$ at the node B after 1000 hours.
- The plastic strain mainly occurs in the processes of the FW fabrication, and there is no additional plastic strain during normal operation.
- Thermal creep can help relax the total stresses of the F82H plate during the operation, but can not recover the deformation which occurs during the FW fabrication.

STRESS RELAXATION BY CREEP DEFORMATION



SUMMARY

- Full time-dependent elasto-plastic-creep analysis is performed in a operating time of ~ 1000 hours for the FW, and a long operating time such as 10,000 h or even longer may need to be analyzed.
 - ✓ Calculated local creep strain $\sim 0.17\%$ and the plastic strain is $\sim 0.72\%$ at the Node A after 1000 hours. The local plastic plus creep strain is $\sim 0.9\%$.
 - ✓ Expected local creep strain is roughly $\sim 1.57\%$ after 10,000 h and the total strain is $\sim 2.4\%$ ($< 5\%$ local strain limit), however it needs confirmation by analysis (**assuming the initial creep rate of $1.57 \text{ E-6 } 1/\text{h}$**)
- Further assessments of the structural strains are needed to compare other two strain limits, also including to study ITER SDC-IC
- Possible design methods to reduce the local total stresses and local creep strain of the F82H
 - ✓ Round the sharp corner where it causes local primary stress

