Towards viable nuclear fusion reactors 2

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Towards viable nuclear fusion reactors

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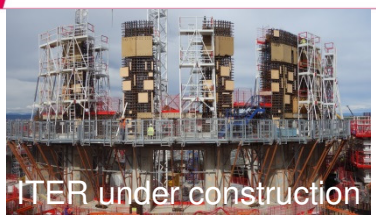
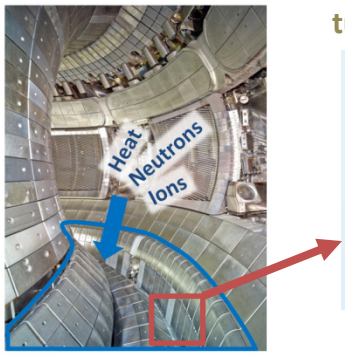


Research goal: Can the heat extractor (divertor) withstand the extreme loads in a future fusion reactor for a sufficient amount of time?



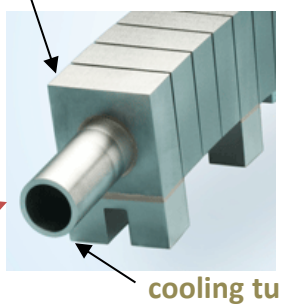


Figure 1: the divertor in the JET reactor (www.iter.org, left) consists of many tungsten monoblocks (on the right).

Help to realize nuclear fusion.

↓

Make the wall of the fusion reactor withstand the extreme loads.

↓

Understand the degradation processes in the divertor monoblocks.

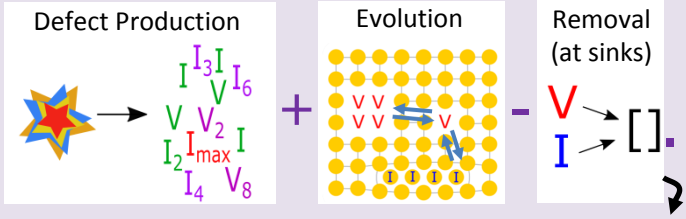
↓

Study the microstructural evolution of tungsten under the combined **heat** and **neutron** loads.

Research goal

Method 1 Grain level: neutron damage

$$\frac{dC}{dt} = \text{Defect Production} + \text{Evolution} - \text{Removal (at sinks)}$$

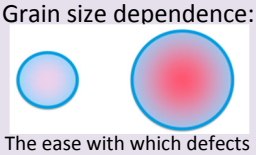


Method: **Cluster dynamics model** for the concentrations of vacancies (V), self-interstitial atoms (I) and dislocations.

Scale : $\text{Å} - \mu m$

Based on Li (2012), Stoller (1990), Yi (2015), Jourdan (2015)

Grain size dependence:



The ease with which defects find the grain boundary sink.

2 Polycrystal level: recrystallization

Mean-field model (Scale 1-100 μm)

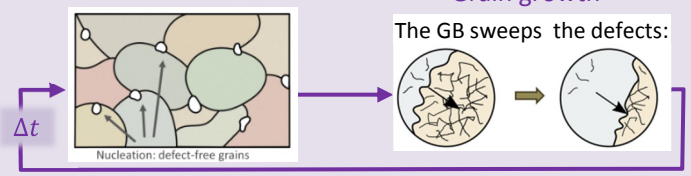
Microstructure: a set of representative grains.

- Radius r
- Defect densities ρ, C_I^m, C_V^n
- # of represented grains N

Each grain interacts with the average microstructure medium.

Nucleation

Grain growth



Nucleation depends on:

- GB (grain boundary) mobility
- Defect density: **stored energy**
- GB surface area

Grain growth is based on the velocity of the grain boundaries:

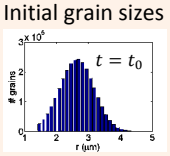
$$v = m(T)\Delta E_{average/grain}$$

GB mobility · Defect density

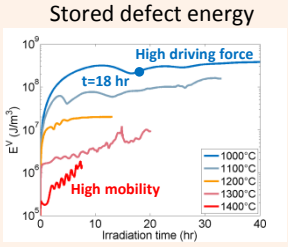
Based on Bernard (2011), Lopez (2015)

Results Microstructural evolution

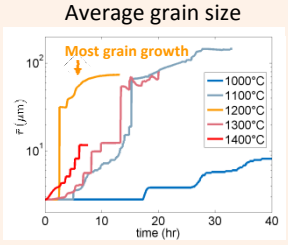
Initial grain sizes



Stored defect energy



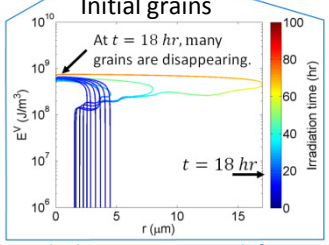
Average grain size



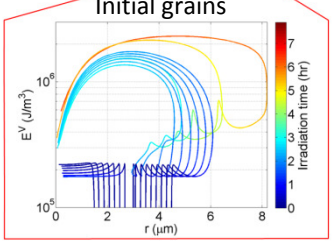
High driving force · Most grain growth · Most nucleation · High mobility

1000°C · 1100°C · 1200°C · 1300°C · 1400°C

Initial grains



Initial grains



The largest grains vanish first (most damage accumulation).

The smallest grains vanish first (the GB surface energy dominates).

Damage accumulation vs. recovery

- Defect accumulation / GB mobility / point defect mobility / nucleation rate / individual grain behavior can all be studied with this model.
- Pace of renewal of the microstructure.

Conclusions/Outlook

- The multi-scale model for the microstructural evolution of tungsten under heat and neutrons shows to be a versatile tool to study the temperature dependent stability of the original microstructure and the competition between the various processes for damage and recovery.
- In future, lifetime of the divertor monoblocks will be studied by combining the (stress-dependent) microstructural model with a mechanical FE analysis.