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FÜR PLASMAPHYSIK

Deuterium retention in self-ion irradiated tungsten: influence of irradiation temperature, damage dose, and alloying elements

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EUROfusion

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Motivation: Evolution of D retention in W with damage dose
displacement-damaging at room temperature

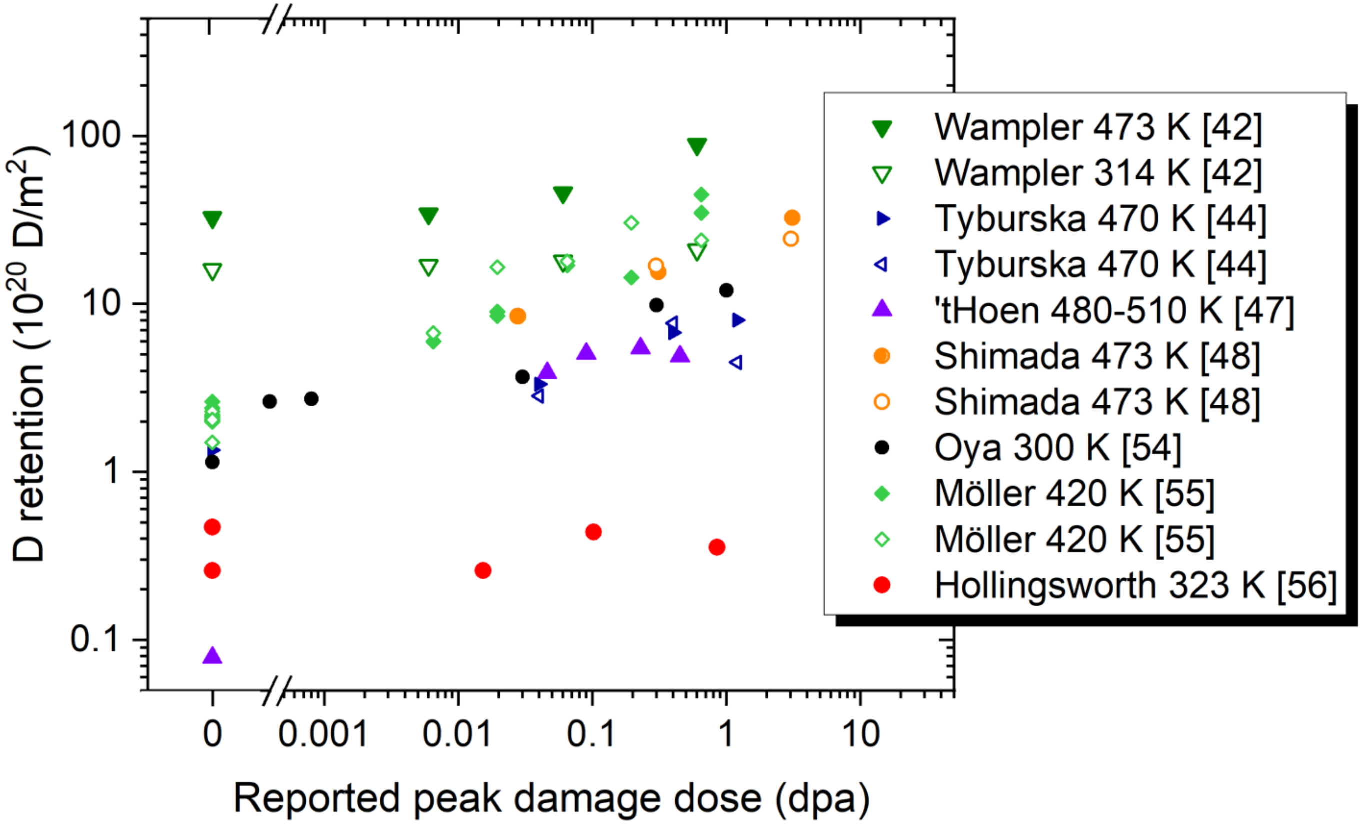
MeV ion irradiation to simulate displacement damage produced by fusion neutrons

– D retention scatters

– Typically very limited dpa range

⇒ Total retention values of little use (TDS)

⇒ Possible defect creation during D loading



T. Schwarz-Selinger, Mater. Res. Express 10, 102002 (2023).

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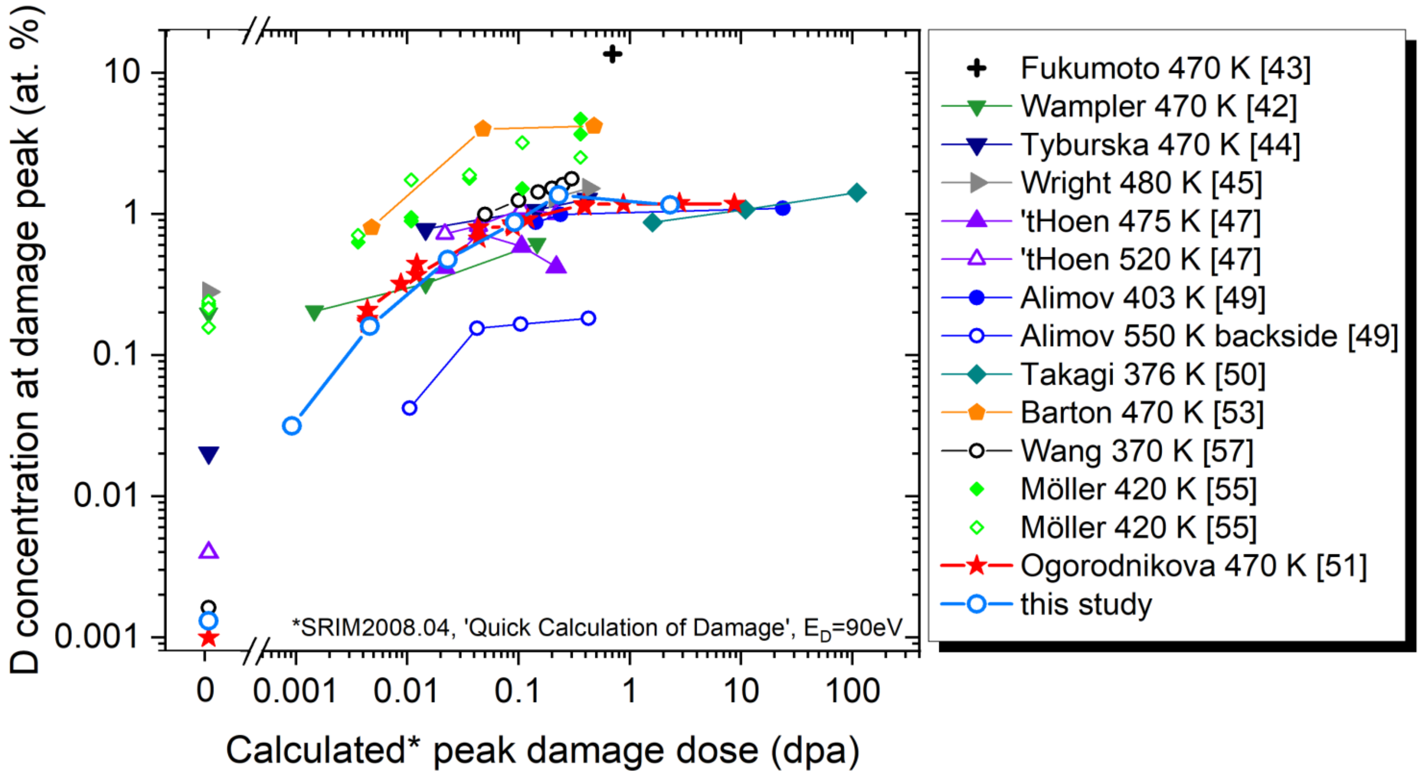
⇒ Absolute D concentrations necessary (GD-OES, NRA)



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Experimental methodology

1. ‘Defect-free’ samples

2000 K annealed W (10-50 μm grain size)

Polycryst. W

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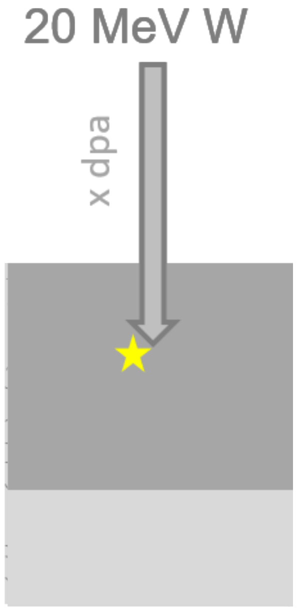
2. Creating displacement damage



20 MeV W ion irradiation

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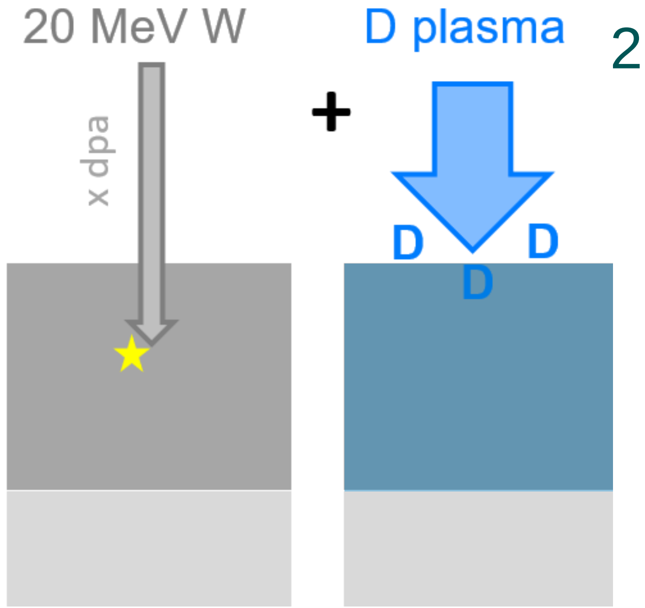

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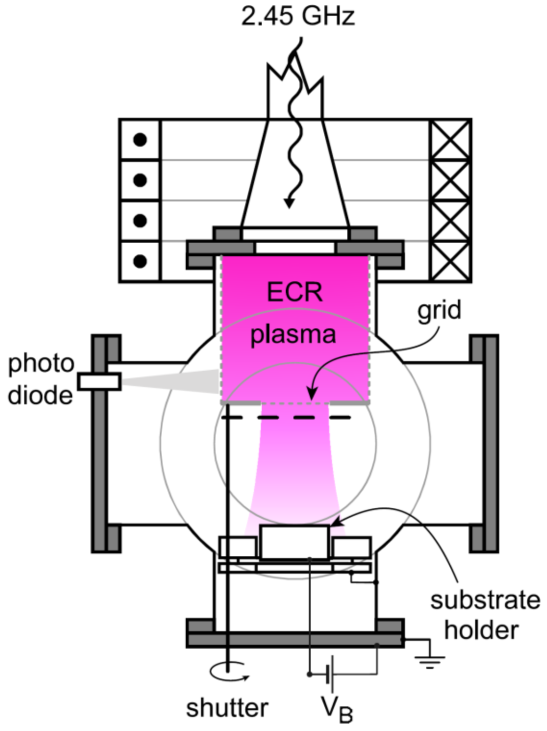

3. Decorating damage with deuterium

< 5 eV/D, < 10^{20} D/m^{2}s, 370 K, > 10^{25} D/m^2

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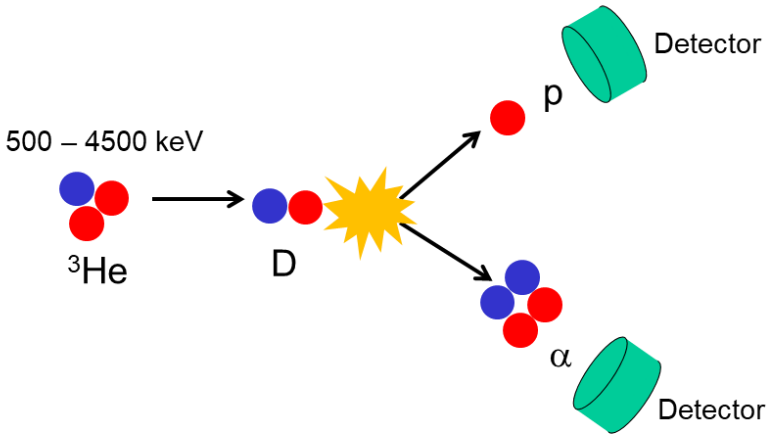

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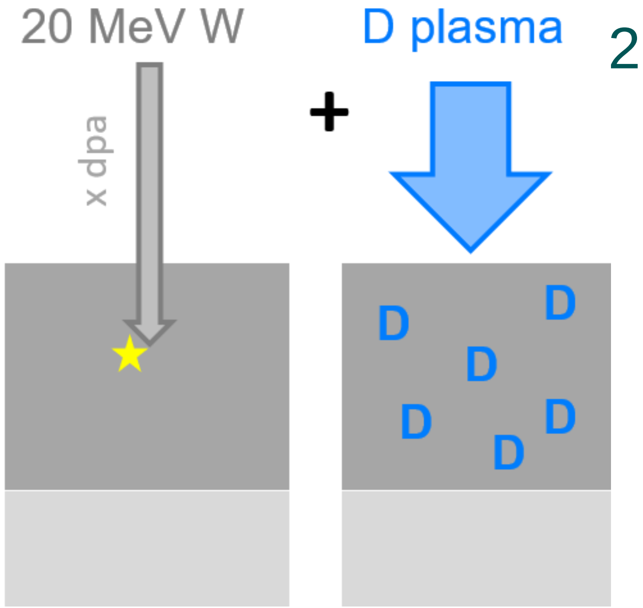

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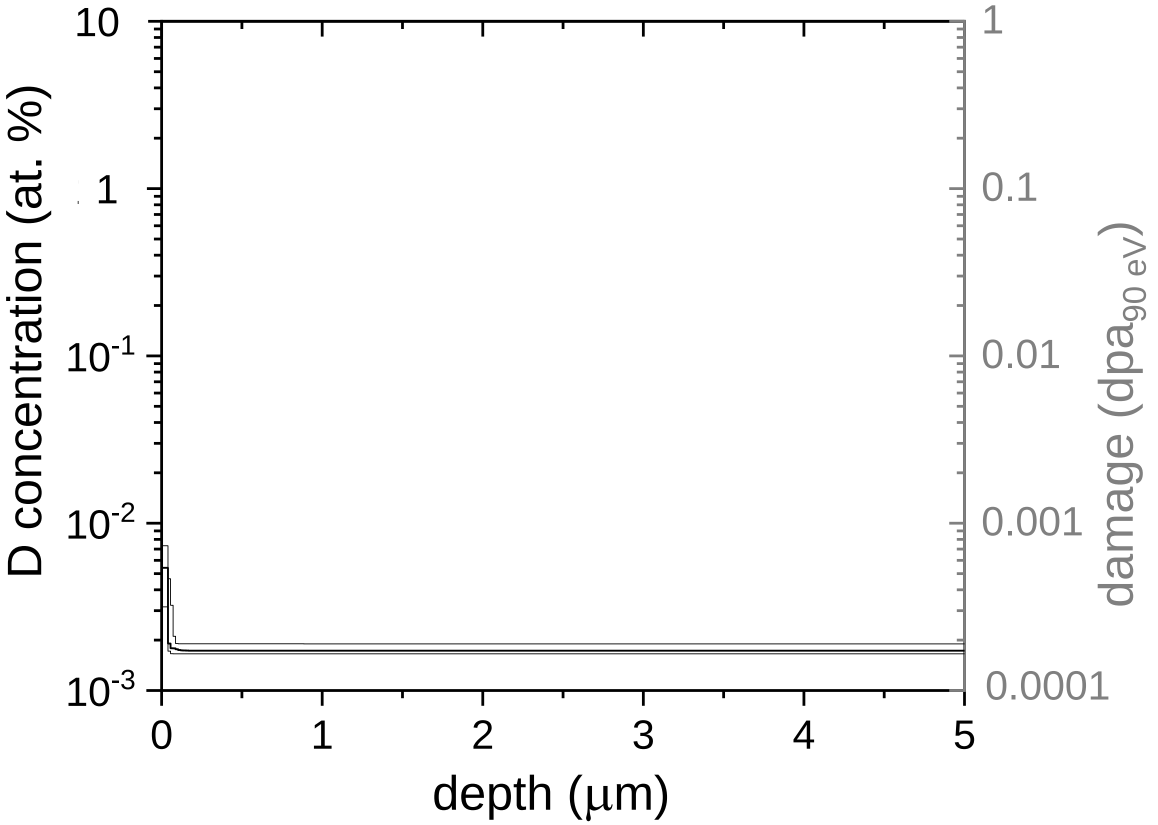
4. Quantitative analyses

D(^{3}He,p)α NRA depth profiling / TDS

Evolution of D retention in W with damage dose
displacement-damaging at room temperature

370 K gentle plasma exposure of recrystallized W for 72 h / 1.5×10^{25} D/m^2

- ⇨ Plasma exposure does not create defects
- ⇨ But only decorates the existing defects



T. Schwarz-Selinger et al., unpublished

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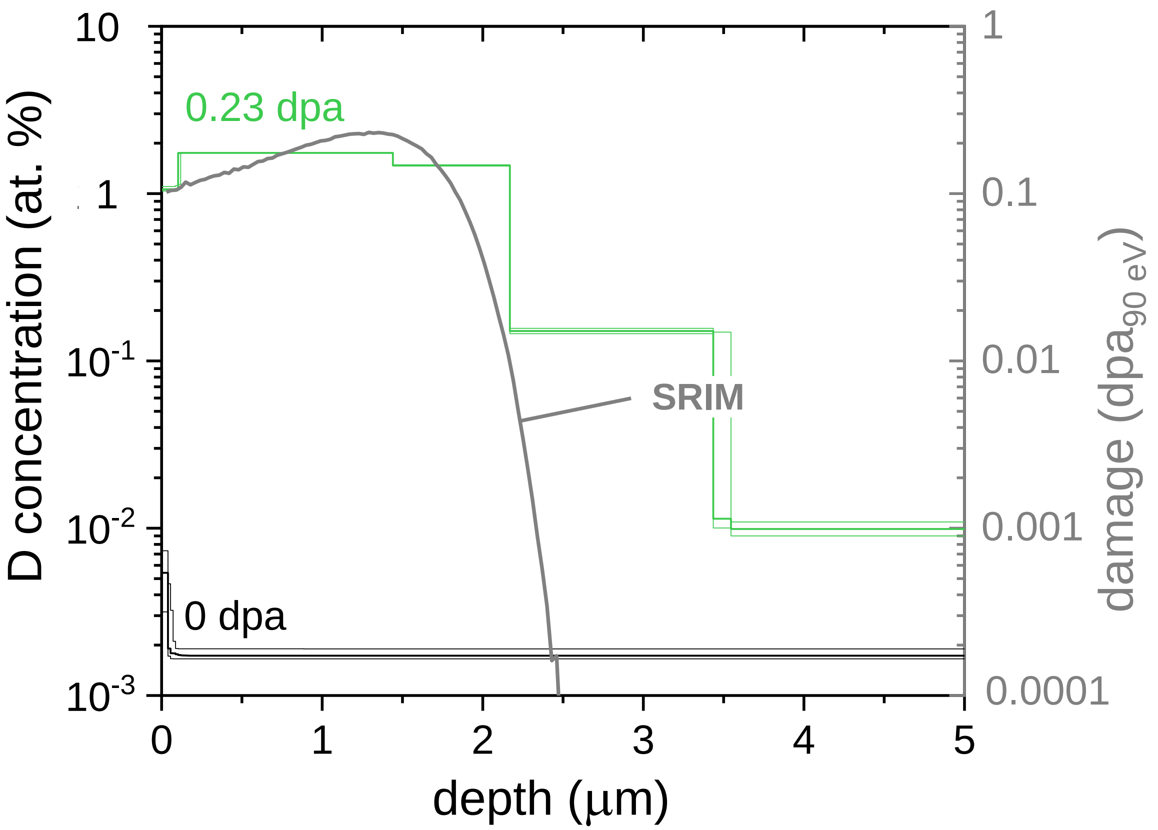
Same plasma exposure of 20 MeV W-irradiated W (0.23 dpa)

+ D retention increases by three orders of magnitude

+ D depth coincides with damage depth



T. Schwarz-Selinger et al., unpublished

⇨ **Methodology valid to study evolution of defect densities**

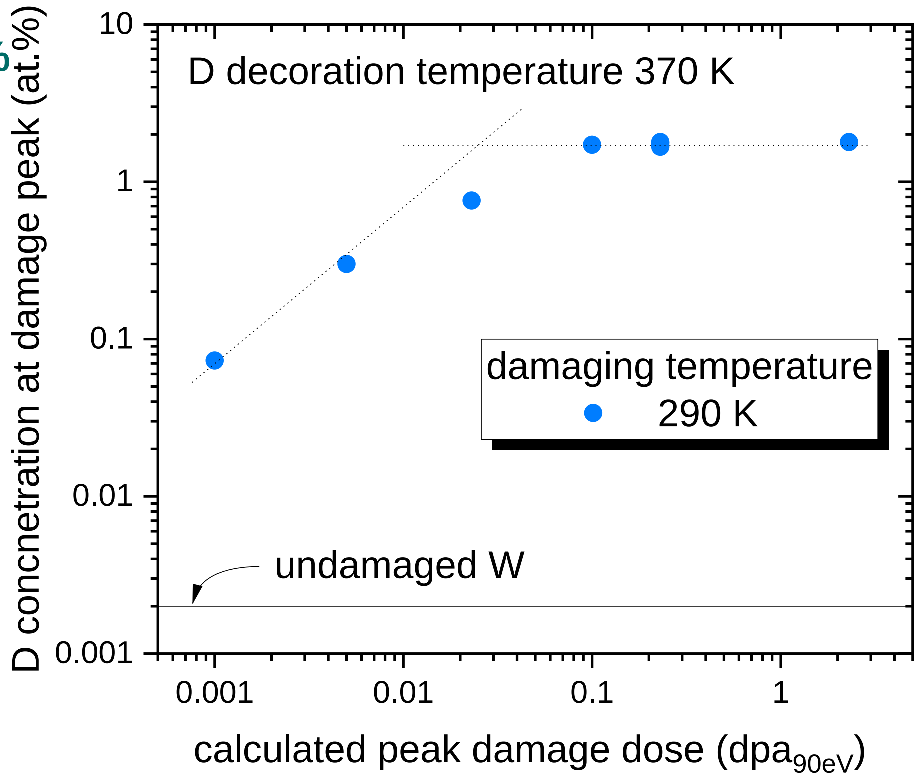
Evolution of D retention in W with damage dose

displacement-damaging at room temperature

Experimental observations:

- $D_{max} \propto$ dpa in the milli-dpa range
- Starts to deviate around 10 milli-dpa
- Reaches saturation value above 0.1 dpa
- D_{max} = 1.7 at.% for damaging at 290 K,
  i.e. 3 orders of magnitude above pristine W

< 2 at.%



T. Schwarz-Selinger et al., unpublished

Comparison with modelling
displacement-damaging at room temperature

D.R. Mason et al., Phys. Rev. Mater. 5 (2021) 095403:

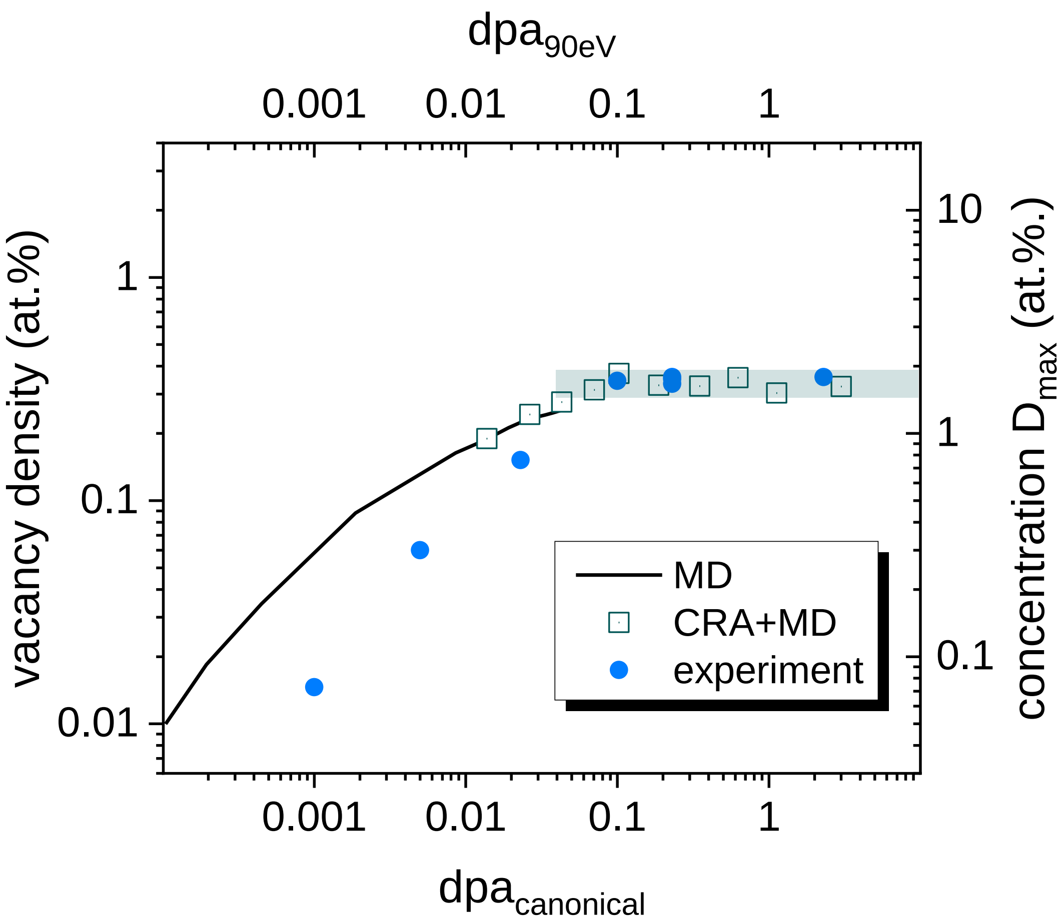
- Parameter-free modelling
- Assuming five D atoms per vacancy gives:
  D_{max} = 1.5 – 2.0 at.%

Perfect match with present experiments in terms of:

- Saturation behavior
- Absolute concentration D_{max}

But: Damaging at room temperature

What about DEMO-relevant temperatures?



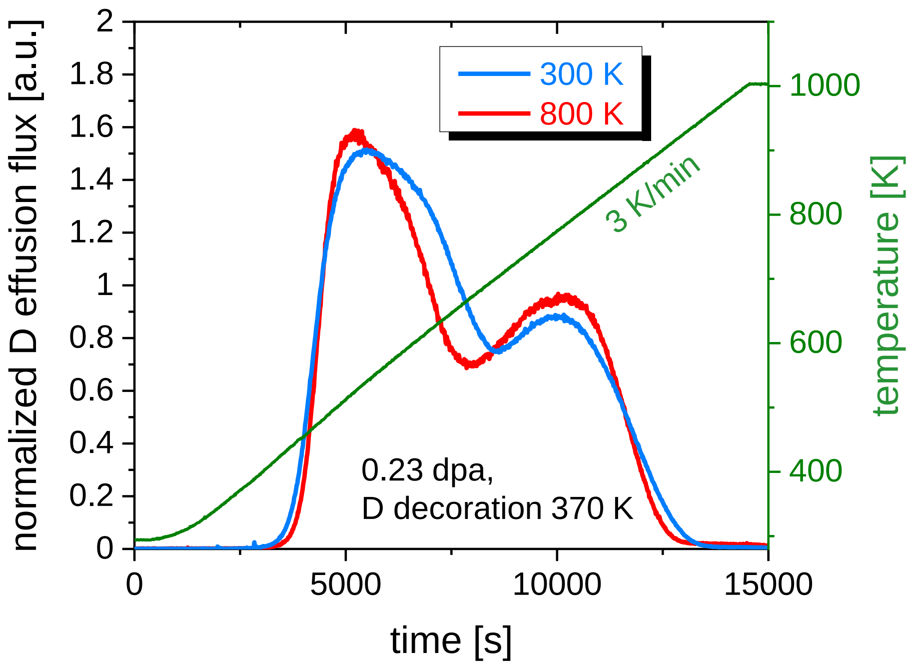
MD: Molecular Dynamics

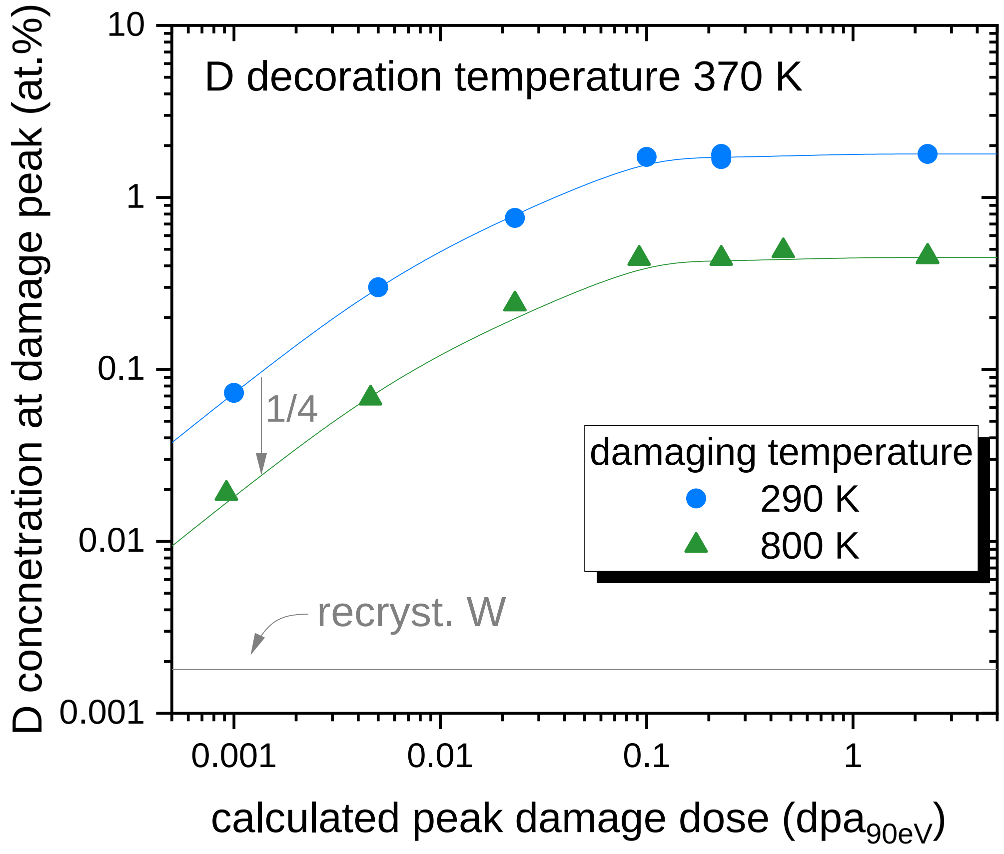
CRA: Creation Relaxation Algorithm

Evolution of D retention in W with damage dose
displacement-damaging at elevated temperature

800 K:

- Similar dependence on dpa as for 290 K
- D_{max} is 4 times smaller compared with 290 K
- TDS spectra shape similar as for 290 K





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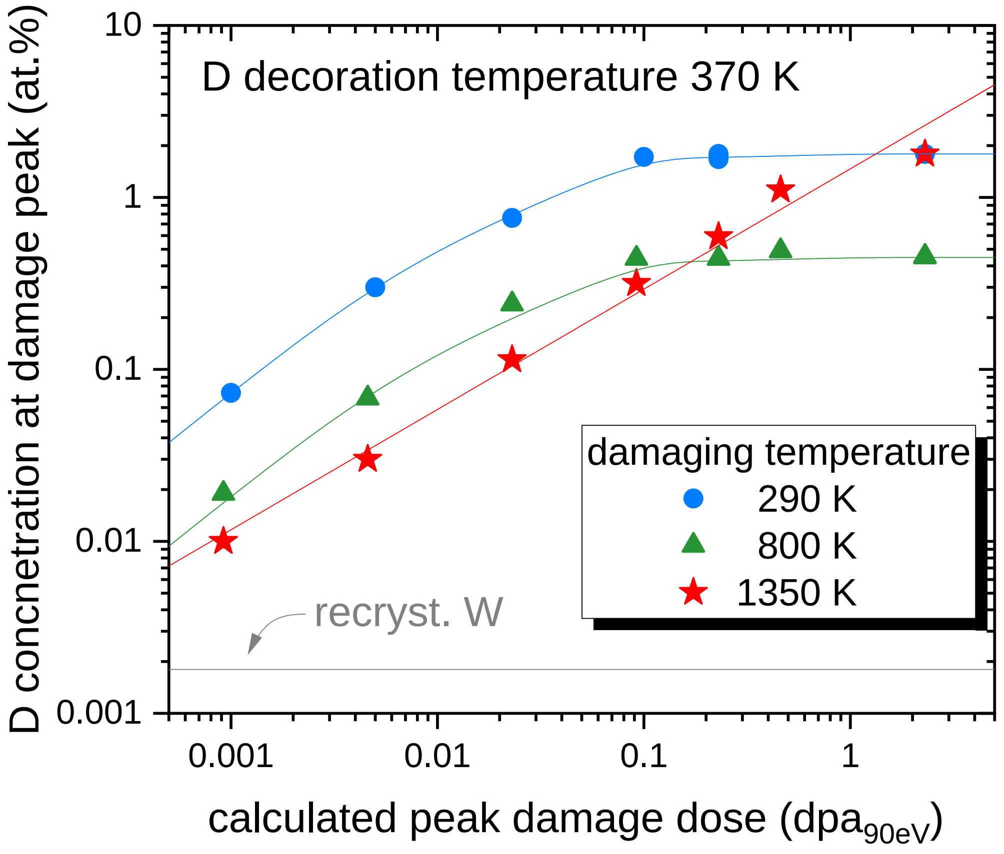
- D_{max} = 1.8 at.% at 2.3 dpa!



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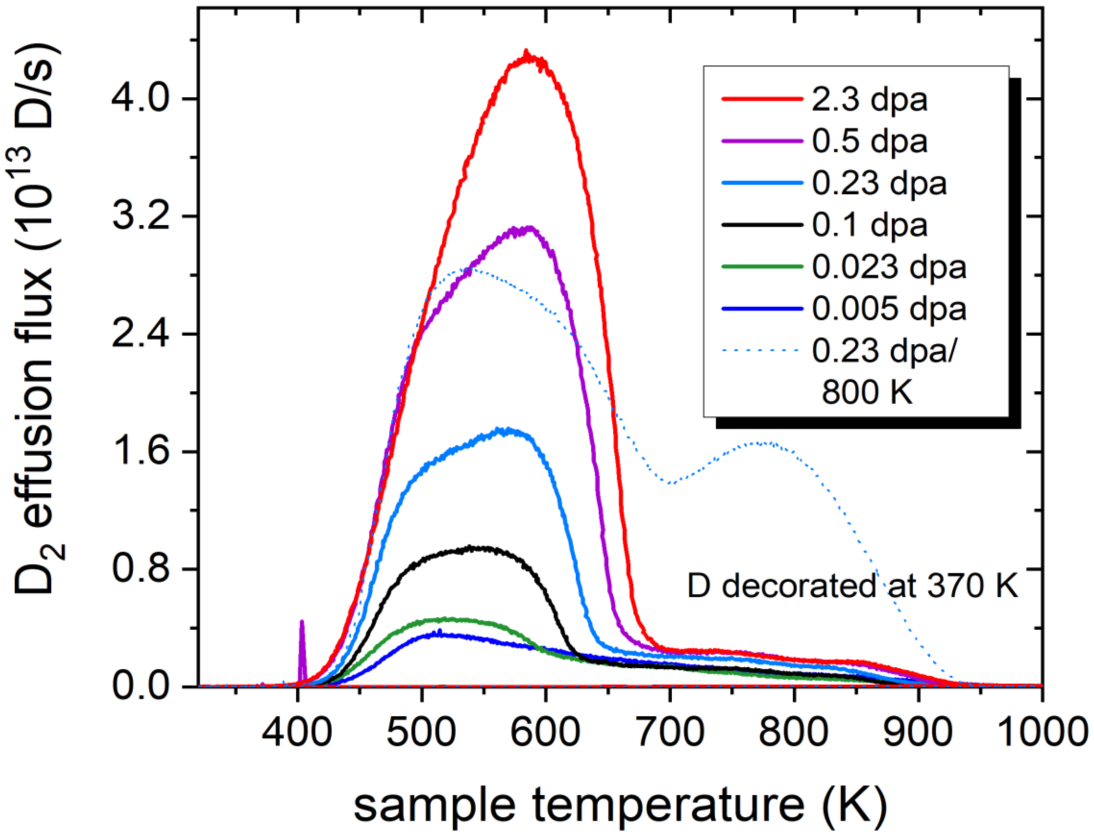
- Different TDS spectra compared with 290 and 800 K
- **Change of defect type?**



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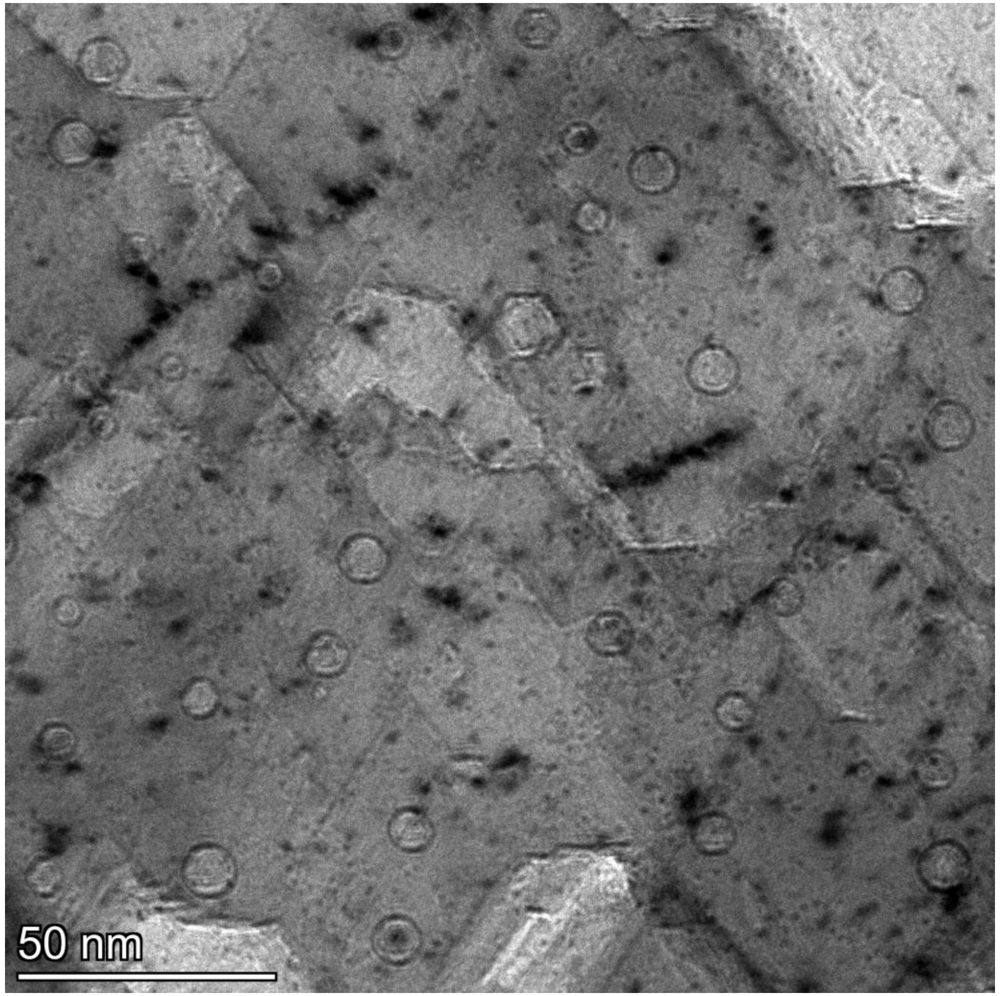
- **Nanometer-sized voids are visible in TEM**

2.3 dpa at 1350 K

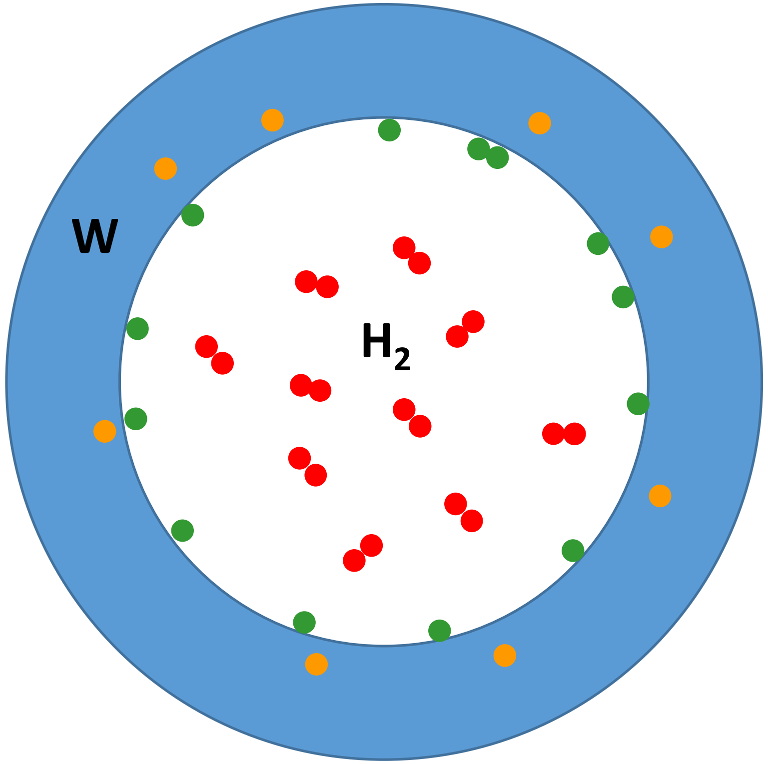


T. Schwarz-Selinger et al., unpublished

Hydrogen trapping and release from cavities

- Cavities can retain H atoms at the surface and H_2 molecules in the volume
- Different physics compared with ‘conventional’ traps (vacancies,…)
- Recently developed reaction-diffusion model to describe these phenomena

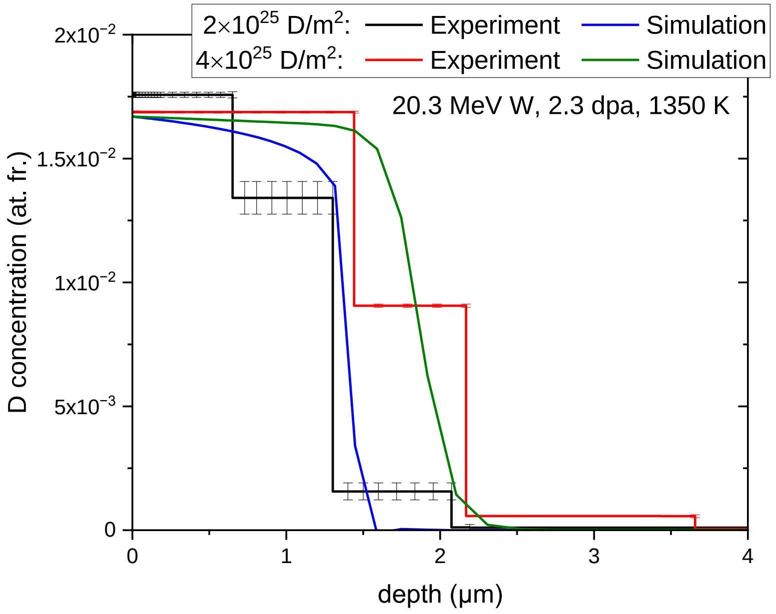
M. Zibrov, K. Schmid, Nucl. Mater.Energy 30 (2022) 101121
M. Zibrov, K. Schmid, Nucl. Mater.Energy 32 (2022) 101219



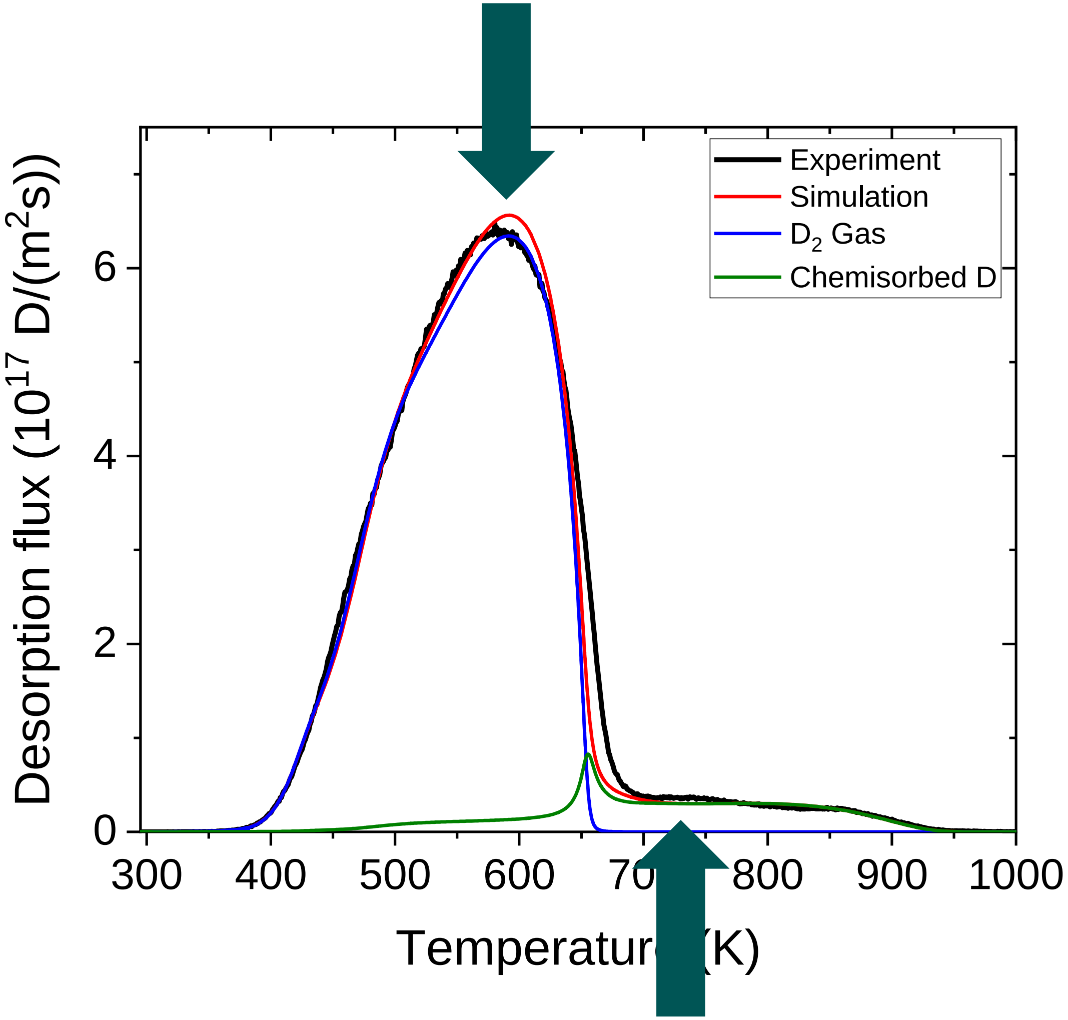
States of H:
1. H_2 gas in cavity volume
2. H atoms adsorbed at cavity surface
3. H atoms in interstitial sites in W

Simulation results
Model by Zibrov and Schmid

- Can quantitatively describe the experiment
- Reduced solubility of 0.93 eV (Frauenfelder 1.04 eV)
- Very sensitive to bubble size and solute D conc.



D₂ from the cavities

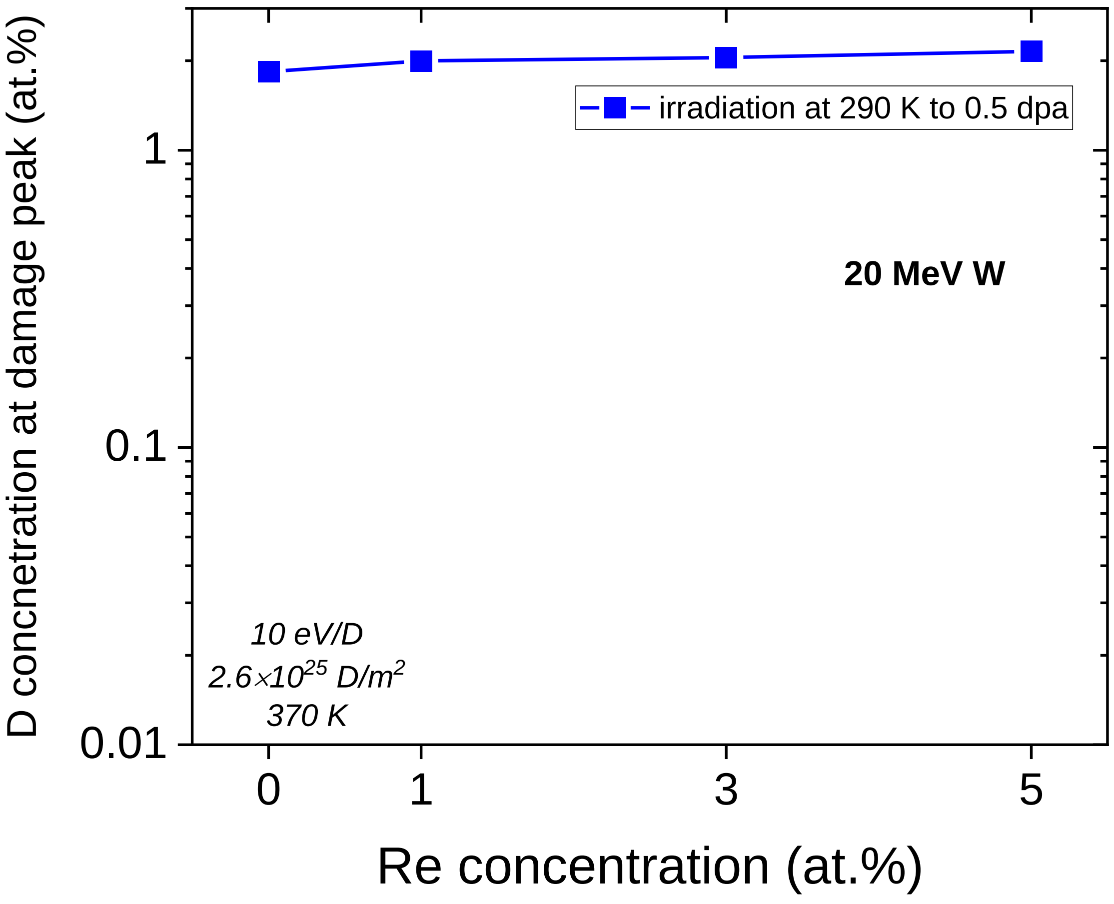


D from cavity surfaces

- More independent measurements necessary (diff. solute, …)

Influence of Re on displacement damage in W

- 3.8% Re produced in W after 5 fpy in DEMO
- Synergies between displacement damage and Re production?
- Study W-Re alloys (1–5% Re)
- **290 K**: Little Re effect



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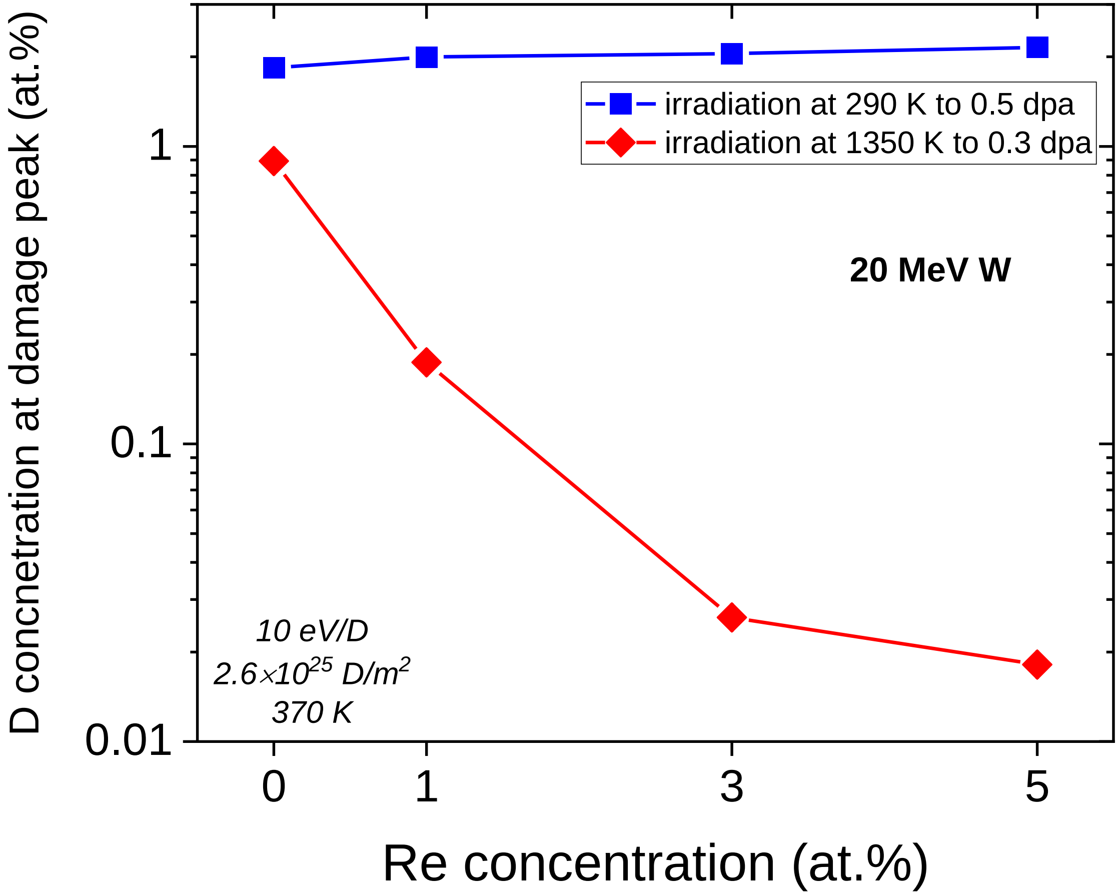

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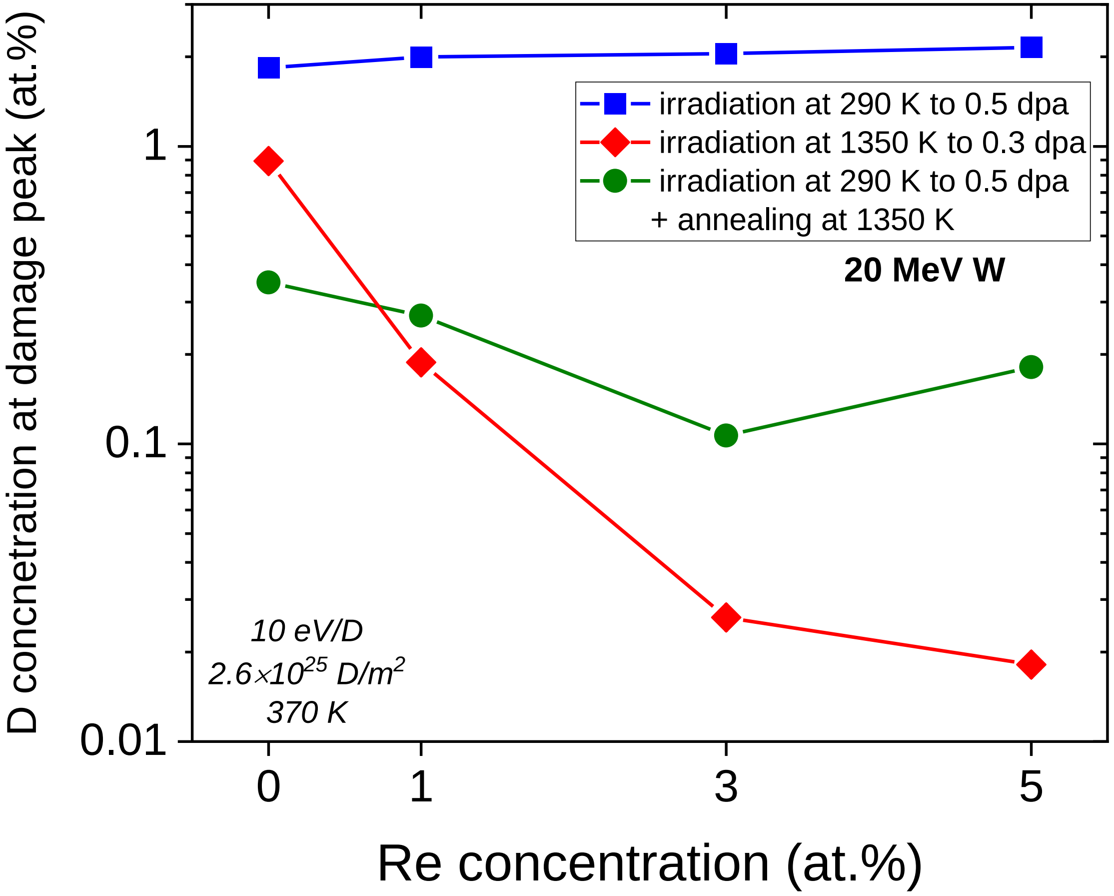
- **290 K**: Little Re effect
- **1350 K**: Strong reduction of D concentration with increasing Re concentration
- **290 K + 1350 K annealing**: Milder reduction of D concentration with increasing Re conc.

$\Rightarrow$ **Irradiation at elevated T is not the same as post-irradiation annealing!**



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Summary

- D concentration
  - saturates for 290 K and 800 K irradiation above 0.1 dpa
  - shows no saturation yet up to 2 dpa for 1350 K irradiation
- Thermal desorption spectra
  - resemble each others for room temperature and 800 K irradiation
  - lack the high temperature peak for the 1350 K irradiation
  - D_2 gas in voids?
- Influence of Re
  - small effect for 290 K irradiation
  - strong reduction of D concentration with increasing Re concentration for irradiation at 1350 K