4. Plasma unstable by nature: large instabilities

✧ Up to 6% of total stored energy released in ms (>10MJ.m\(^{-2}\))

- Thermal cycling of the surface
  - Large number of events \((10^6)\)
Effect of transients

After 5 large ELMs (2MJ/m²)

- Increasing power density

- Incident beam
  - Cracking roughening
  - Homogeneous melting
  - Melt ejection
  - Boiling and droplet formation

Recommended damage threshold ~0.5 MJm⁻² now adopted by ITER (factor of 10 reduction!)

→ Will require ELM mitigation strategies to keep $E_{ELM} < 1$ MJ
Effect of transients

- Plastic deformation during heating due to thermal expansion
- Tensile stress in cooling phase
- Cracking at grain boundary and intergranular if thermal stress > yield stress

Experiments in QSPA allow evaluation of material damage under relevant heat flux densities.

Mass loss of 1.5g/m\(^{-2}\) for tungsten at 1.5MJ/m\(^{-2}\).
4. Interplays between quiescent and off-normal plasma effects
   ✦ Surface modified by high-flux plasma
   ✦ Temperature excursion and high transient heat/particle source

It can get worse... (1/2)
Synergistic effect

- Void formation due to high flux plasma
- Explosive release of material during transient

Plasma-enhanced surface ablation
Possibly a significant concert for divertor lifetime

It can get worse... (2/2)
Material mixing

Be ‘rain’ from FW erosion

D, T, He plasma
W, liner/dome

C strike points (start-up phase)
W (DT phase)

Hot surfaces $T \approx 600-1000$ K

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Multi-material wall and mixed-species plasma
High-temperature and plasma fluence

Possible chemical reactions might strongly modify the material properties e.g. power handling and $T$ retention


Energy Days, Tu/E, 31 May 31
Stable Be-W inter-metallics are:
- ~2200°C (Be2W)
- ~1500°C (Be12W)
- ~1300°C (Be22W)

Formation of such compounds experimentally observed for tungsten targets exposed to D₂/Be plasmas

PFM properties strongly modified in particular melting temperature!

Alloy formation reduces drastically the melting temperature

Limited database (no tokamak equivalent)

The interaction of a thermonuclear plasma with surrounding surfaces represents a daunting challenge because of the magnitude of the issues at stake.

Taming those issues is a must on the way to fusion energy.

Multi-scale problem requiring cross-discipline research.