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FÜR PLASMAPHYSIK

Deuterium retention in displacement-damaged tungsten-rhenium alloys: influence of rhenium concentration and irradiation temperature

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EUROfusion

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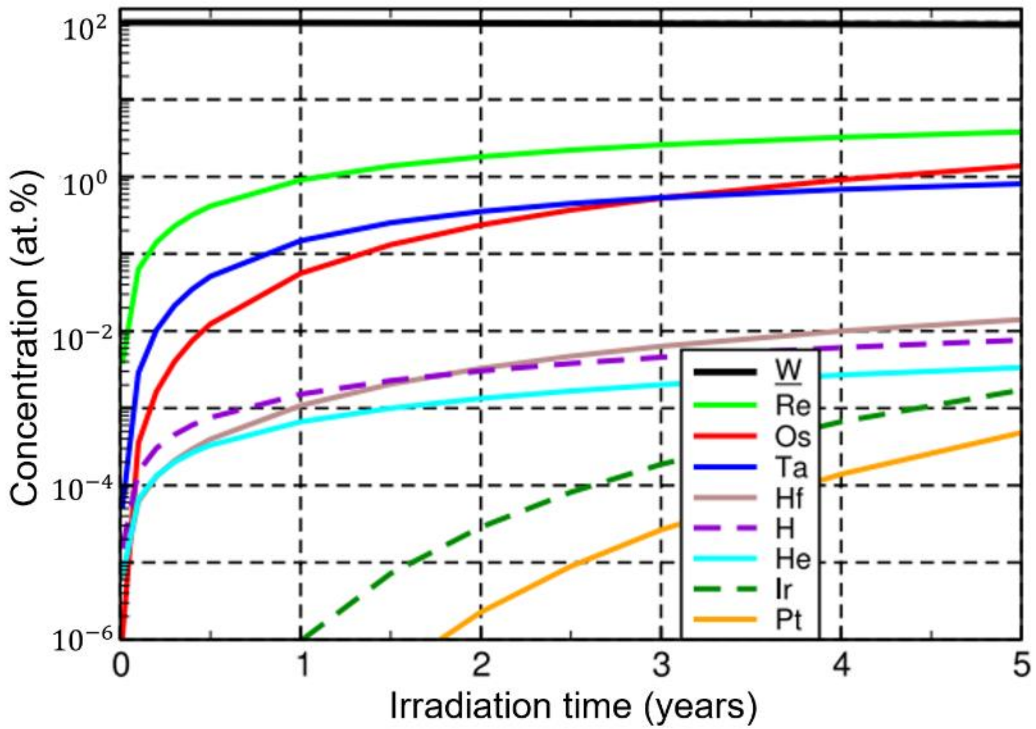
Motivation: Tungsten as a plasma-facing material

14 MeV fusion neutron irradiation effects:

- Creation of **displacement damage**
- Production of H and He
- **Transmutation** of W into Re, Os, Ta…

  $\Rightarrow$ Mainly **Rhenium (Re): 3.8 at.%** after 5 years of DEMO operation

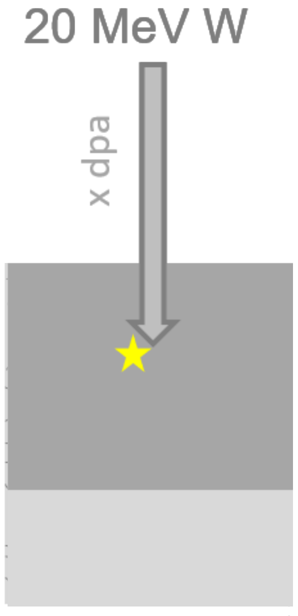


M.R. Gilbert and J-Ch. Sublet. *Nuclear Fusion*, 51(4):043005, 2011

MeV self-ion irradiation
to simulate displacement damage produced by fusion neutrons

1. Creating displacement damage

20 MeV W-ion irradiation to different damage doses (dpa)



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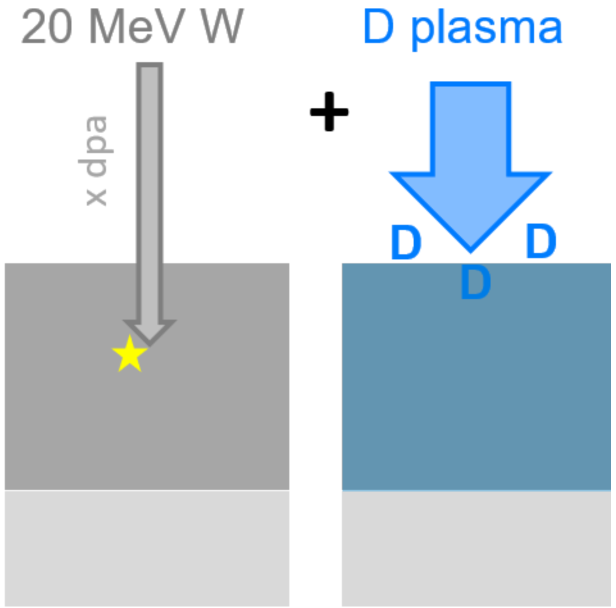

2. Decorating damage with deuterium

T_{sample} = 370 K, E_{ion} < 5 eV/D,
$\Gamma_{ion} < 10^{20}$ D/(m^{2}s), $\Phi_{ion} > 10^{25}$ D/m^2

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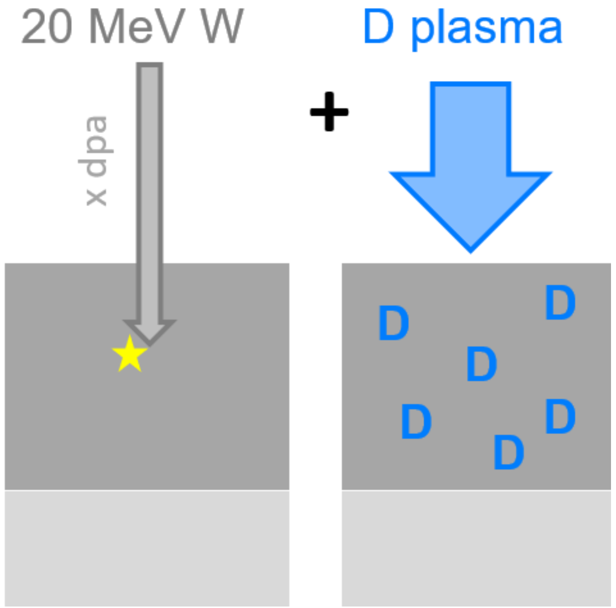

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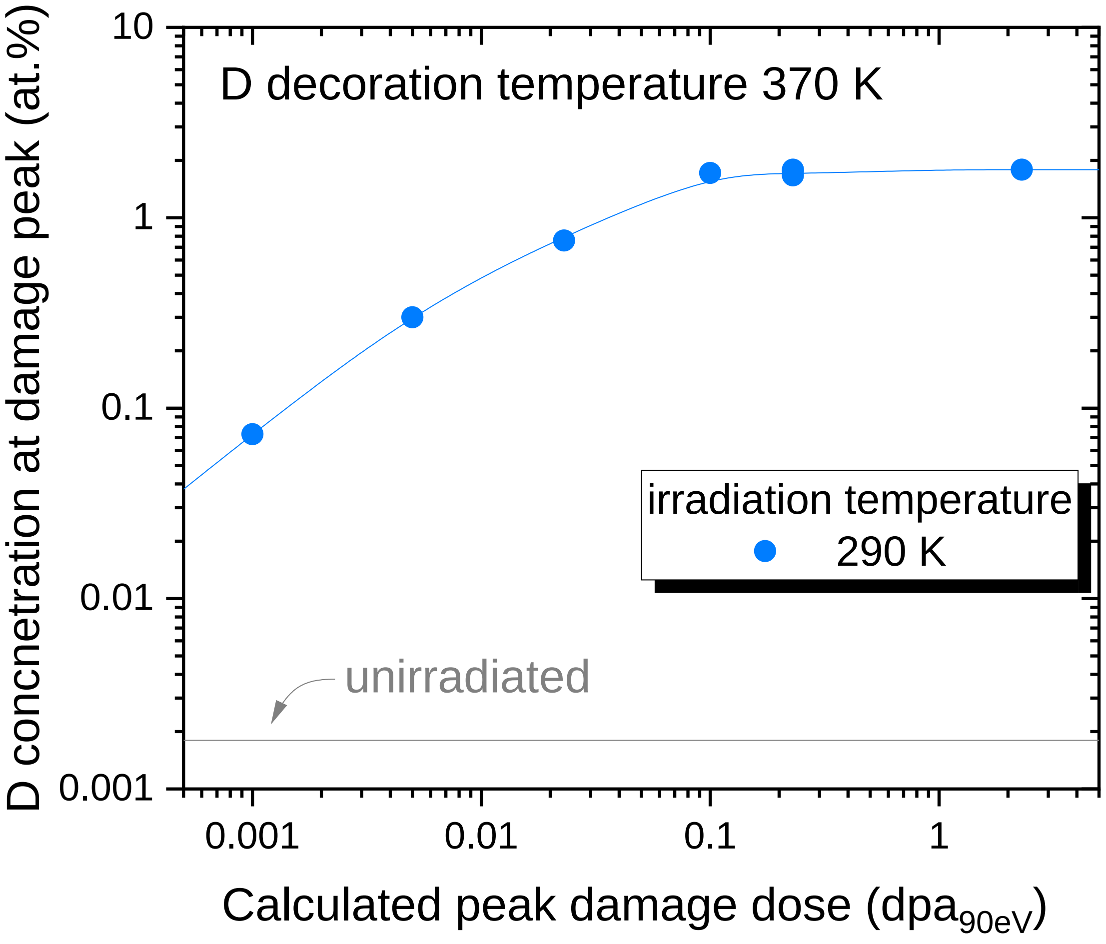
3. Quantitative analyses

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

Trapped D concentration in recrystallized W vs. damage dose
irradiation temperature dependence

290 K:

- $D_{max} \propto$ dpa in the milli-dpa range
- Reaches saturation value above 0.1 dpa



T. Schwarz-Selinger et al., unpublished

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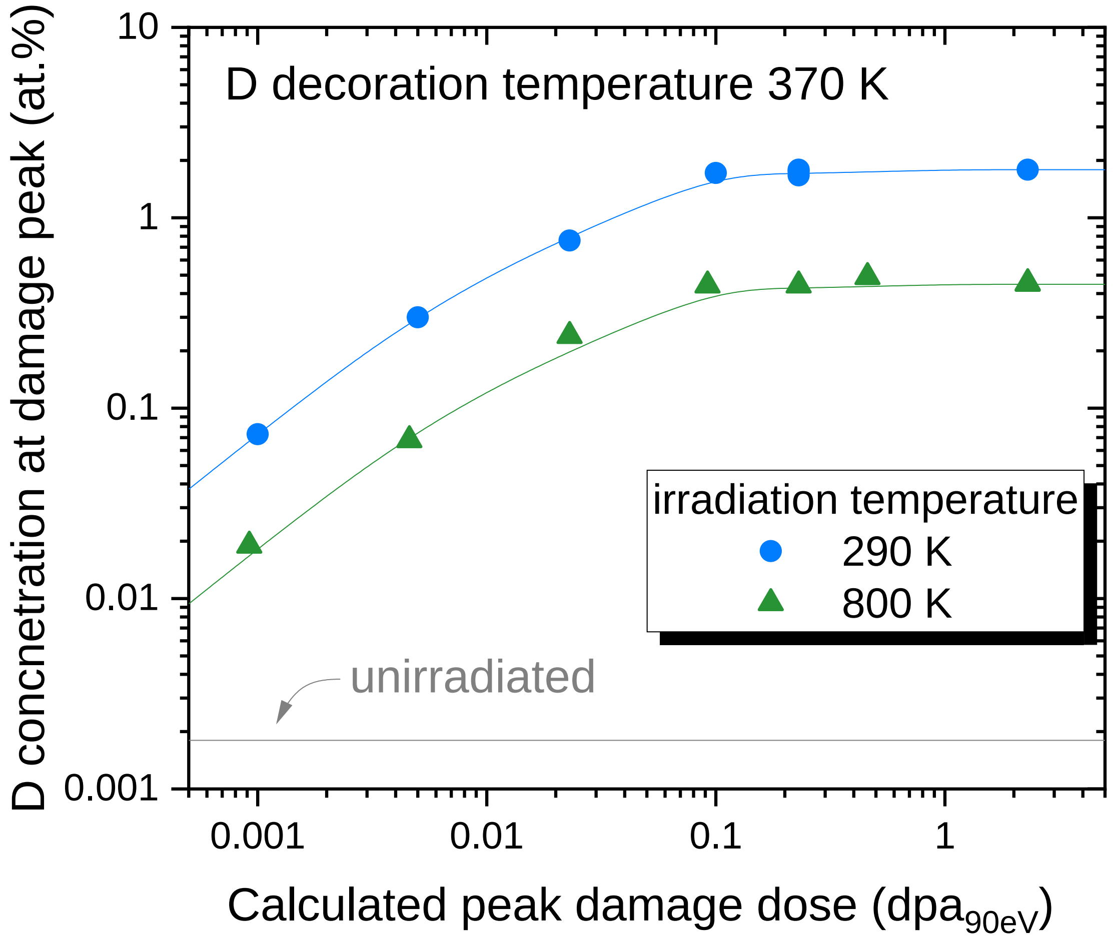
800 K:

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



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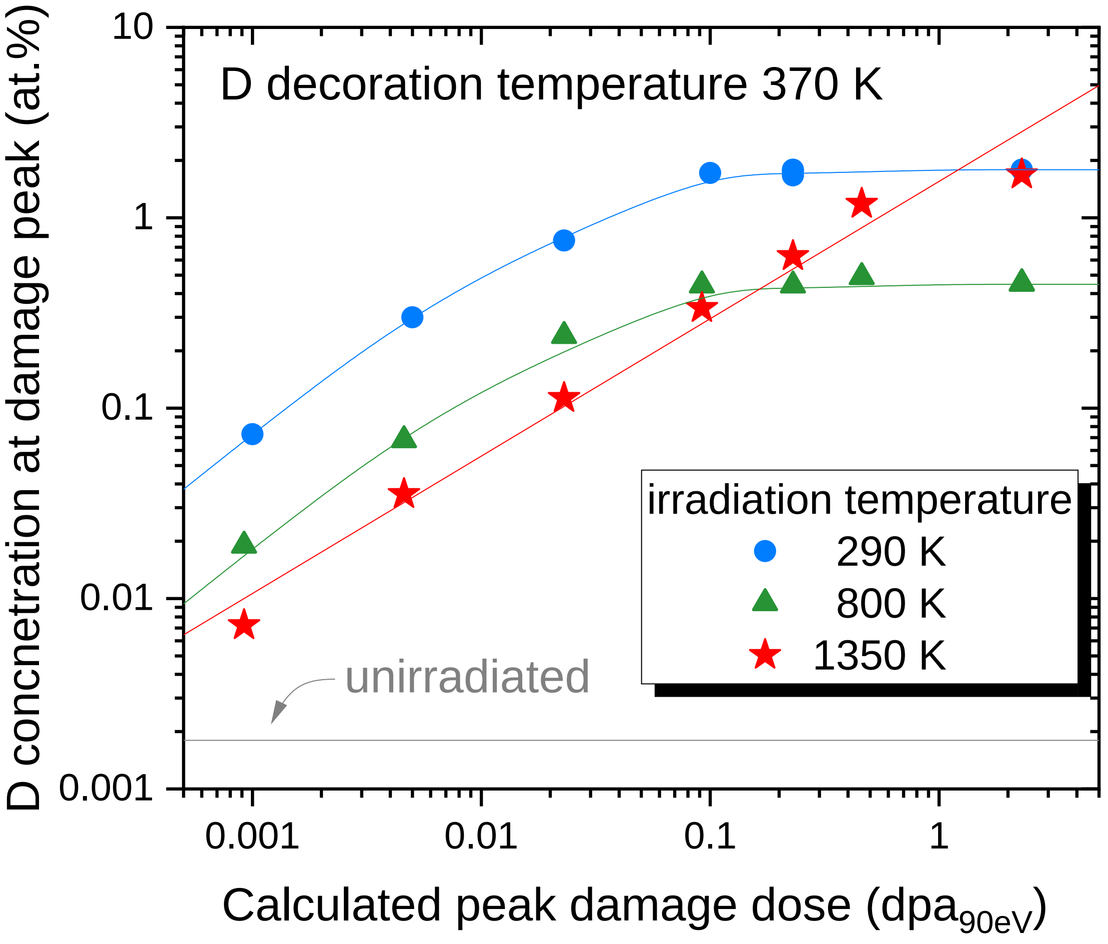
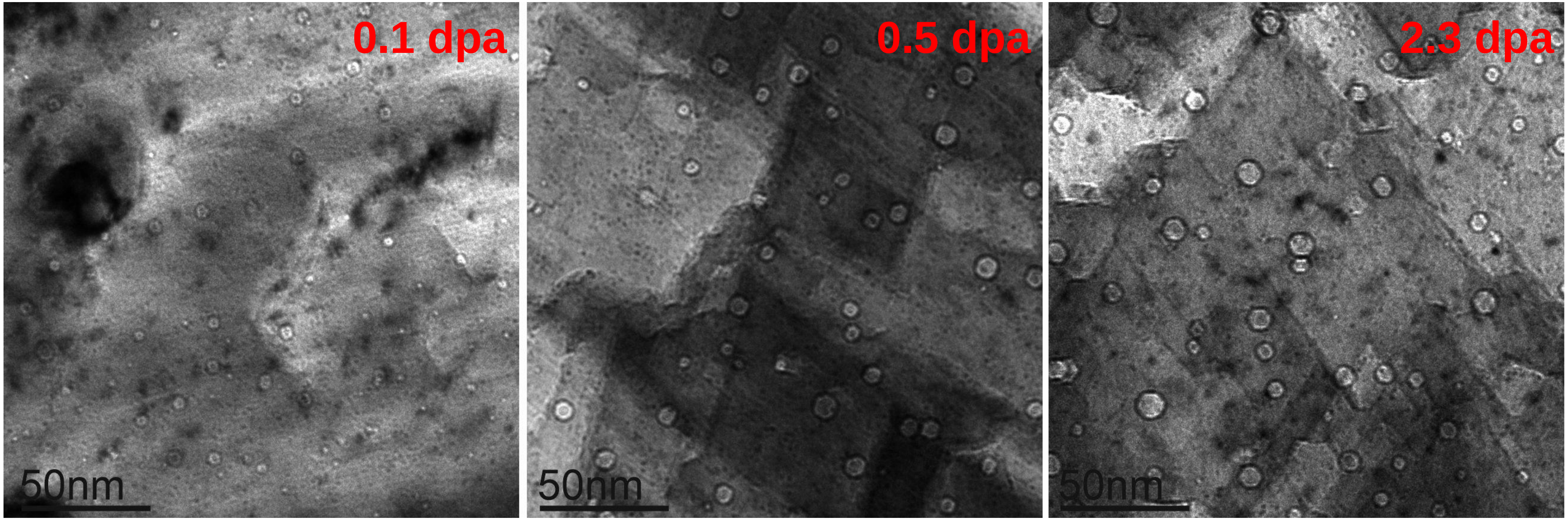
1350 K:

- No saturation yet up to 2.3 dpa



T. Schwarz-Selinger et al., unpublished

Microstructure of recrystallized W irradiated at 1350 K

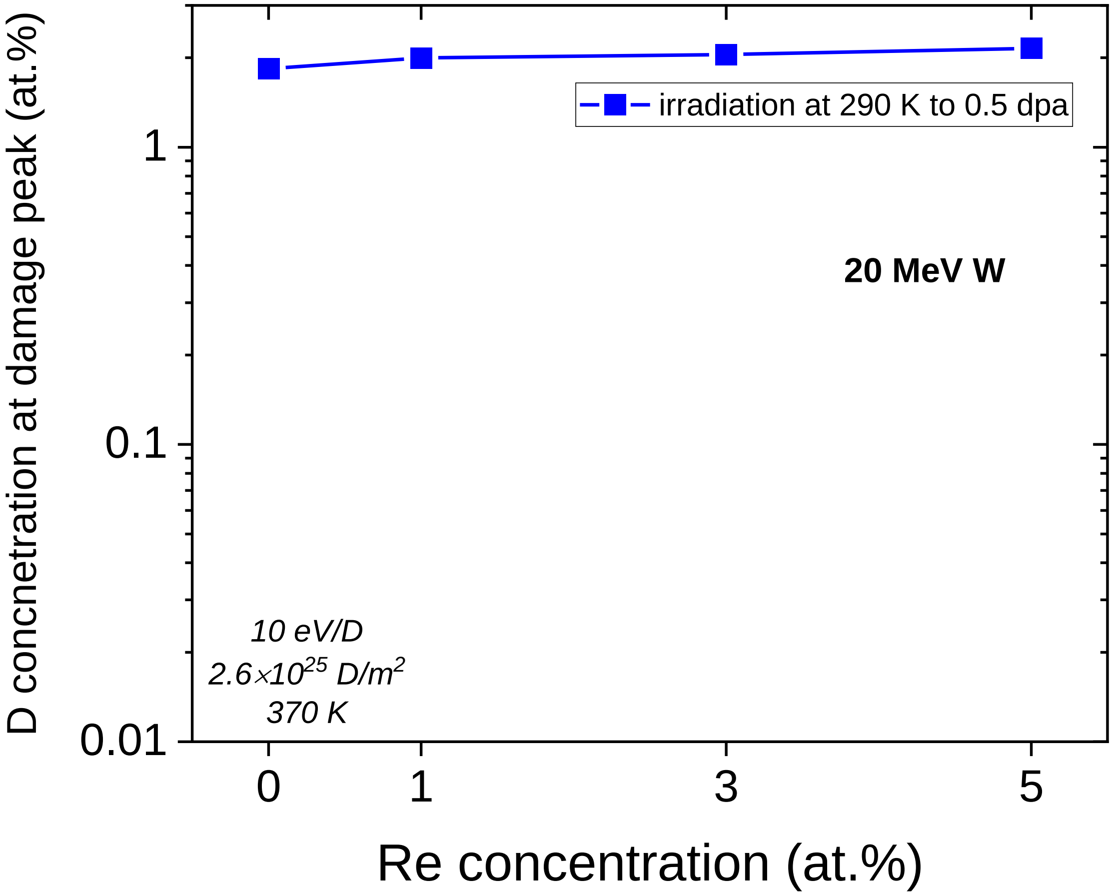


- Nanometer-sized voids are visible in TEM
- Void swelling increases with increasing dpa
- No voids in samples irradiated at 290 K and 800 K

M. Klimenkov, KIT

Influence of Re on displacement damage in W

- Study W-Re alloys (1, 3, 5 at.% Re)
- **290 K**: presence of Re slightly increases trapped D concentration (up to 17%)



M. Zibrov et al., Nucl. Mater. Energy 41 (2024) 101730.

Influence of Re on displacement damage in W

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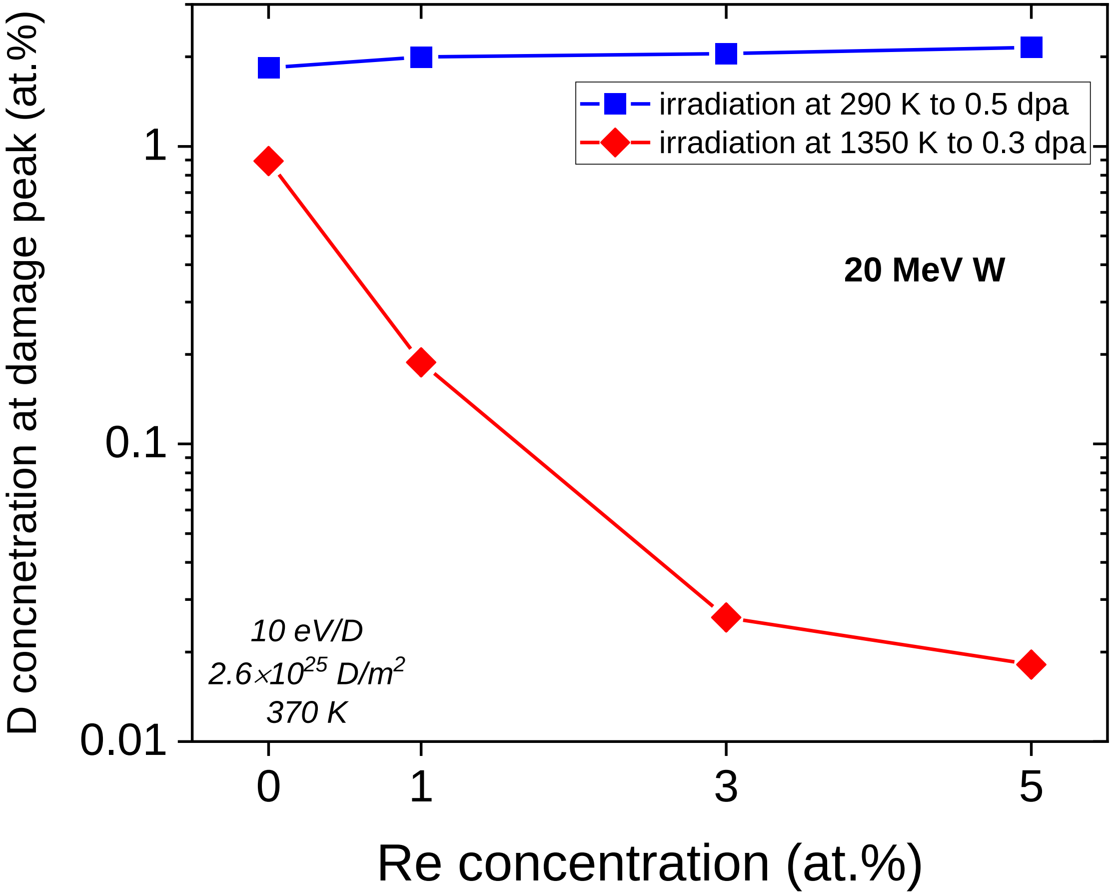

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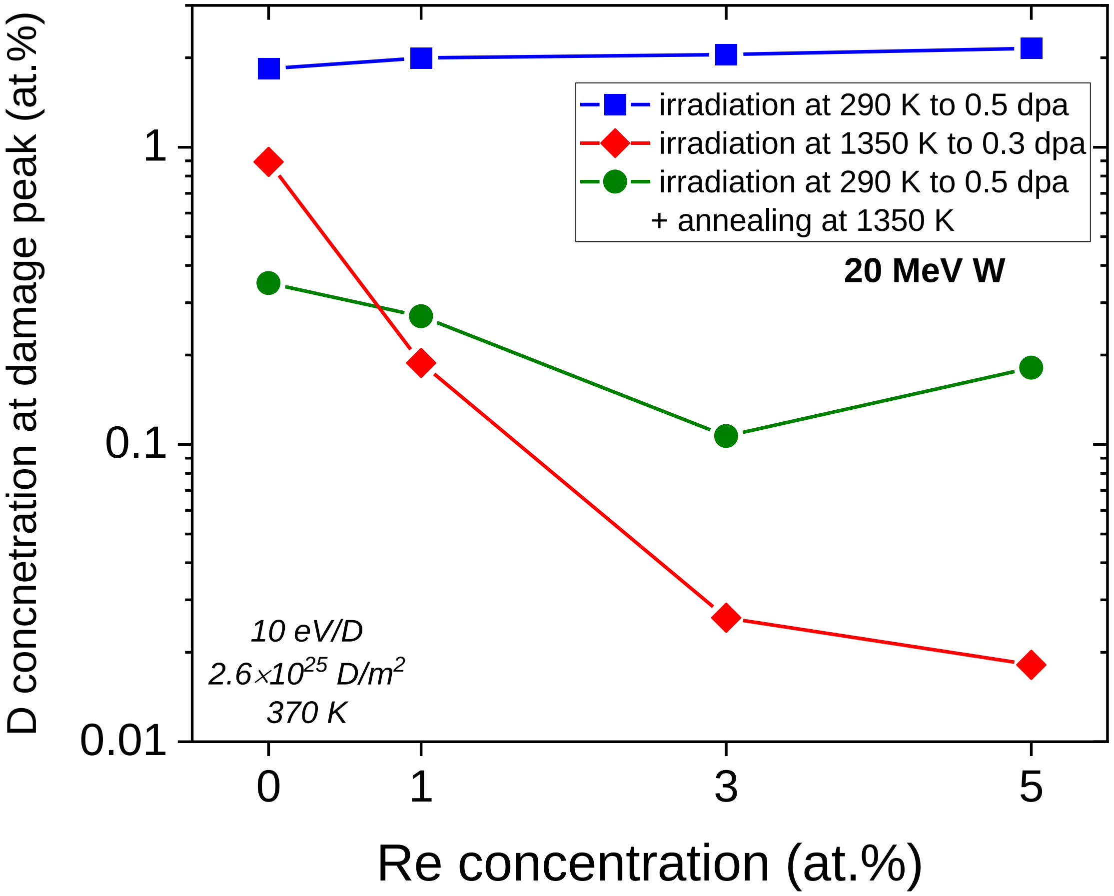
Influence of Re on displacement damage in W

- Study W-Re alloys (1, 3, 5 at.% Re)
- **290 K**: presence of Re slightly increases trapped D concentration (up to 17%)
- **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.

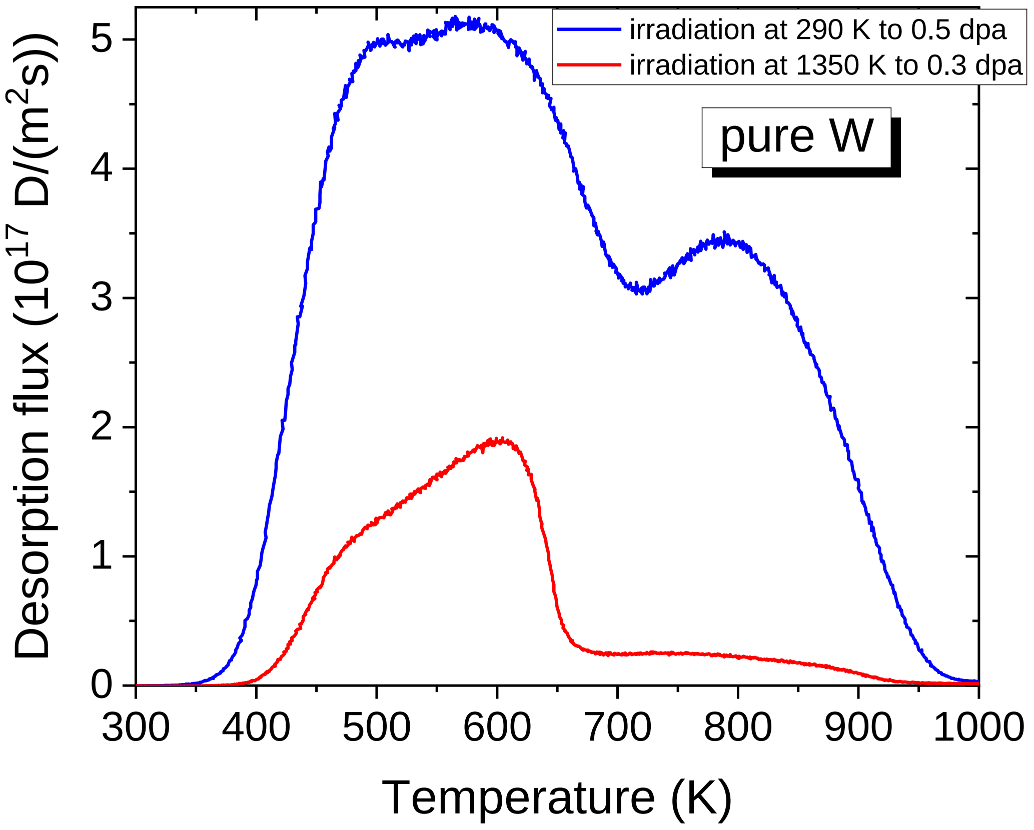
  ⇒ **Synergistic effects under high T irradiation**



M. Zibrov et al., Nucl. Mater. Energy 41 (2024) 101730.

Influence of Re on displacement damage in W

- Different TDS spectra from the samples irradiated at 290 K and 1350 K
  ⇒ change of D trapping mechanism
  ⇒ due to D trapping in voids?



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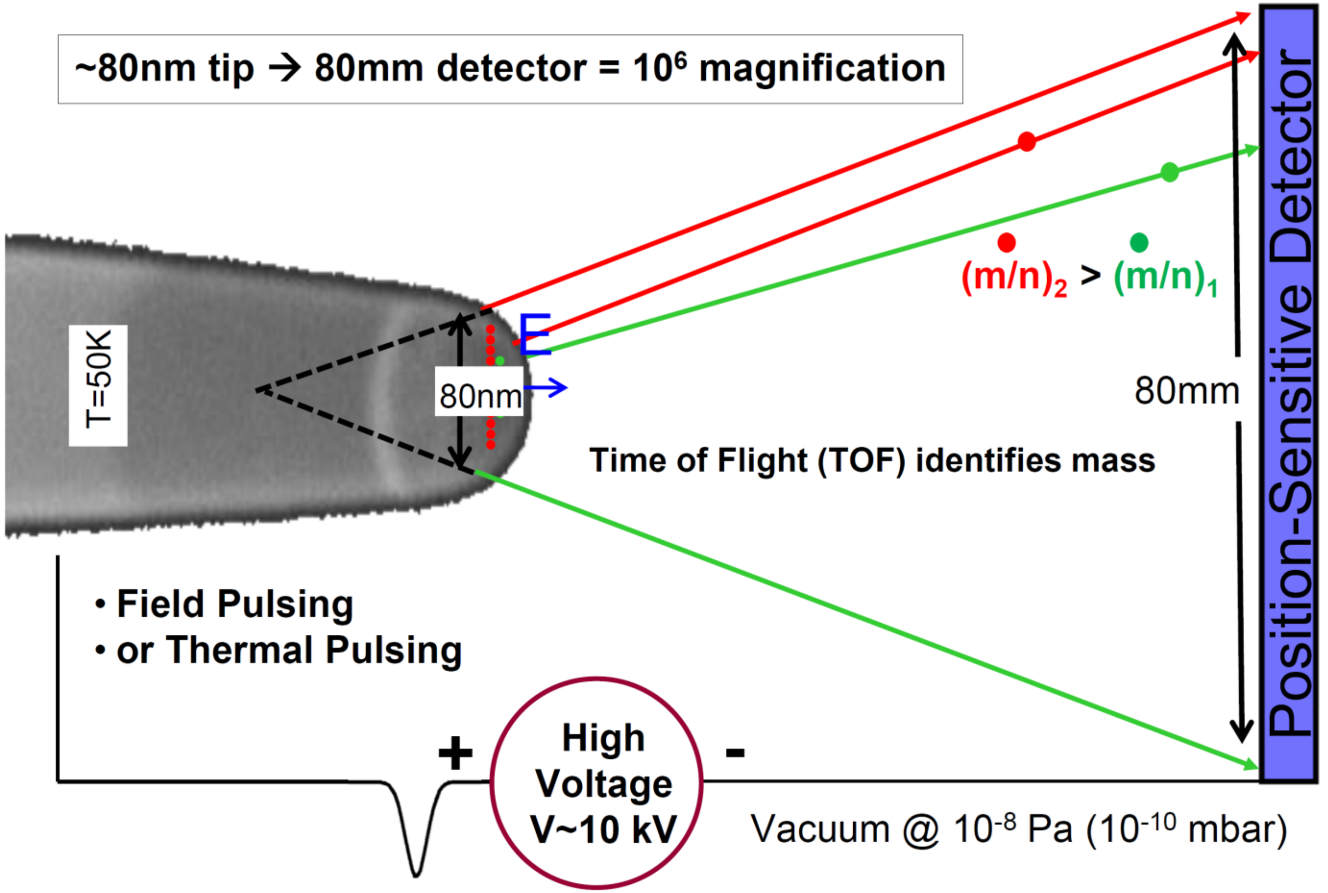
Principles of Atom Probe Tomography (APT)

- Field-evaporate needle shaped specimen, accelerate ions onto detector
- Measure time of flight to determine mass-to-charge ratio and chemically identify each detected ion
- Use detector position to reconstruct tip
- Obtain 3D dataset with very high magnification

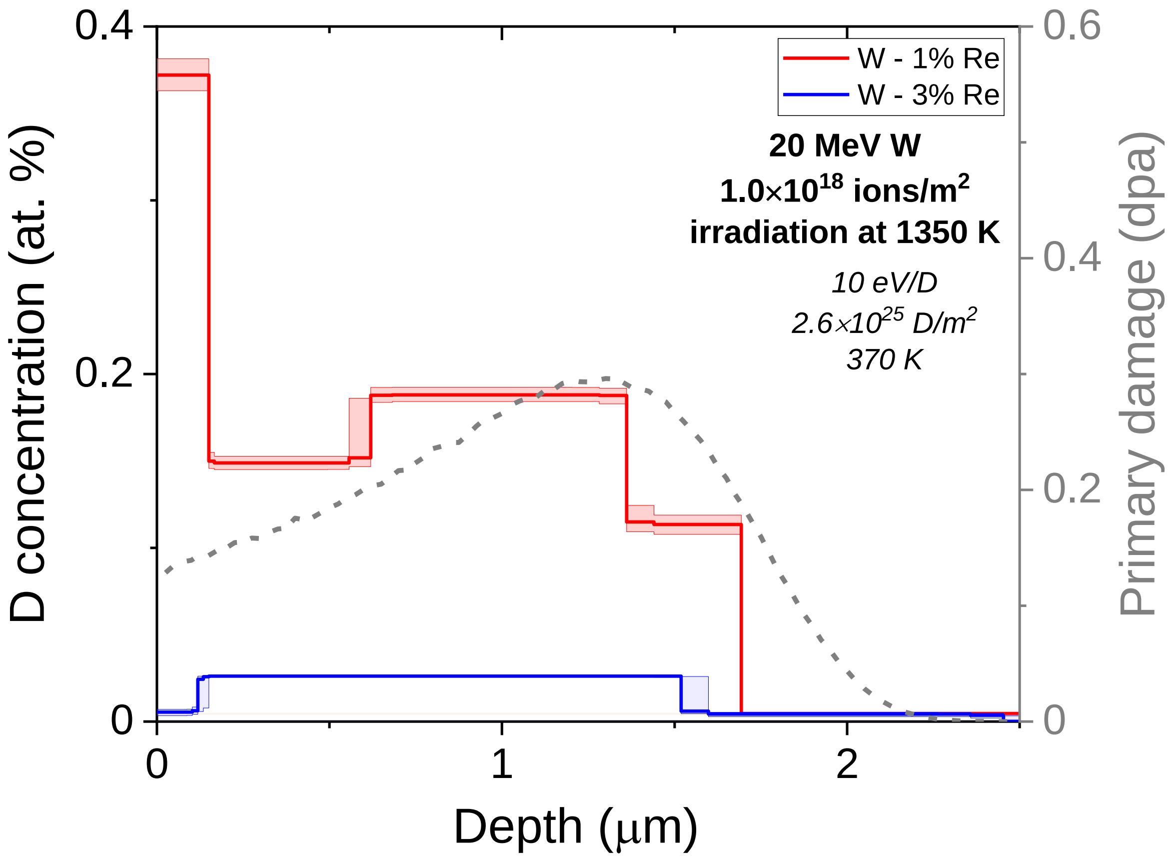


Atom Probe = projection imaging with time-of-flight mass spectrometer

C. Roach, CAMECA

APT results for W-Re alloys irradiated at 1350 K

- Specimens extracted from 1 μm depth (close to damage maximum)



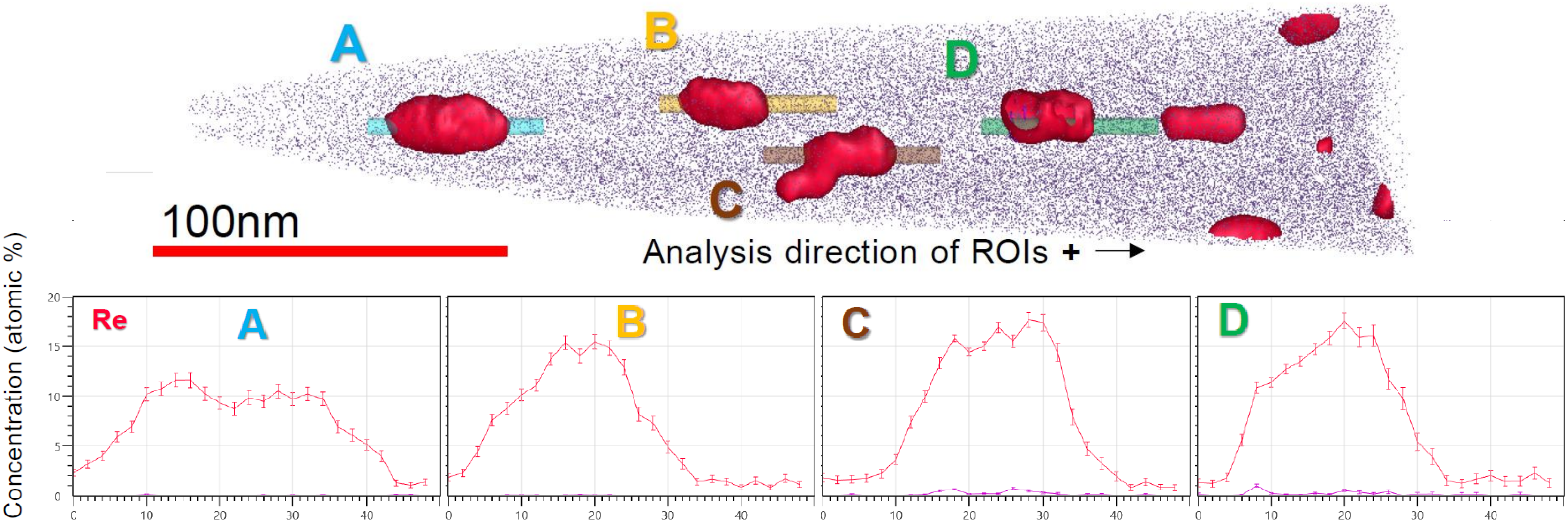
APT results for W-Re alloys irradiated at 1350 K

- Specimens extracted from 1 μm depth (close to damage maximum)
- Red: Re isoconcentration surfaces plotted at 5 at.% Re
- Re is forming clusters in both alloys
- Clusters in W-1%Re alloy appear larger than in W-3%Re alloy
- According to equilibrium thermodynamics,
  Re forms solid solution in W at concentrations up to 26 %

Z.-K. Liu, Y. Chang, J. Alloys Compd. 299 (2000) 153.

C. Roach, CAMECA

1D Profile of Re clusters in W-1%Re



Decomposed, atomic, 1D concentration profiles from Ø5 nm x 50 nm cylindrical ROIs.

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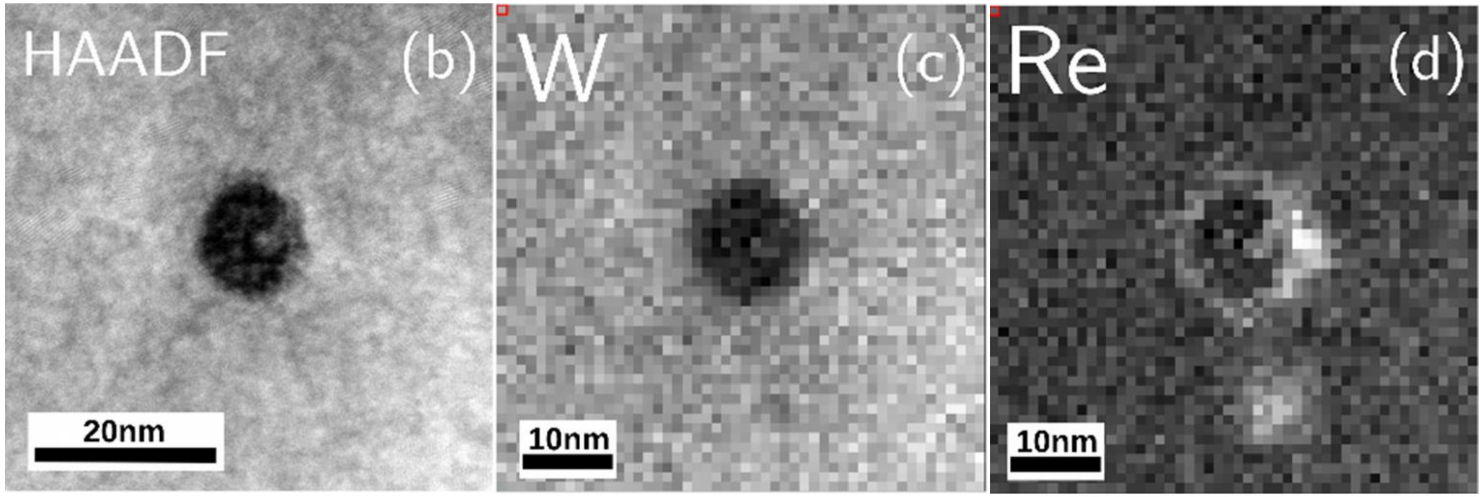
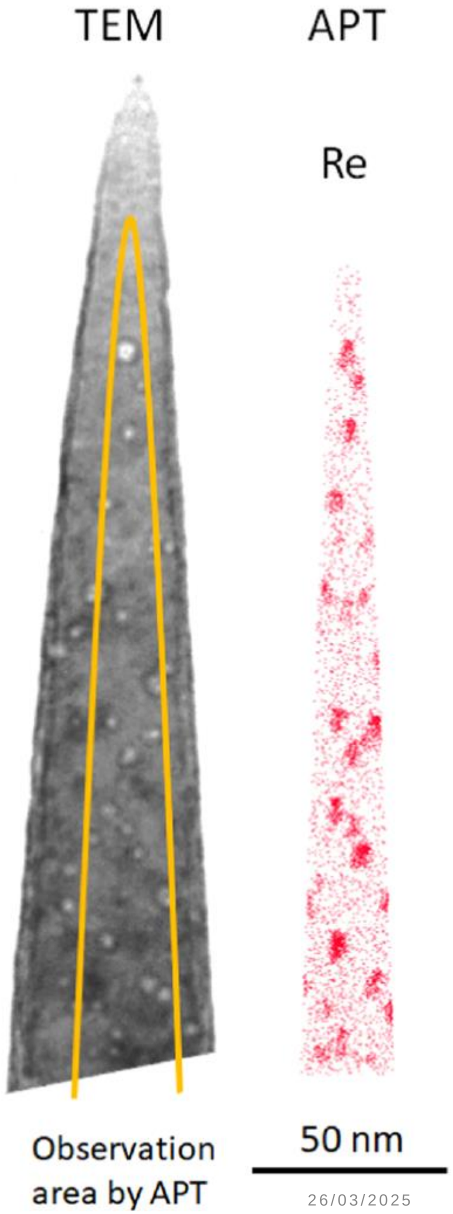
Re-decorated voids vs. Re clusters

- APT measurement cannot distinguish between Re-decorated voids and Re clusters/precipitates
- Both were previously observed in TEM+EDX
- **TEM/EDX measurements of samples irradiated at 1350 K will be performed at JSI (Slovenia) in 2025 (PWIE task)**



M.J. Lloyd et al., Scripta Materialia 173 (2019) 96



K. Inoue et al., Materialia 32 (2023) 101963

Summary

- 290 K irradiation: Re slightly increases trapped D concentration
- 1350 K irradiation: Re significantly reduces trapped D concentration
- Post-irradiation annealing at 1350 K results in much smaller Re effect compared with irradiation at 1350 K
- TEM analysis of samples irradiated at 1350 K will be performed at JSI in 2025

Influence of Re on displacement damage in W
PWIE task in 2025

- Irradiation of pure W with 2 MeV **Re ions**
  ⇒ simultaneous *damage production* and *Re injection*
- Irradiation temperatures: 290 and 1350 K
- Compare with 2 MeV W-ion irradiation of pure W to the same fluence
- Compare with 2 MeV W-ion irradiation of W-1%Re alloy to the same fluence
- D plasma exposure + NRA + TDS