Sandia HHF Tests of LANL PS Be Mockups

Dennis Youchison	Sandia, testing
Tom Lutz	Sandia, testing
Ken Troncosa	Sandia, testing
Fred Bauer	Sandia, testing
Richard Nygren	Sandia, SEM analysis
Kendall Hollis	LANL, mockup fabrication

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy under contract DE-AC04-94AL85000.

Beryllium Armor for the ITER FW

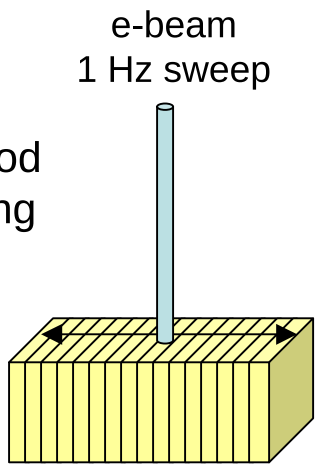
- Six ITER parties will fabricate ITER FW modules. The US is considering solid tiles and plasma-sprayed Be armor as options.

  What control of material can be imposed by ITER?
  Specifications by grade or equivalent or performance.

  There are various suppliers of beryllium and many grades.

  To date, the most comprehensive screening of Be grades was done at Sandia in 1996 using a simple and clever method developed by Bob Watson in a collaboration with the following researchers. ITER still refers to these data.

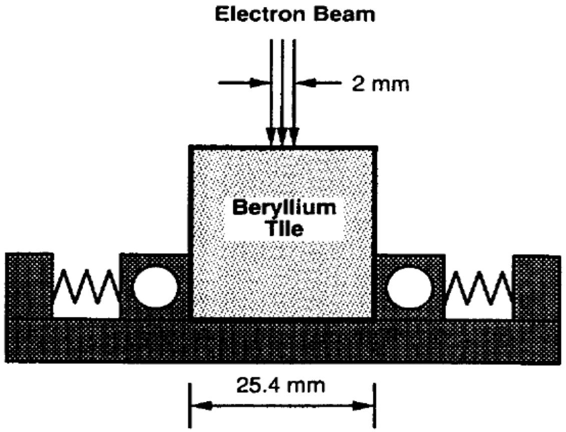
  Dennis Youchison, Bob Watson *(Sandia)*
  Dave Dombrowski *(Brush Wellman, now at LANL)*
  Radmir Guiniatouline, Igor Kupriynov (*Efremov)*

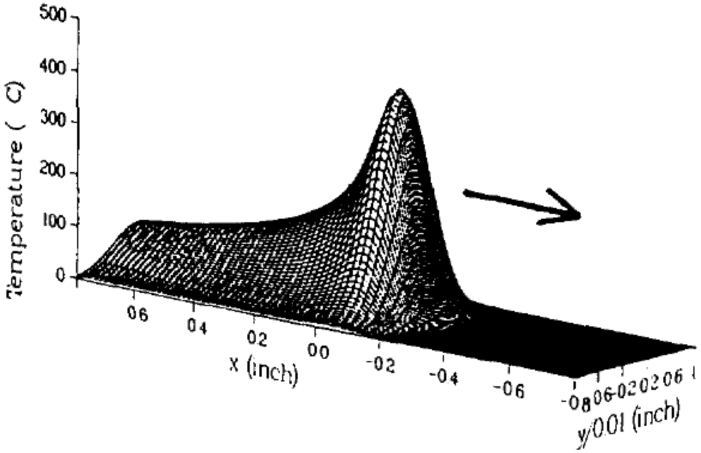


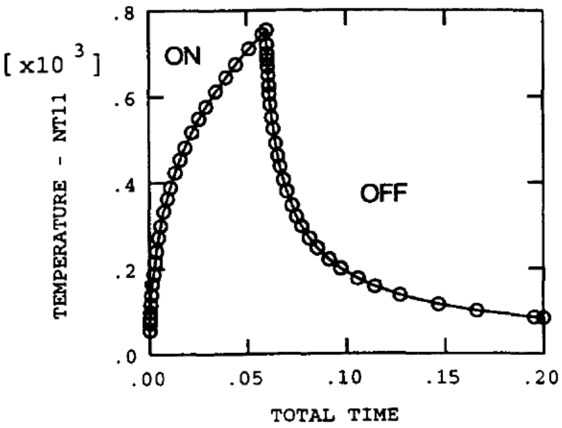
25.4x25.4x5mm Be coupons

Screening of Be Grades (1996)

- E-beam low-cycle thermal fatigue tests efficiently revealed differences in cracking of various Be grades.
  The most thermal fatigue resistant Be grades from those created with pressed powder in this study are S-65C (L) and DShG-200.



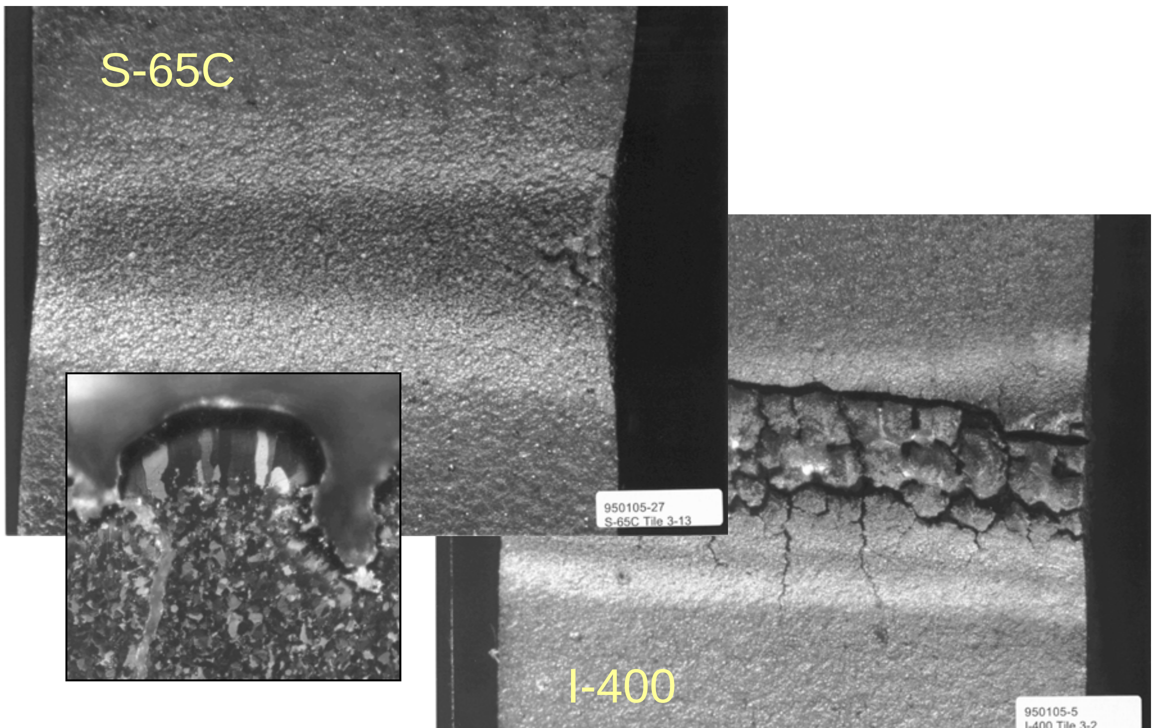




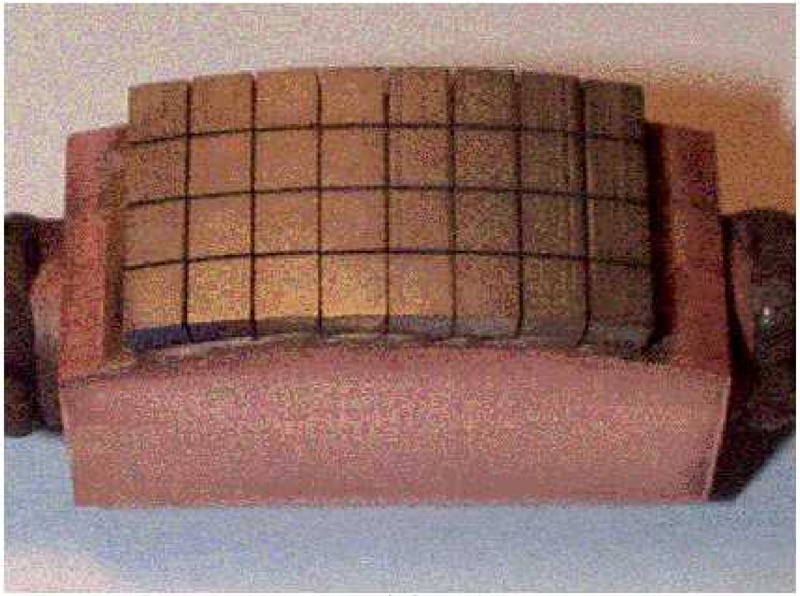
Sandia National Laboratories

Screening of Be Grades - continued

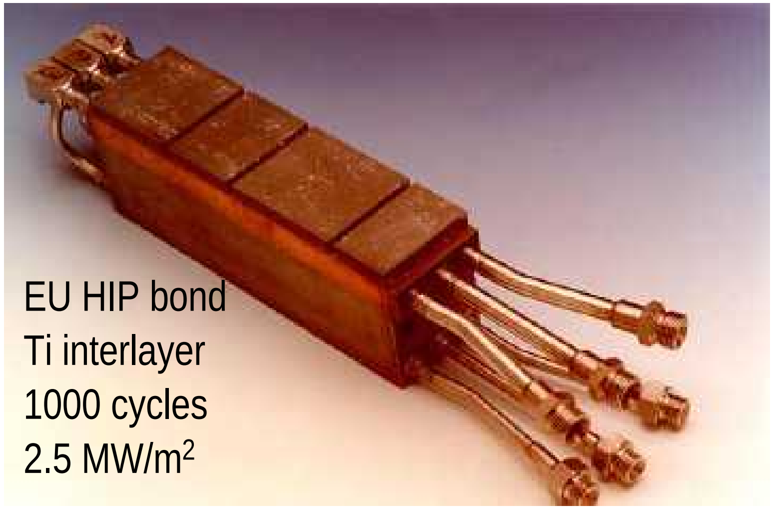
- The most thermal fatigue resistant Be grades from those created with pressed powder in this study are S-65C (L) and DShG-200.



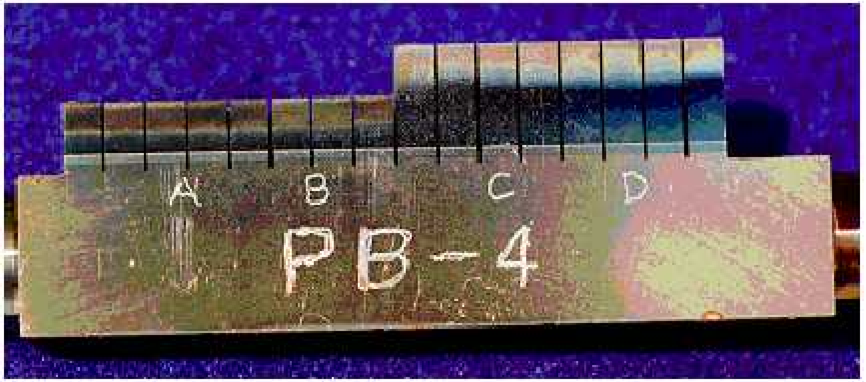
HIPPed & brazed Cu/Be Tile Test Parts



Russian Fast Amorphous
Cu-In-Sn-Ni Braze
4500 cycles at $12 MW/m^2$

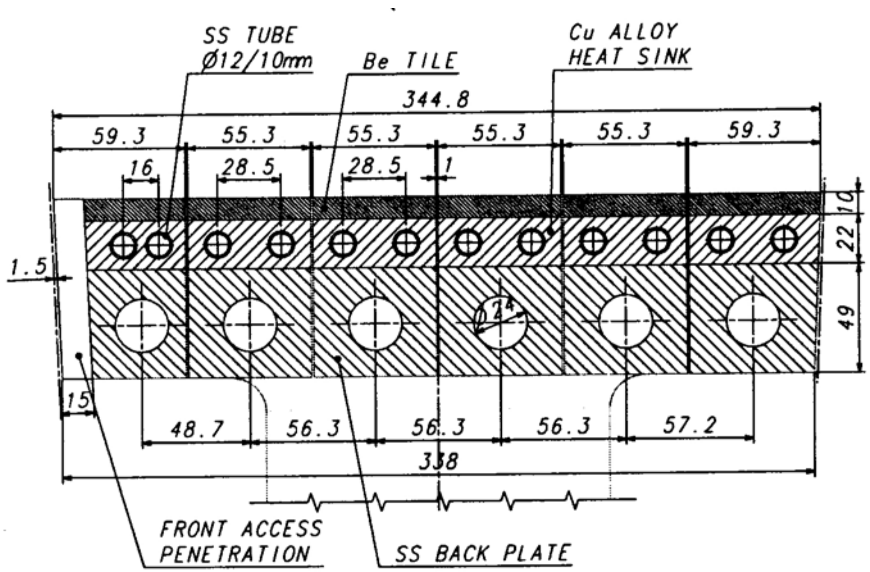


EU HIP bond
Ti interlayer
1000 cycles
$2.5 MW/m^2$

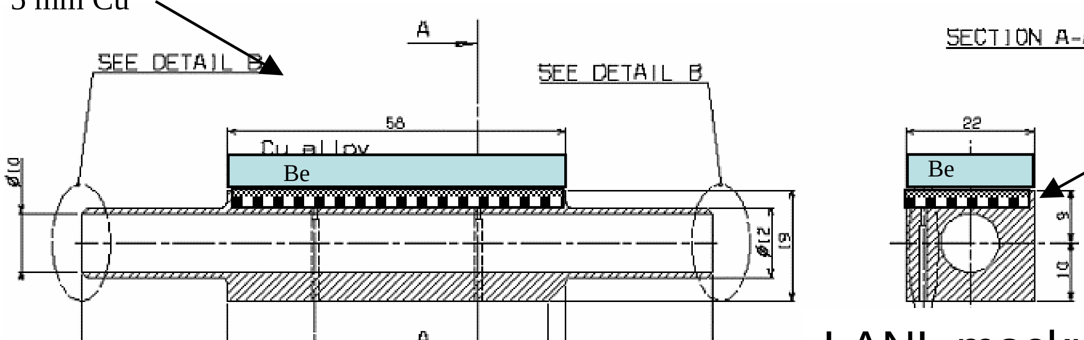


US HIP bond, AlBeMet interlayer
1000 cycles at $10 MW/m^2$

ITER FW and LANL mockup

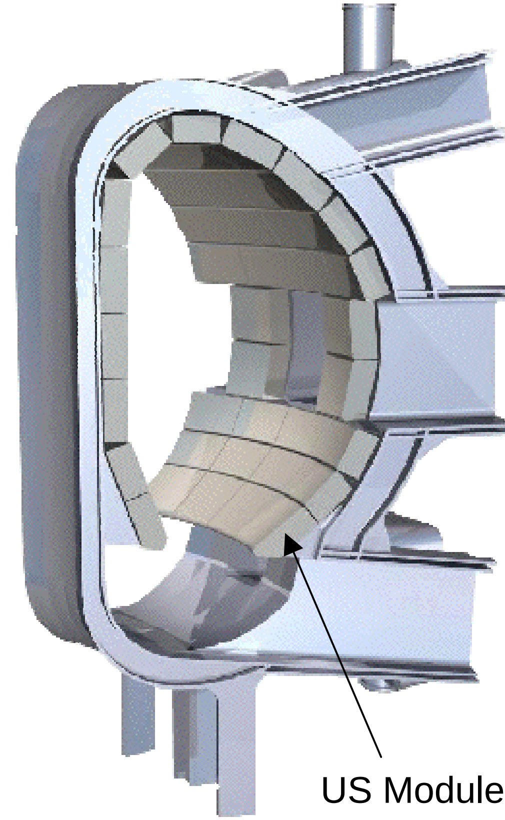


5 mm Cu



3.5 mm Cu
with top surface
castellated

LANL mockup



US Module 18

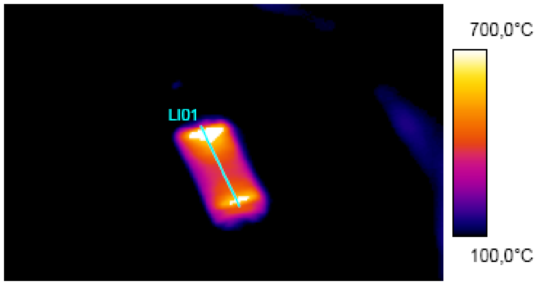
ITER

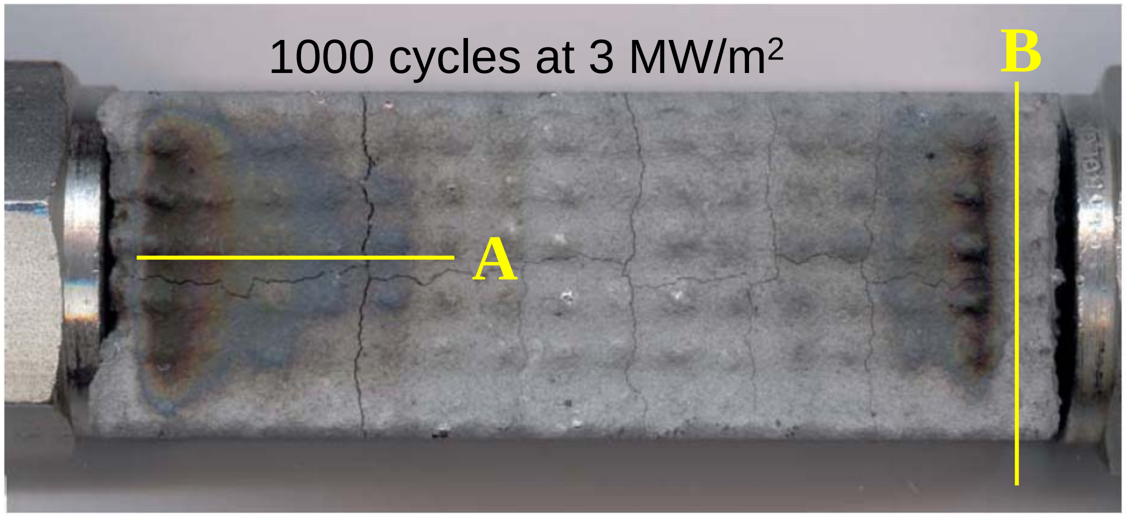
LANL Plasma-Sprayed EFDA FW Be armored mock-ups

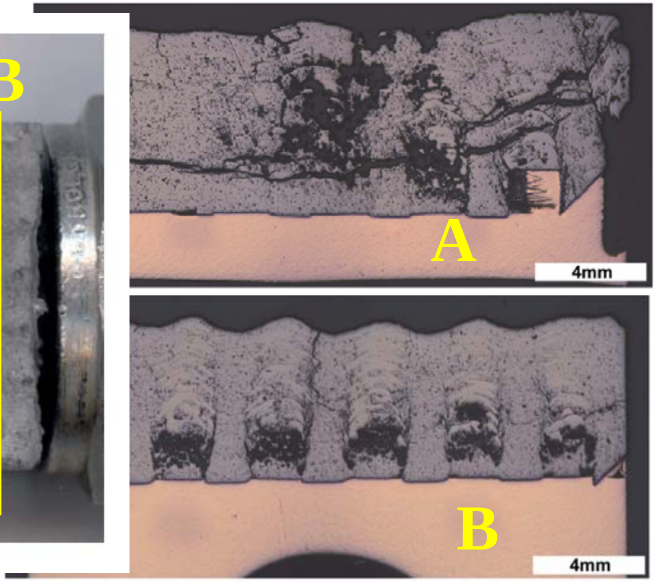
- 5 & 10 mm PS Be square castellated samples tested in JUDITH (FZJ), Germany

  5-mm armor - 1000 cycles @ 3 MW/m^2

  10-mm armor - 1000 cycles @ 1.5 MW/m^2

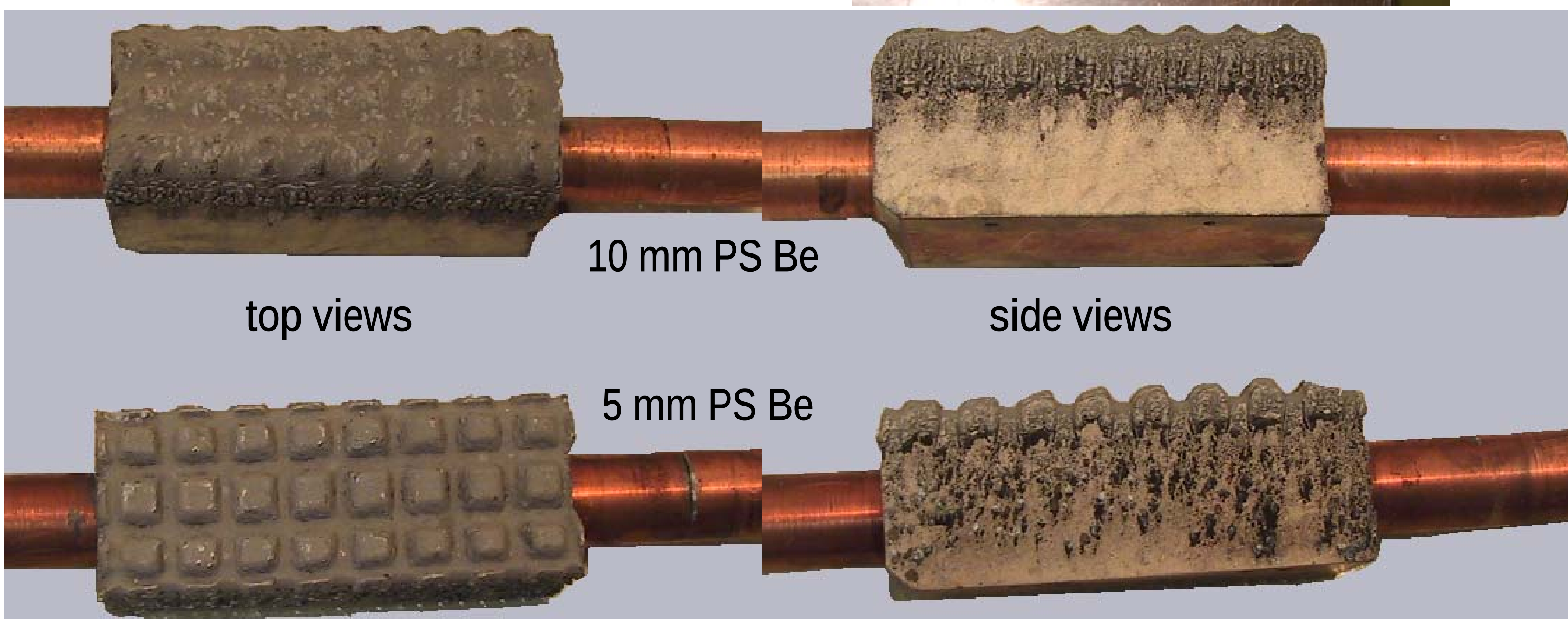






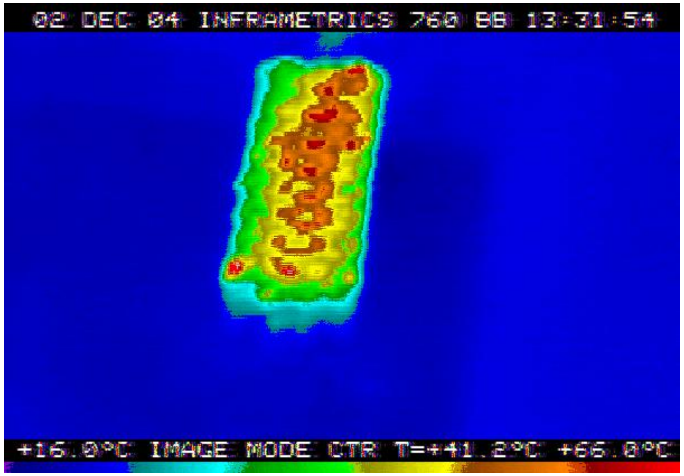
LANL Plasma-Sprayed FW Be armored mock-ups

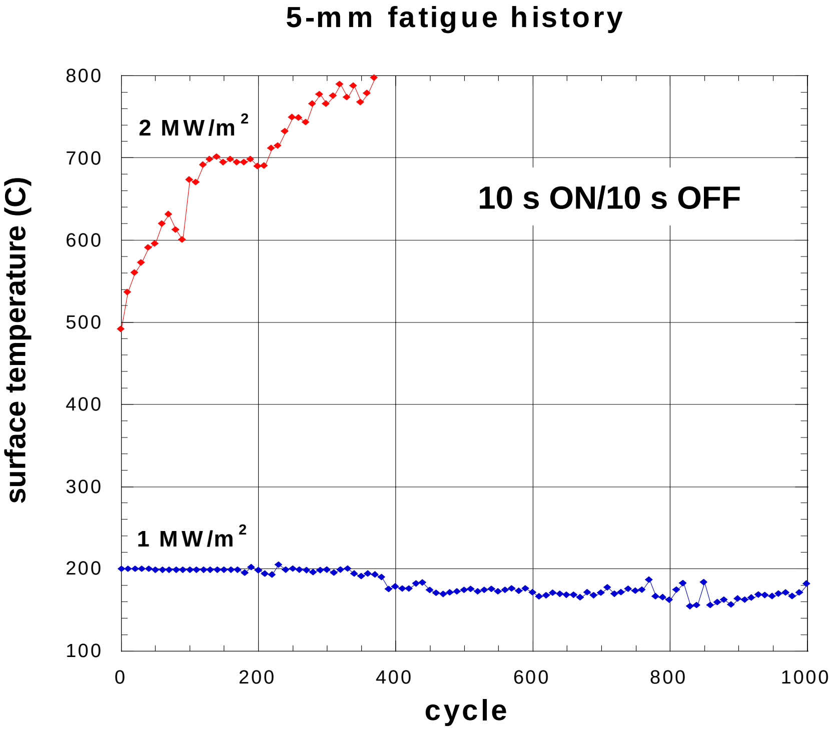
- LANL has developed a method of PS Be deposition onto castellated Cu that mechanically locks the armor in place and fixes preferred crack locations.



LANL PS Be-armored mock-up test results

- 5 and 10 mm PS Be with dovetail castellated tested in the EBTS, Sandia
  - 5-mm armor survived 1000 cycles @ 1 MW/m^2, and 370 cycles @ 2 MW/m^2
  - 10-mm survived 856 cycles @ 1 MW/m^2
- Flow: 10 m/s, 1.0 MPa, 16-20˚C water
- Surface temperatures (IR) were consistent
- 1000 cycles at 1 MW/m^2 with no damage.

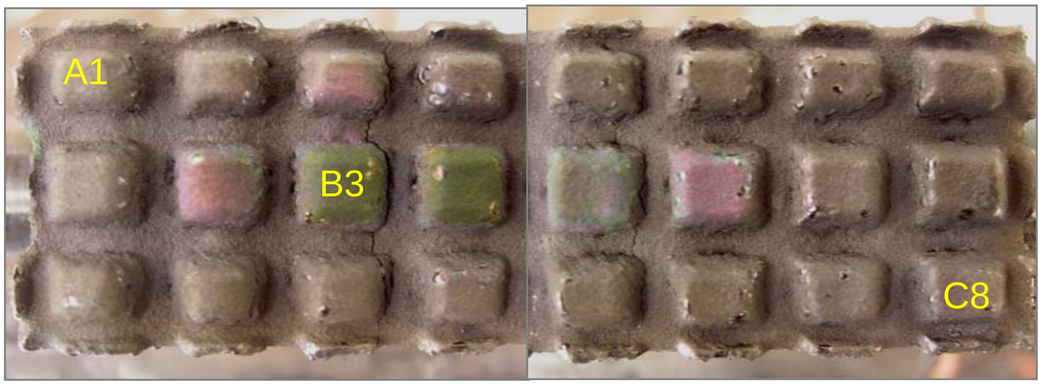


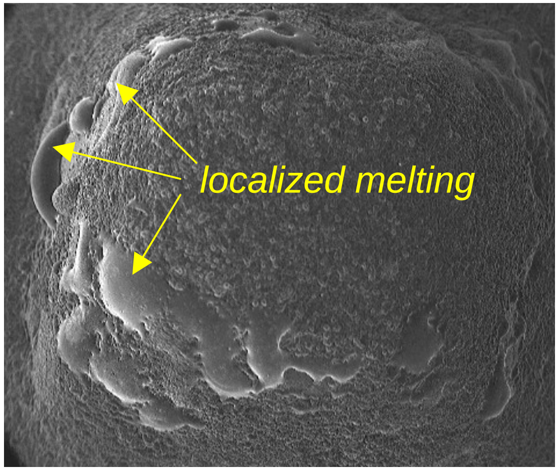


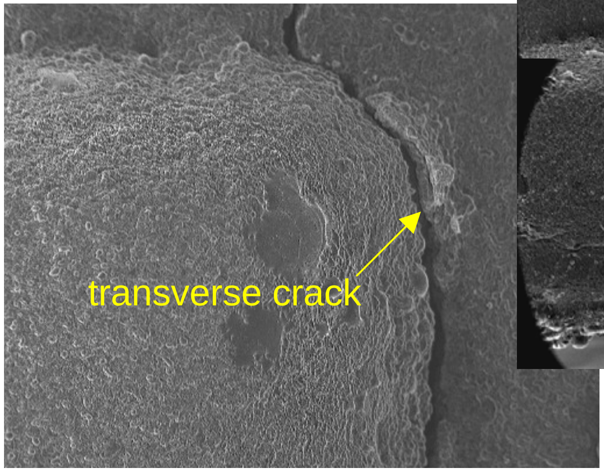
SEM exam of LANL mockups

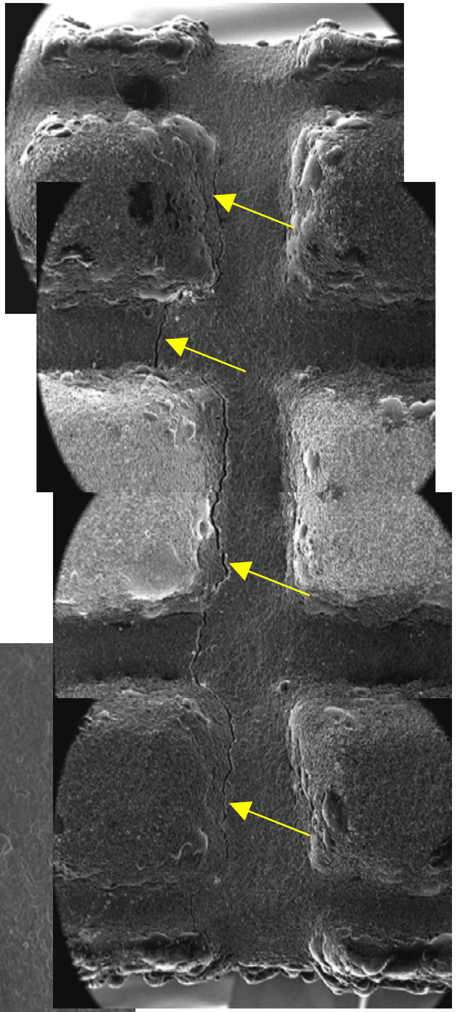
- The US samples had localized melting at peaks and transverse cracking only.

5-mm sample



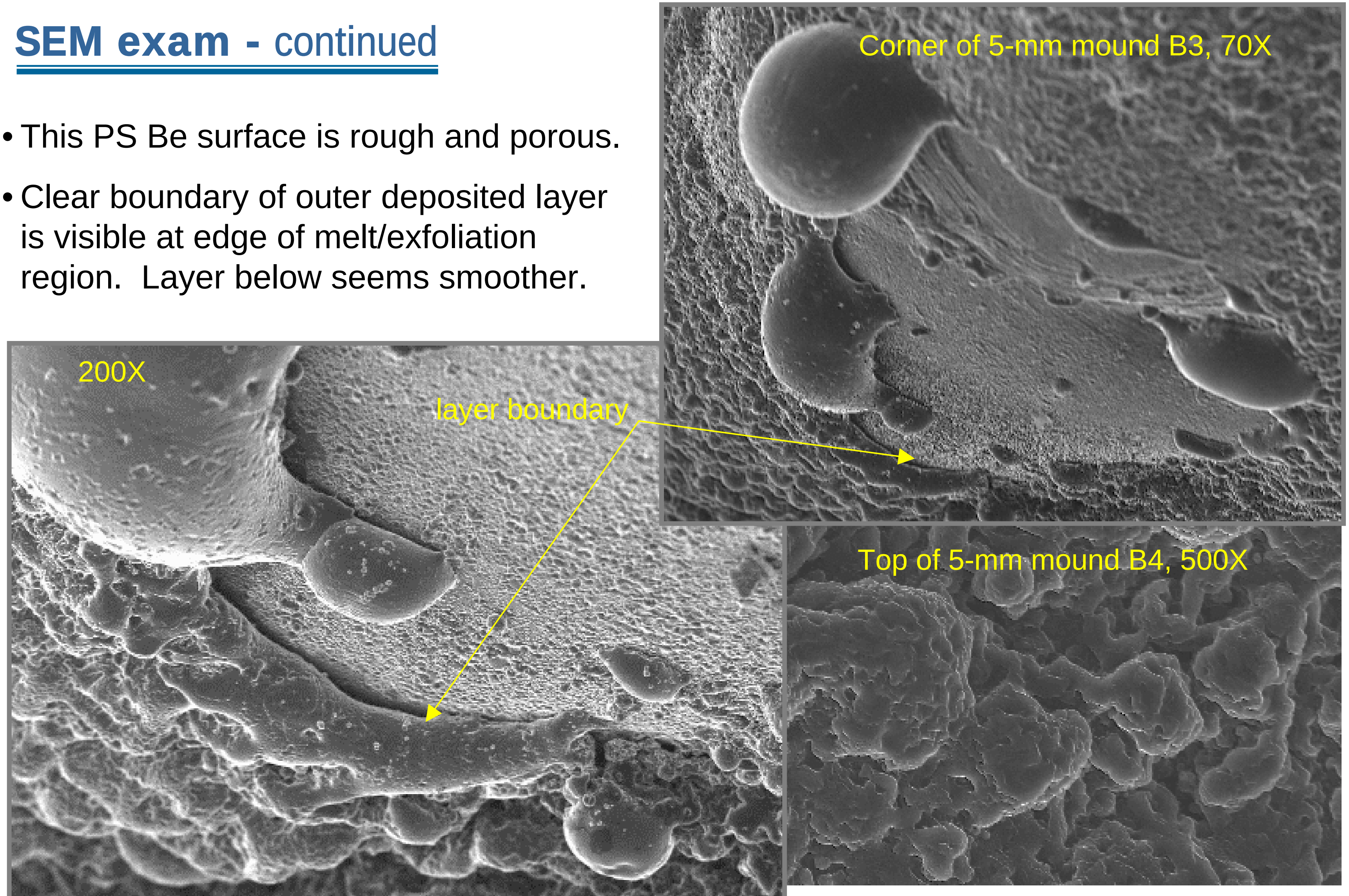






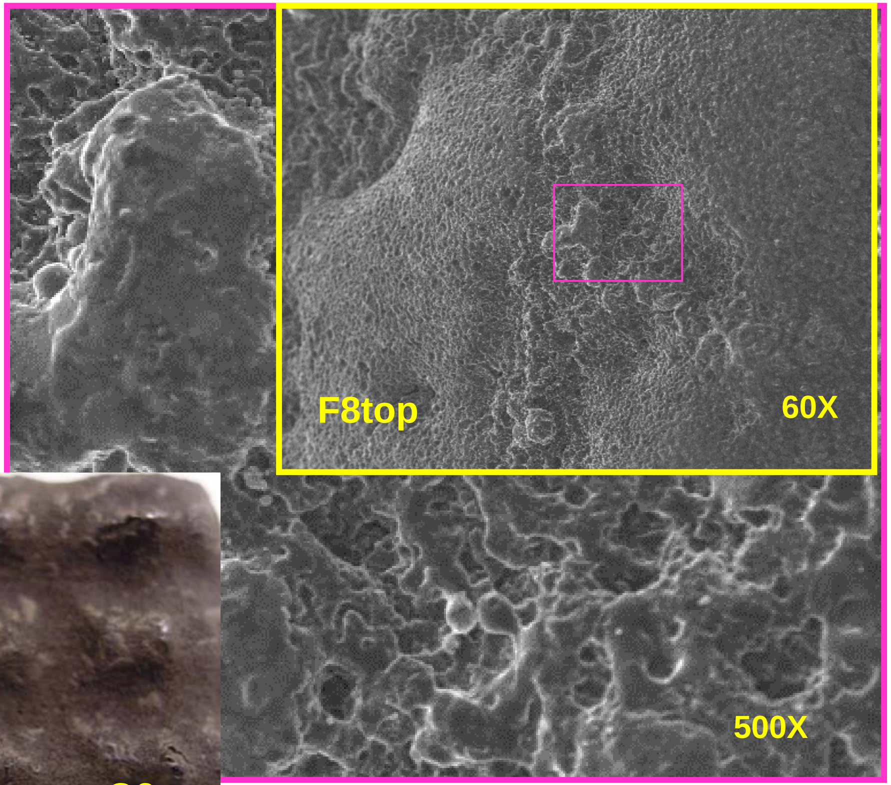
SEM exam - continued

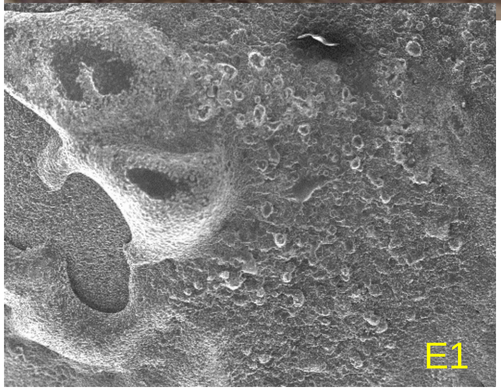
- This PS Be surface is rough and porous.
- Clear boundary of outer deposited layer is visible at edge of melt/exfoliation region. Layer below seems smoother.

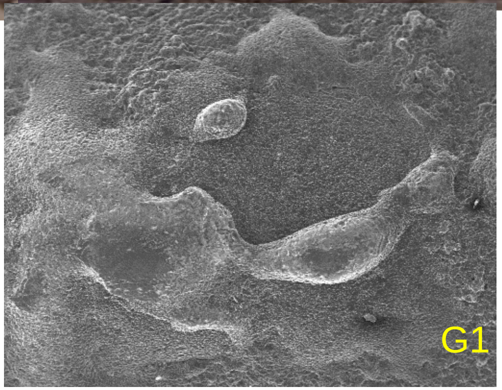


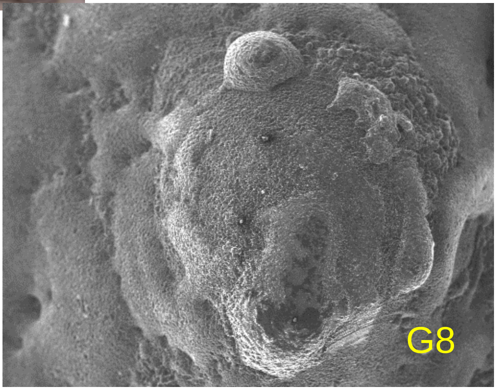
SEM exam - continued

- The 10-mm PS Be mockup had more melting and “slumping” on mounds. Slumped areas moved but retained some structure (not smooth melt surface).



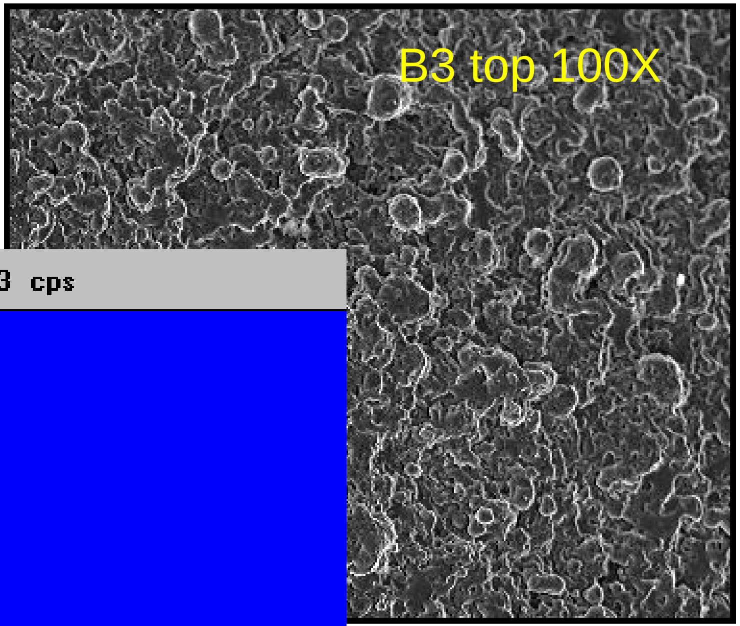


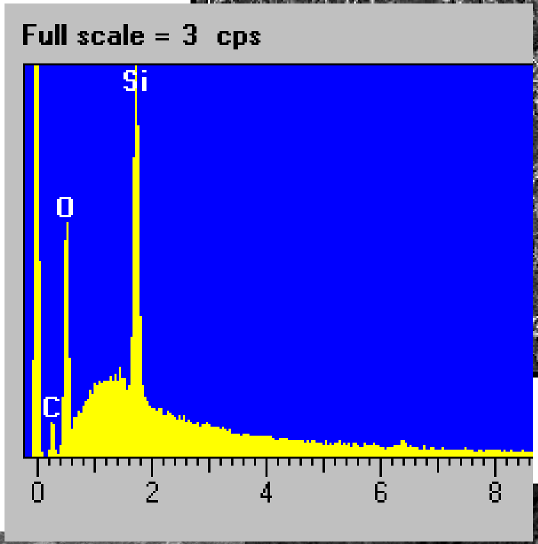


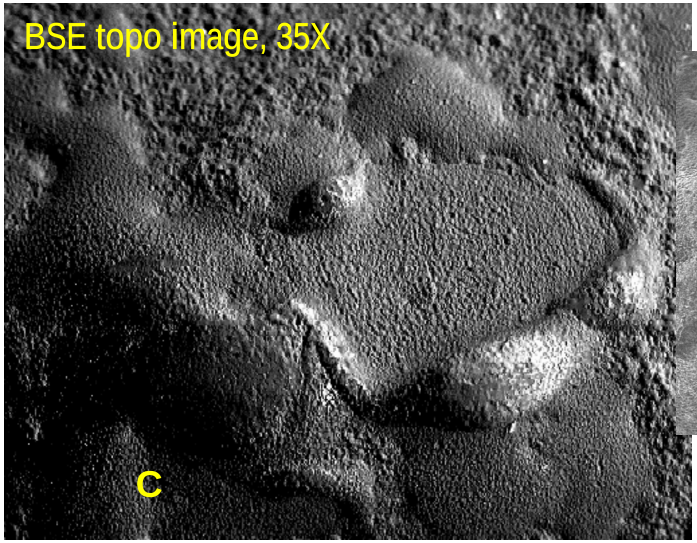


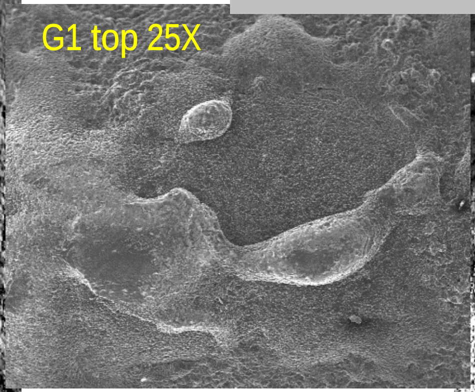
SEM exam - continued

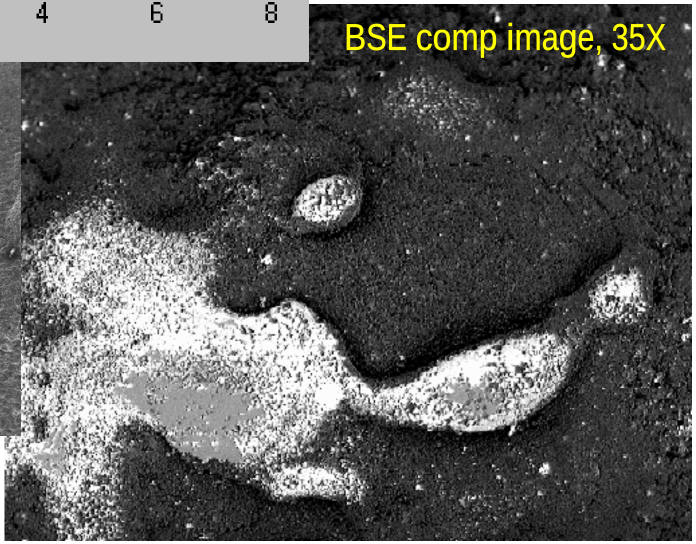
- X-ray spectrum (B3 top) shows C, O and Si peaks typical for PS Be.
- In backscattered (BSE) images, “topo” shows relief and “comp” shows differences in composition. The melted areas probably have more oxygen “gettered” in EBTS.





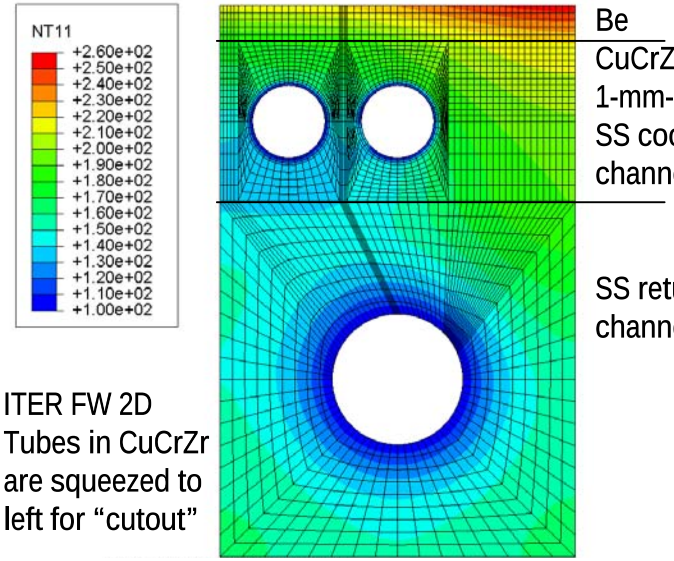




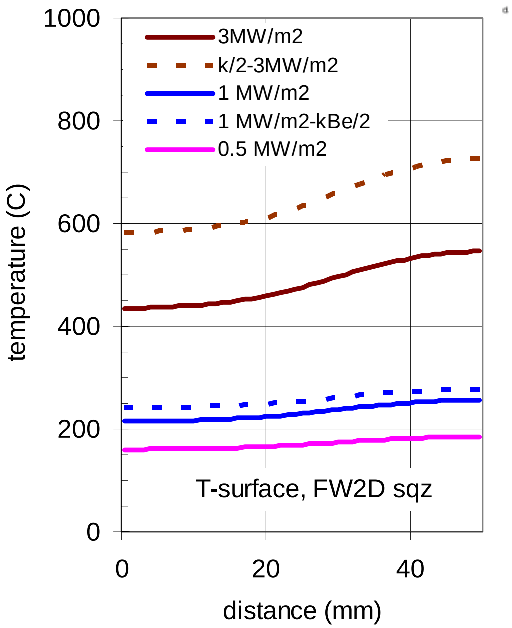


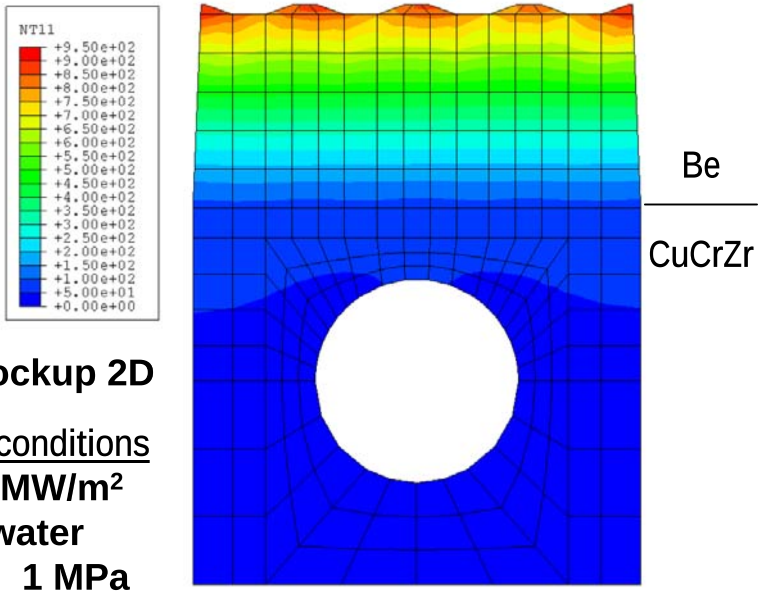
Thermal modeling

- We model the ITER FW with PS Be armor and the LANL PS Be mockups.
- Using 2-D cases of the type shown below, we estimated the thermal conductivity of the PS Be armor was ~1/4 that of S65-C.



ITER FW 2D Tubes in CuCrZr are squeezed to left for "cutout"





Be mockup 2D

<u>model conditions</u>

q" = 2MW/m²

25°C water

10m/s 1 MPa

Conclusions

- 3-D castellation of substrate to control cracking in PS Be during thermal fatigue appears promising. Manufacturing techniques require R&D, e.g. 3-D castellations and smooth sided FW fingers.
- For *in situ* repair with PS Be, technique and residual powder are issues.
- PS Be with low density and low thermal conductivity are not acceptable for ITER. H_2 additions and higher substrate temperatures (1000 ^{o}C) may be required to achieve the 95% theoretical k_t obtained in the EDA. This may require subsequent heat treatment of the CuCrZr heat sink.
- Good collaborations exist to carry R&D forward.
- *Discussions at Sandia on March 9-11 with Ioki and Elio (ITER) and Dombrowski and Hollis (LANL) clarified the US interest and the ITER Home Team's concerns with plasma-sprayed Be armor.*
- *In June in Garching, Ulrickson/Nygren will participate in a six party discussion of requirements and fabrication issues for ITER FW modules.*