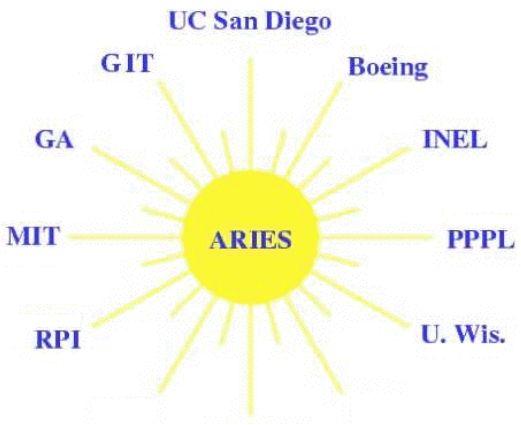
Robust High-Performance First Wall Design and Analysis



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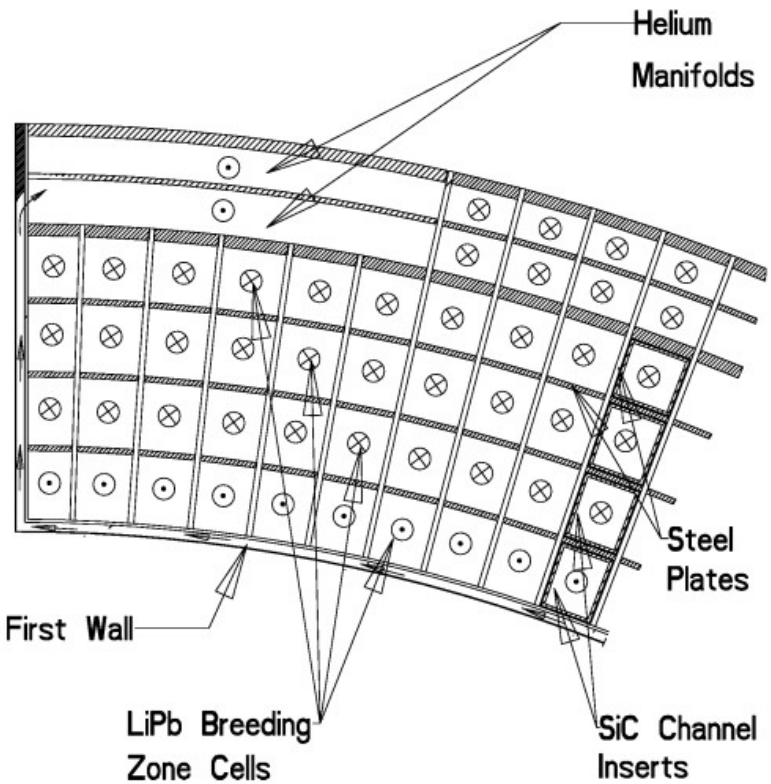
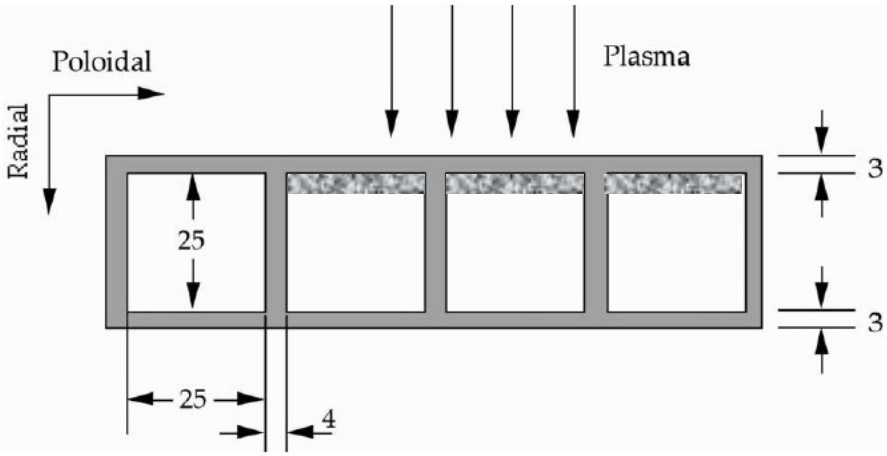
The EU "blanket box" first wall was adopted for the original DCLL blanket

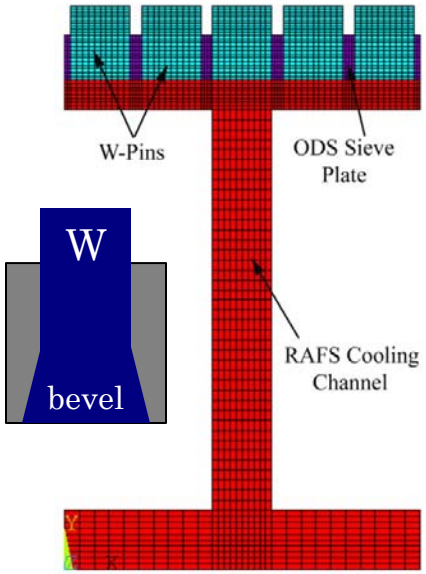
1. Robust, thoroughly analyzed and well tested.
2. Adopted in ARIES (since ARIES-ST) as a good steel FW design.
3. Limited to roughly 0.8 MW/m^2

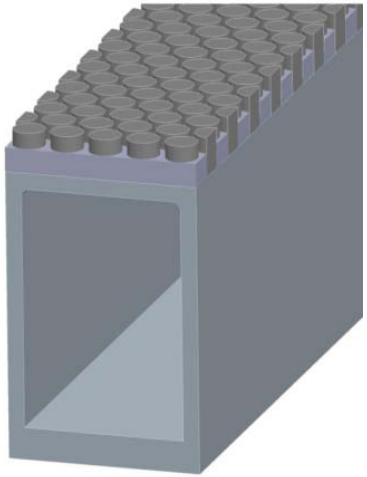




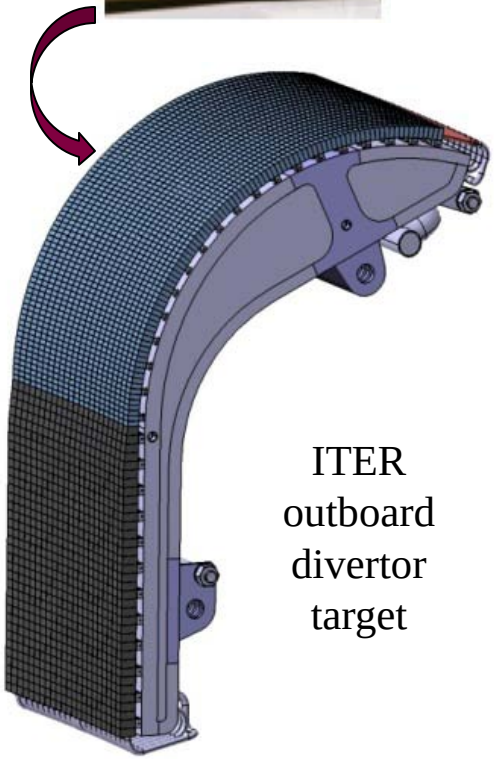
Single-sided roughening used to enhance heat transfer with only 25% penalty on pressure drop

A modified first wall concept using W pins was proposed to better resist transients





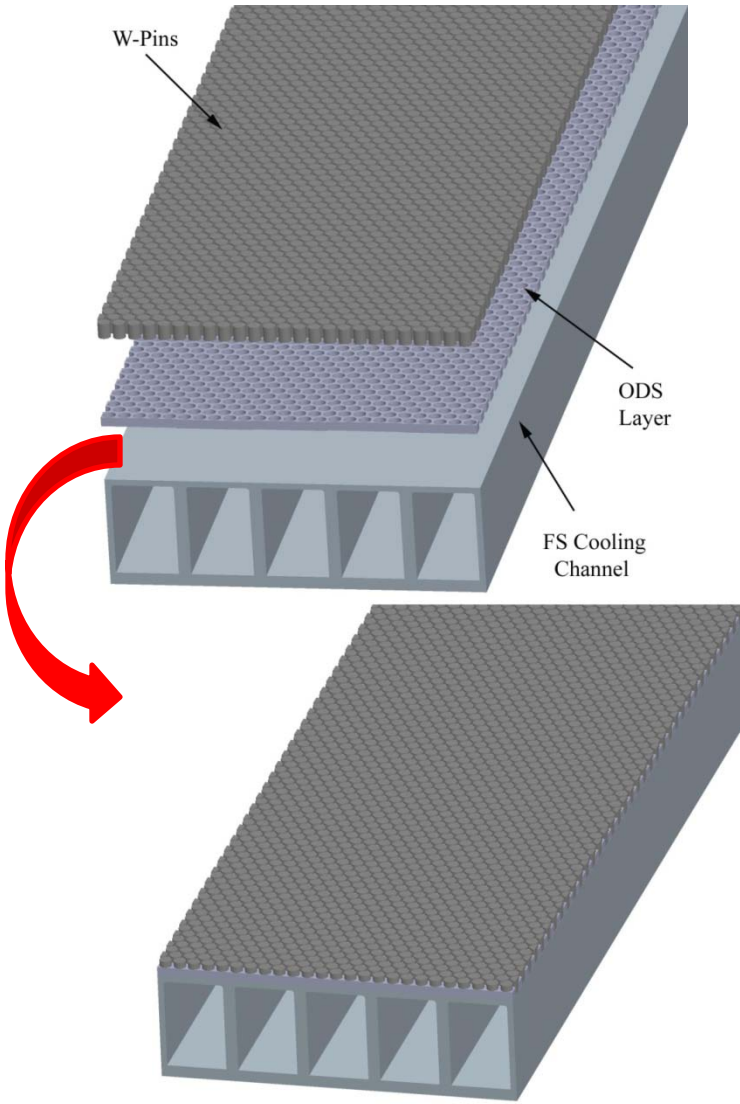
- Similar to micro brush concept developed for the ITER divertor
- W pins are brazed into ODS steel plates, which are brazed to RAFS cooling channels
- Pins help resist thermal transients and erosion
- Minor impact on neutronics (under investigation)
- Goal of 1 MW/m^2 normal, 2 MW/m^2 transient



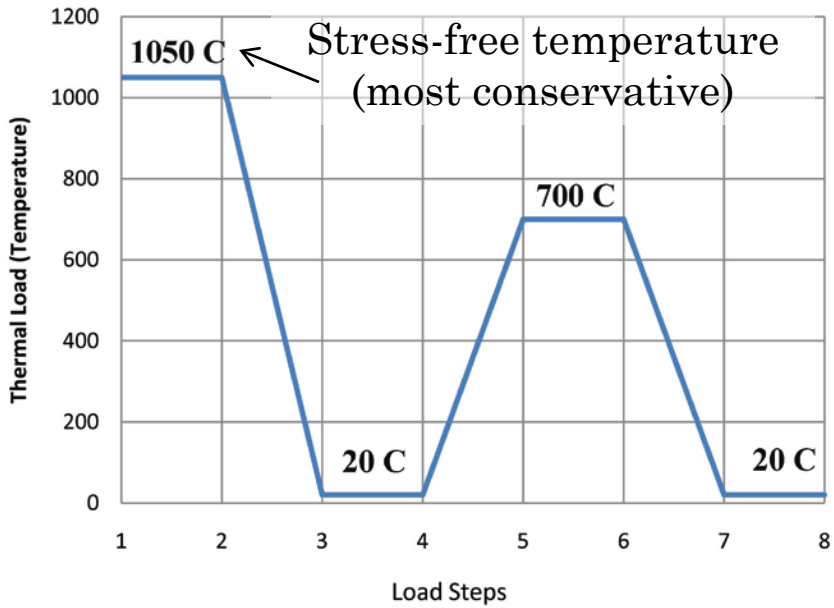
ITER outboard divertor target

Fabrication method for plasma-facing panels

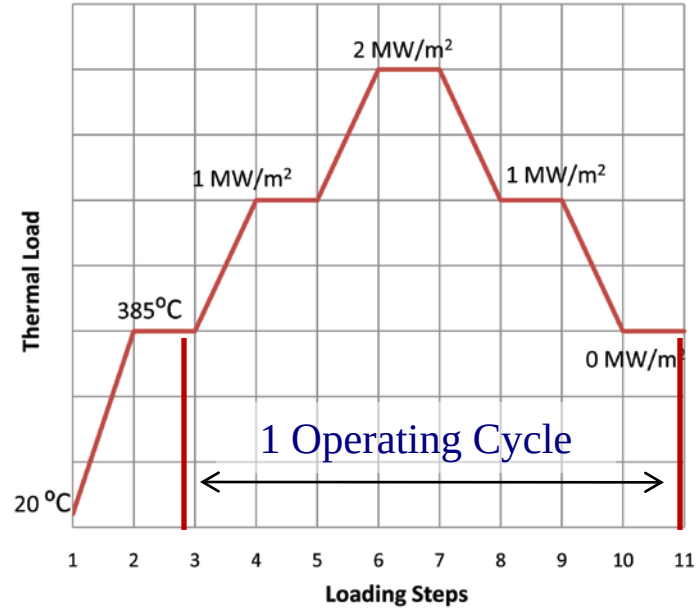
1. The main cooling panel is formed by Hot Isostatic Pressing (HIP) of RAFS.
2. Holes are drilled in a simple flat "sieve plate" made from high-temperature ODS-steel.
3. Brazing foils, rings or pastes are placed on the top of the FW cooling panel and in the sieve plate holes.
4. The unconstrained assembly is placed in a furnace and slowly heated to the braze temperature (1000~1100 °C). Residual stresses are relaxed.
5. The assembly is cooled to room temperature to seal the braze joints. Some local plastic deformation will occur during this step.
6. The assembly is tempered at 700~750 °C for ~ 1 hour. Most of the residual stresses in the RAFS will be relaxed, but the temperature is too low for creep relaxation in the W or ODS steel.
7. The assembly is cooled to room temperature. Some plastic deformation may occur by exceeding the yield strength, especially in the RAFS cooling ducts.



Operating scenarios, "birth to death"



Loading profile for fabrication steps including heat treatment



Loading profile for operation with warm shut-down and "over-power" transient

✓ Note: all of the ANSYS plastic material models are rate-independent except thermal creep. Therefore, changing slopes of the temperature and heat flux curves will not change the results. The thermal creep is not yet included.

Our FW design criterion allows for plasticity

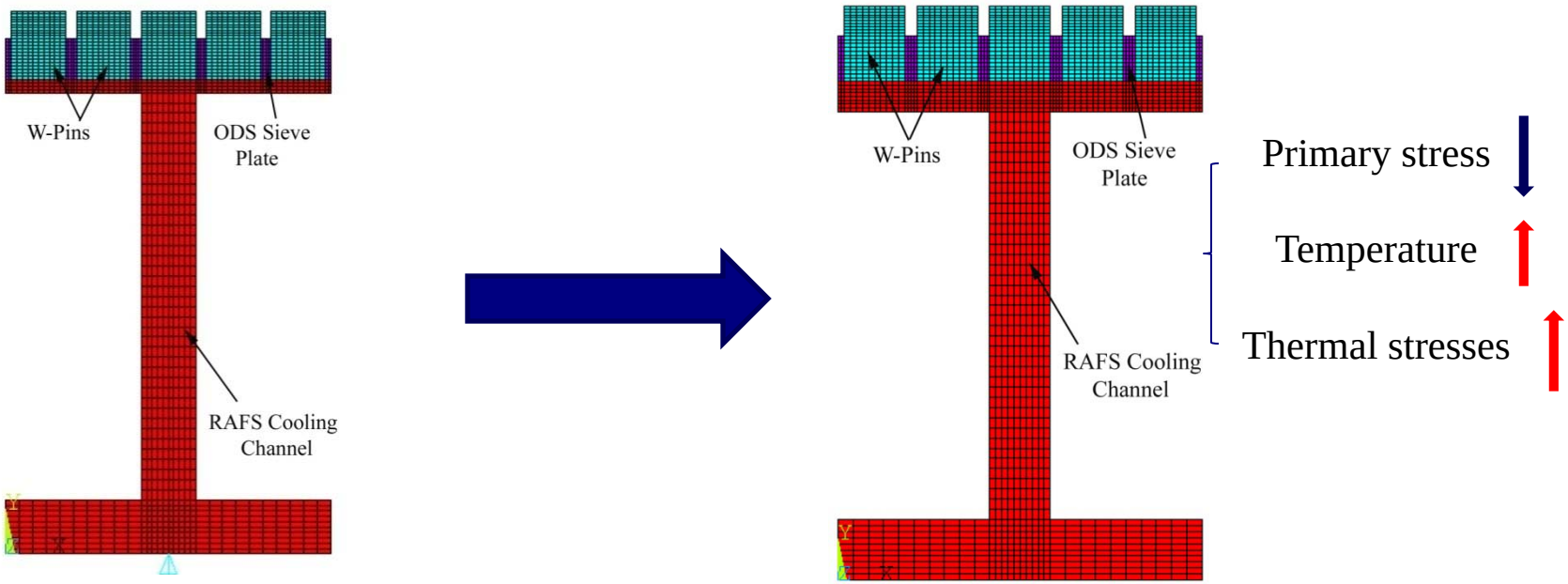
$$\varepsilon_{inelastic}^{principal} < \varepsilon_{allowable}^{BaseMaterial}$$

where $\varepsilon_{inelastic}^{principal}$ is the maximum value of the **accumulated** principal strains over the operating life,

and $\varepsilon_{allowable}^{BaseMaterial}$ is 1/2 of the uniform elongation (ue=the strain at necking).

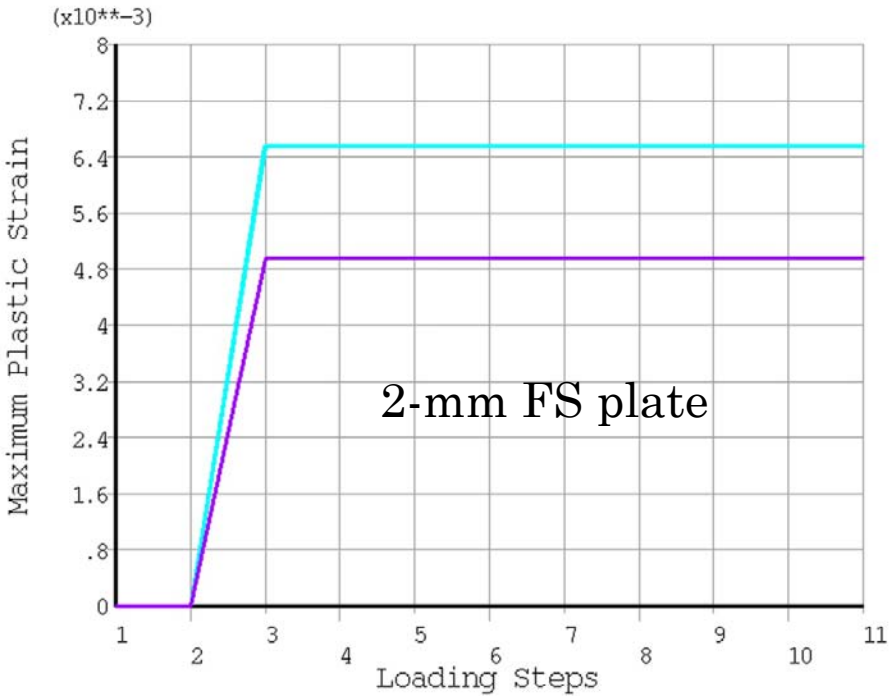
	Temperature (C)	Allowable strain (%)
F82H	30	2.4
F82H	500	2.7
ODS Eurofer	30	2.3
ODS Eurofer	700	2.4
Pure W	270	0.8
Pure W	1200	1.0

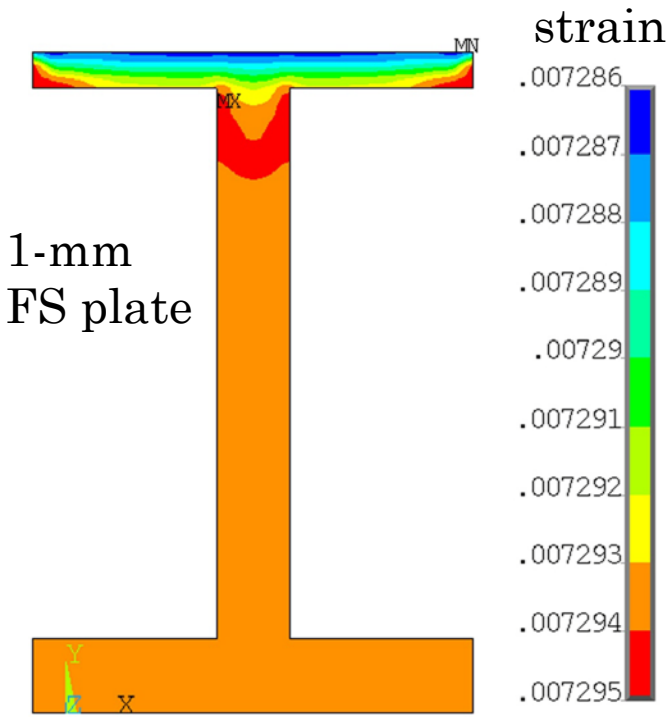
“Front plate” thickened to reduce ratcheting



- Thickness of the RAFS front-plate was varied from 1 mm to 2 mm
  - 1 mm front plate may be unrealistic for fabrication
  - 2 mm front plate can reduce primary stress and plastic deformation, thus avoiding ratcheting during transient operations.
- Total FW depth kept constant (38 mm)

Analysis of fabrication steps

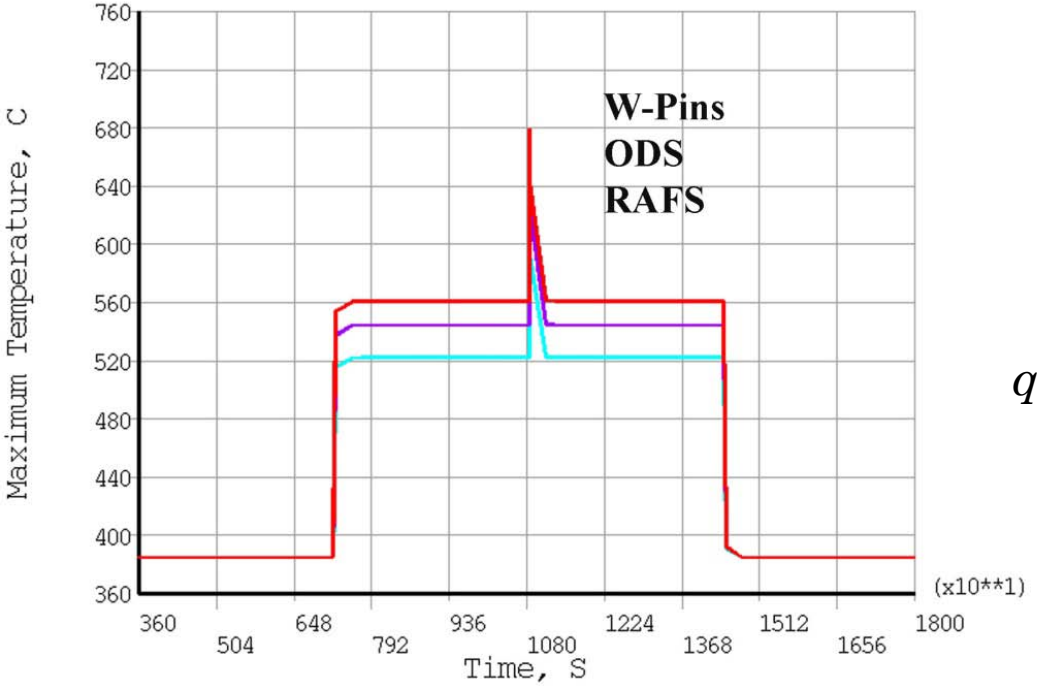




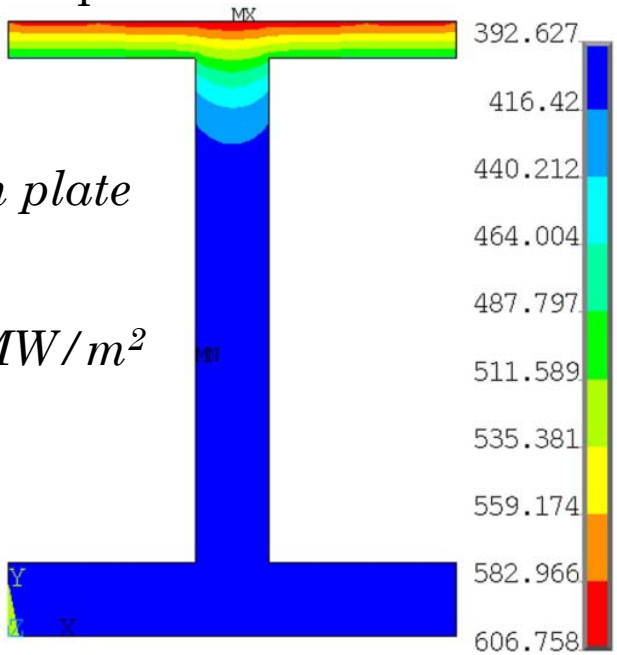
The maximum plastic strains are reached at room temperature, and are far less than allowables for both designs.

	2-mm RT strain (%)	1-mm RT strain (%)	Allowable strain (%)
F82H	0.65	0.73	2.4
ODS	0.5	0.48	2.3
W	0	0	0.8

Thermal analysis during operation



Temperature in F82H

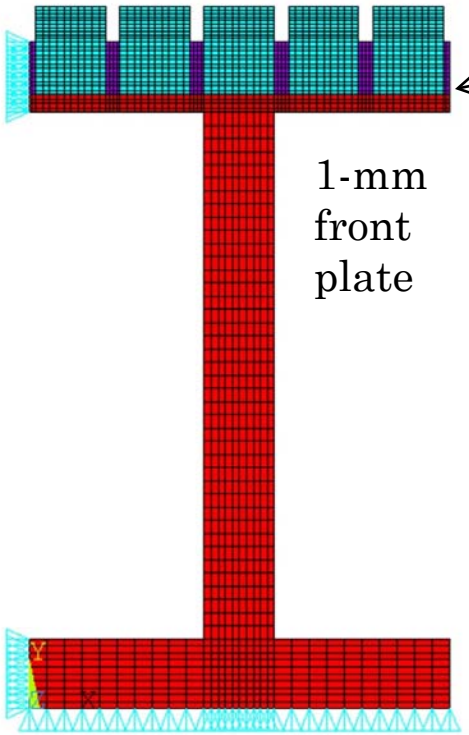


2-mm plate

q”=2 MW/m²

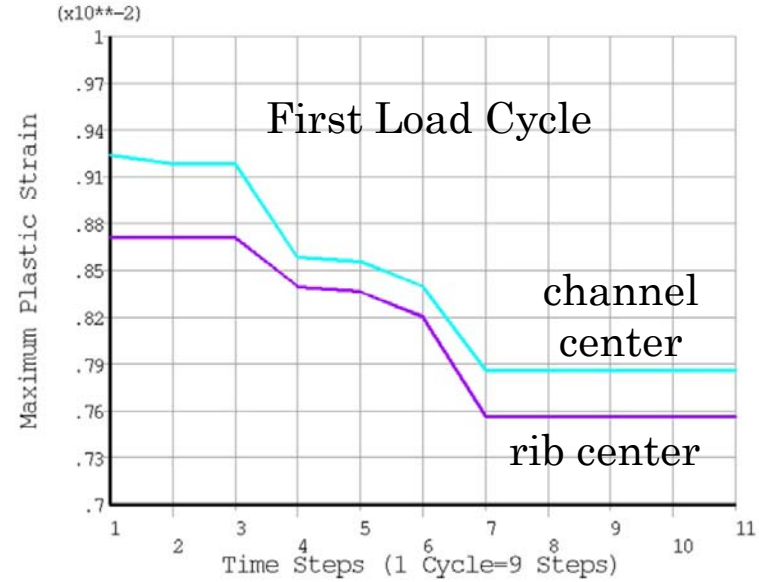
	T (2-mm) ˚C 1(2) MW/m²	T (1-mm) ˚C 1,2 MW/m²	T (nominal) ˚C 1,2 MW/m²	Allowable ˚C 1,2 MW/m²
F82H	522 (607)	480 (542)	562 (642)	550
ODS	544 (648)	500 (582)	650 (826)	700
W	560 (680)	515 (618)	–	1200

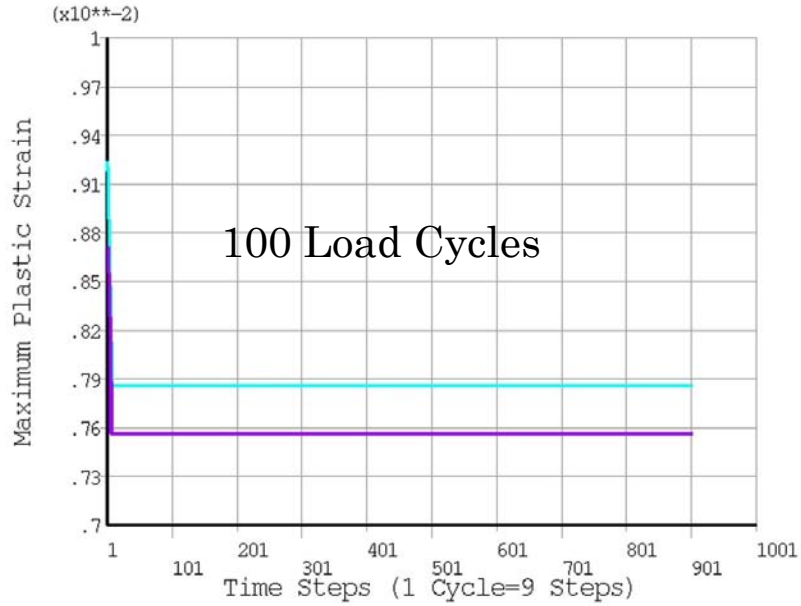
Stress analysis of cycling with warm shutdown



Strains in F82H
at the braze location
(highest strain cases)

1:	T=20 C
2:	T=385 C
3:	Power on
4,5:	q=1 MW/m^2
6,7:	q=2MW/m^2
8:	q=1 MW/m^2
9:	q=0
10:	T=385 C

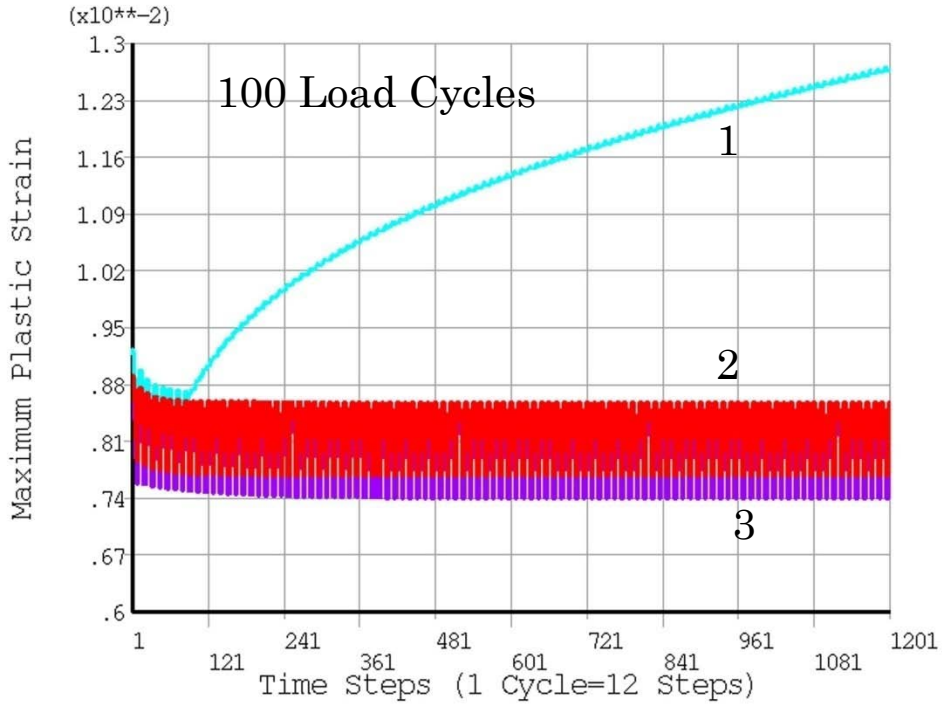


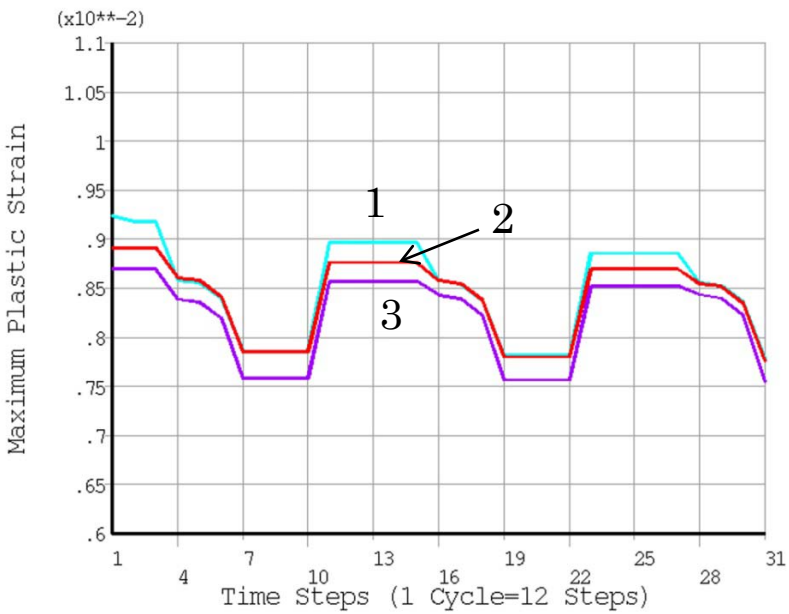


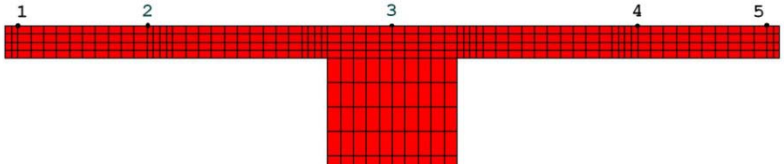
- The maximum plastic strain at the interface ε_{pl}= 0.92% (< ε_{allow} =1.1%) occurs at 30˚C.
- There is no ratcheting observed after 100 load cycles.
- The plastic strain saturates during the first load cycle, with maximum ε_{pl}= 0.79%

Stress analysis of cycling with cold shutdown

- The plastic strain reaches the limit (< ε_{allow} =1.1%) after ~40 load cycles.
- The potential for ~40 cycles during the lifetime of the blanket down to RT(~20°C) requiring draining of liquid metal from the blanket is probably sufficient.

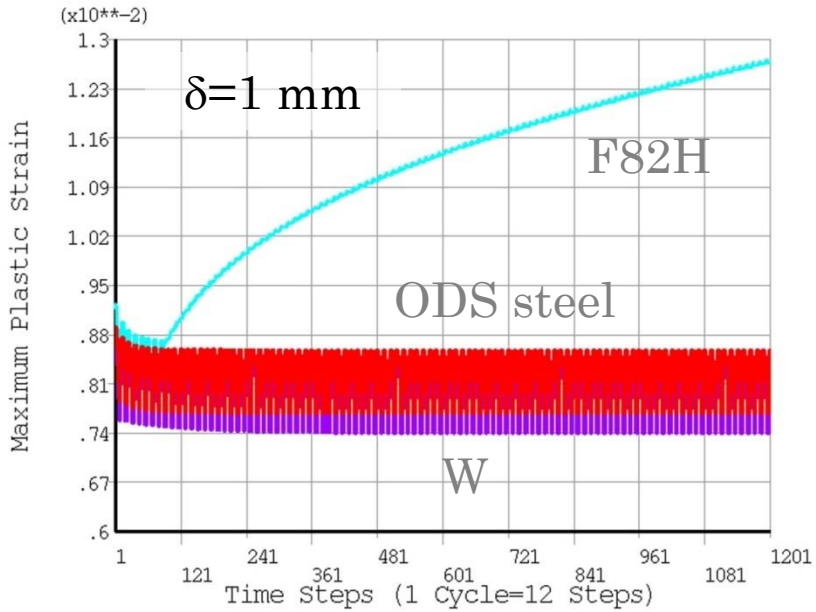


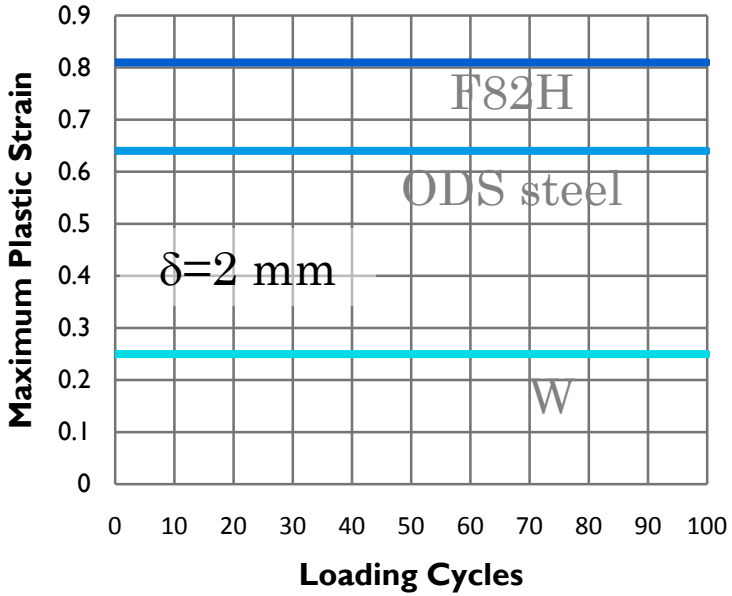




Partial FE model showing artificial node numbers

Ratcheting was halted completely by increasing the F82H front plate thickness





(In fact, both designs are probably acceptable)

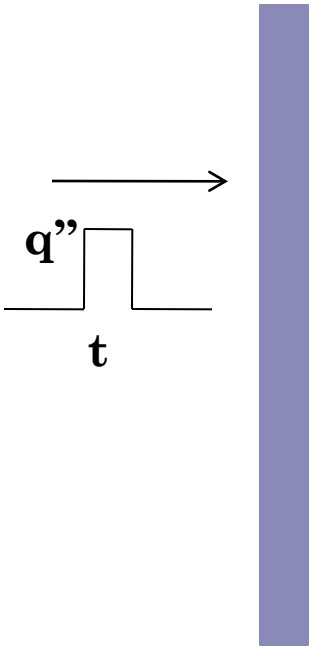
Transient ELM heat loads to the FW

- ΔW_{ELM} x f_{ELM} ~ constant = 0.2–0.4 x P_{div}
- f_{ELM} (ITER, worst case) = 1-2 Hz & ΔW_{ELM} (ITER, worst case) = 20 MJ
- ΔW_{ELM} to FW = 5% for small ELMs and ~ 20% for largest ELMs
- $\tau_{ELM,rise} \sim 2\pi R_{q95}/c_{s,ped}$ ($c_s=10^6(\gamma Z T_e)^{1/2}$ cm/s)
- $\tau_{ELM,fall} \sim$ 2-3 x $\tau_{ELM,rise}$
- All of the energy lands outboard
- Peaking of 2-4x associated with filaments expanding off the plasma.
- Filaments do not land in the same place all of the time: random location.
- For T_{ped}=4000 eV, **P_{max}~ 2 GW/m^2 over 50-100 μs**

Peak Temperatures from ELM's

$$T - T_o = \frac{2q''(\alpha t/\pi)^{1/2}}{k}\exp\left(\frac{-x^2}{4\alpha t}\right) - \frac{q''x}{k}erfc\left(\frac{x}{2\sqrt{\alpha t}}\right)$$

- **Steel first wall, 2.5 GW/m^2 over 75 μs**
  - ΔT = 1480 K
  - δ = 43 μm
- **Tungsten-coated first wall, 2.5 GW/m^2 over 75 μs**
  - ΔT = 1080 K
  - δ = 100 μm



Summary and future directions

- The new first wall concept can withstand higher heat flux than the original design.
- Design limits on temperature and strain are met. Ratchetting is completely avoided if a cooling channel wall thickness of 2 mm is used.
- The new design is more tolerant toward ELM's.
- We are now working to include thermal creep in our analysis.