Fuel retention in high energy ion damaged tungsten

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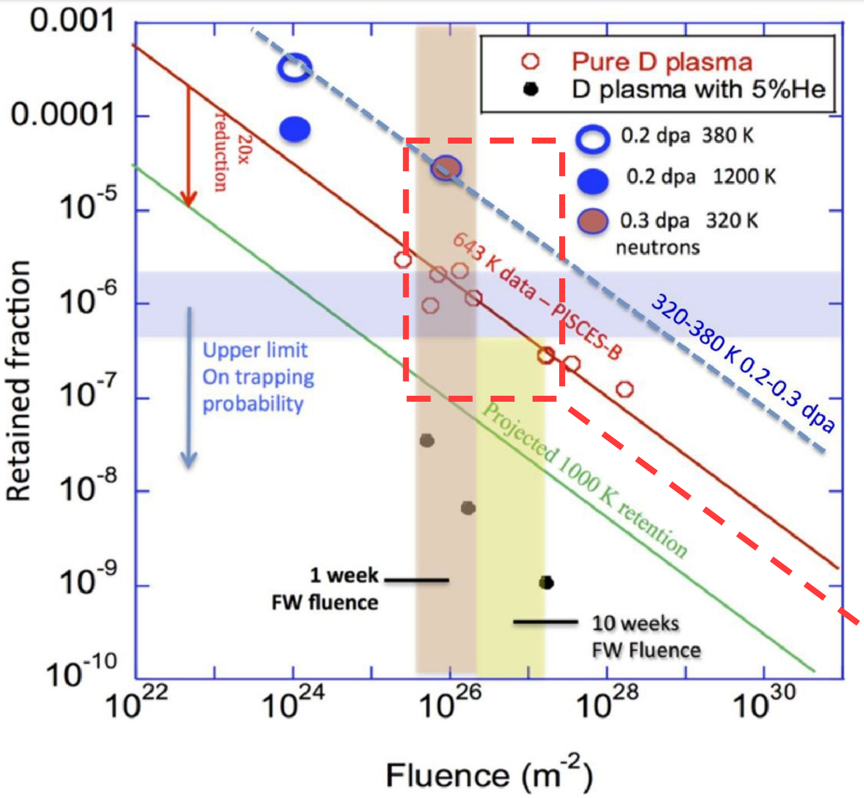
Motivation

- Current understanding of H retention in high energy ion damage
- Research gaps that need to be addressed
  - **Synergisms**
- How to make use of MPEX unique capabilities
  - **FPP divertor-like conditions**

Very low T retention critical to TBR > 1



G.R. Tynan *et al.* 2017 NME 12 164-168

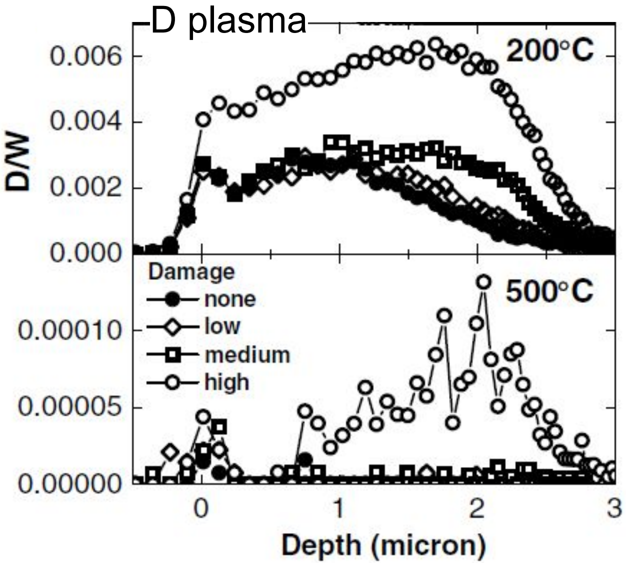
- Tritium Breeding Ratio (*TBR*) above 1 is necessary for viable fusion
- Probability to permanently trap T (p_{trap}) must be below ~10^{-6} to have TBR>1
- T trapping in neutron-induced defects can exceed this upper limit
- Need to study retention under FPP conditions

MPEX - systematic study

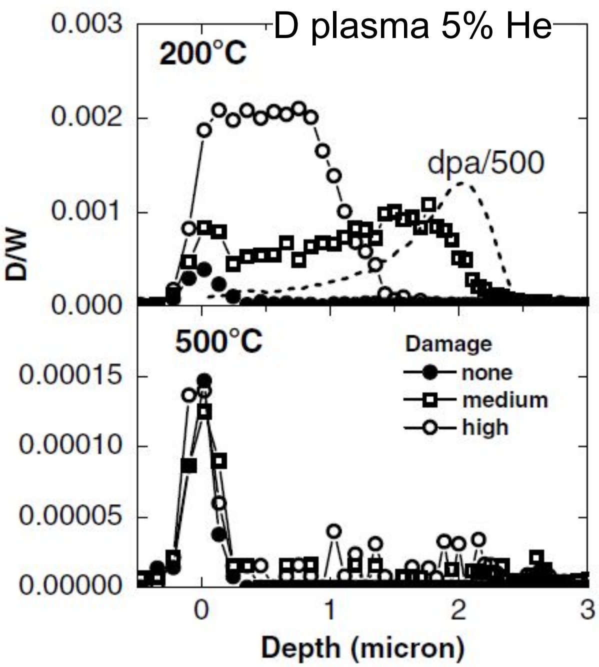
D plasma 5% He significantly reduces D retention

PISCES

W.R. Wampler and R.P. Doerner
2009 NF 49 115023

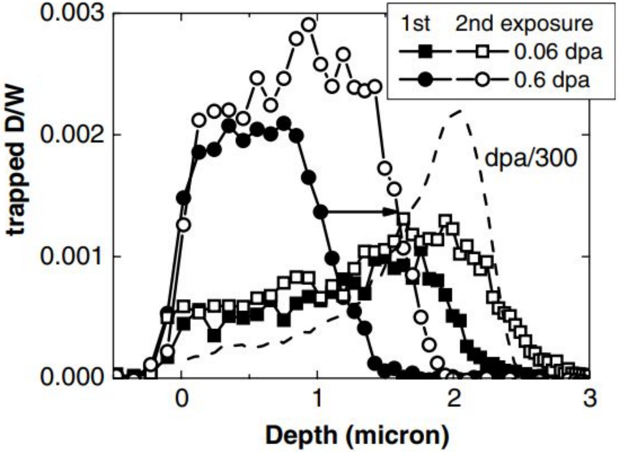


D plasma



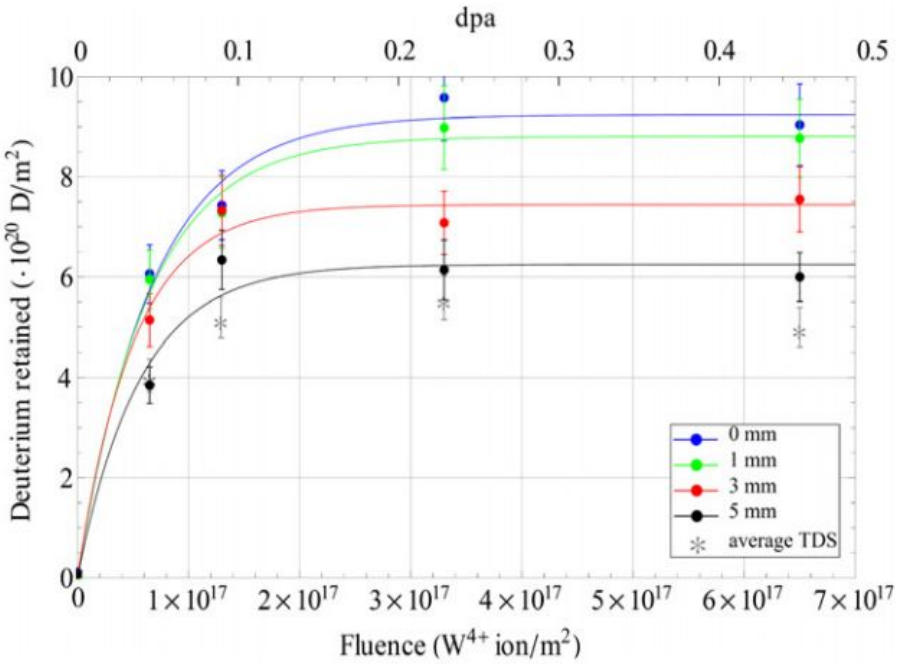
D plasma 5% He

D plasma 5% He, 200 °C

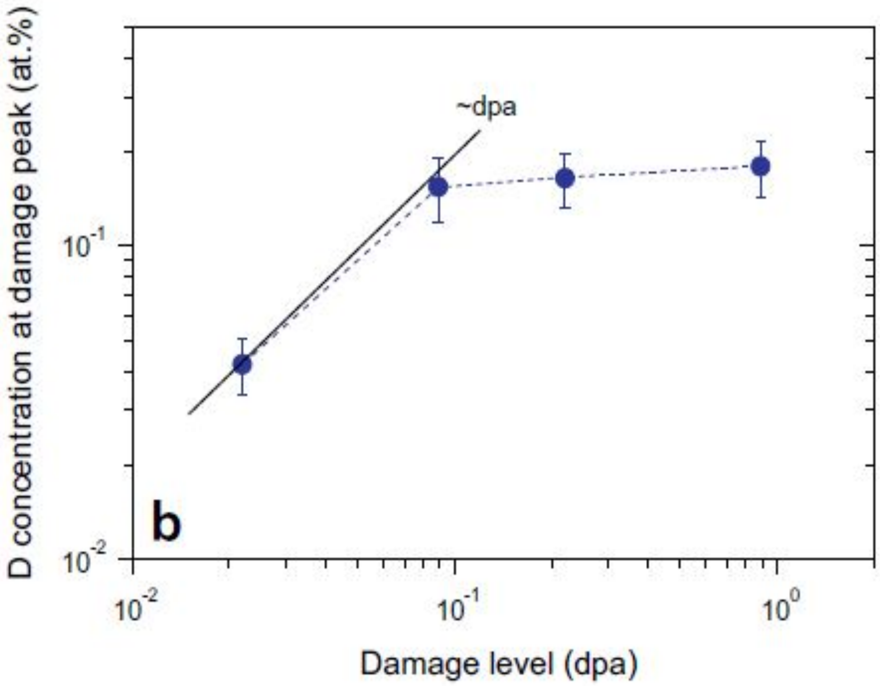


- D plasma with 5% He slows filling of Si-ion damage
- Further study under divertor-like conditions is needed (oblique incidence? detached?)

H retention shown to saturate ~0.2 dpa

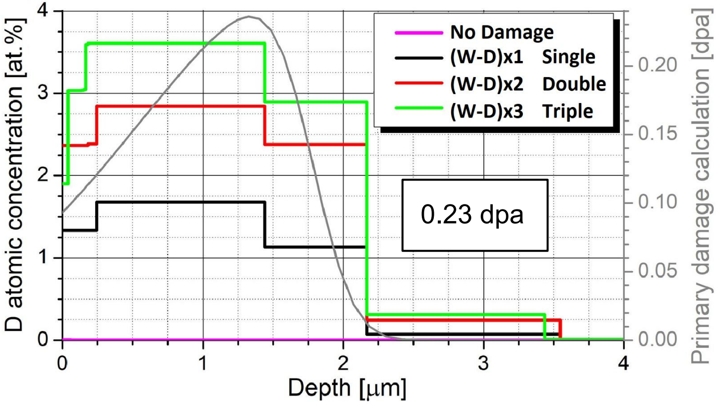


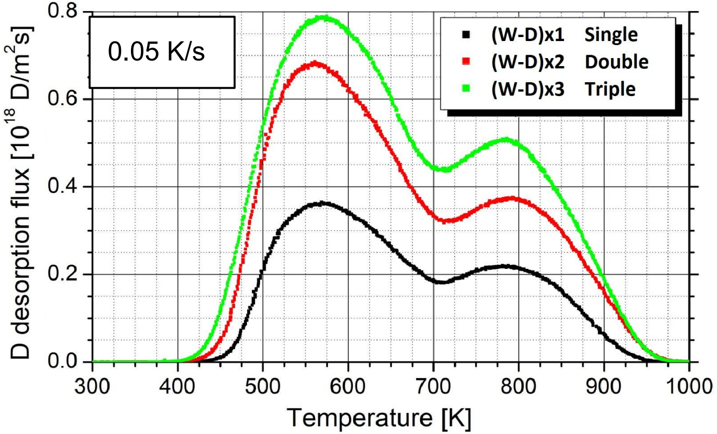
t'Hoen *et al.* 2012 NF 52

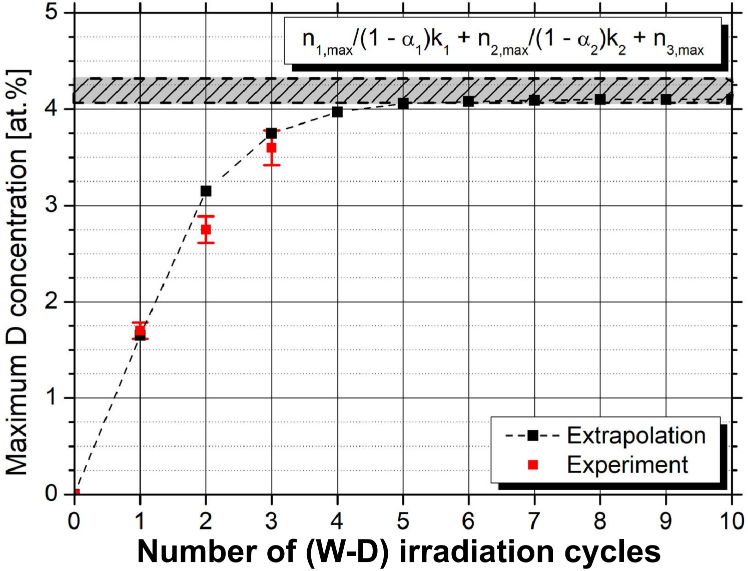


Alimov *et al.* 2013 JNM 441

Previous saturation is broken by H synergism



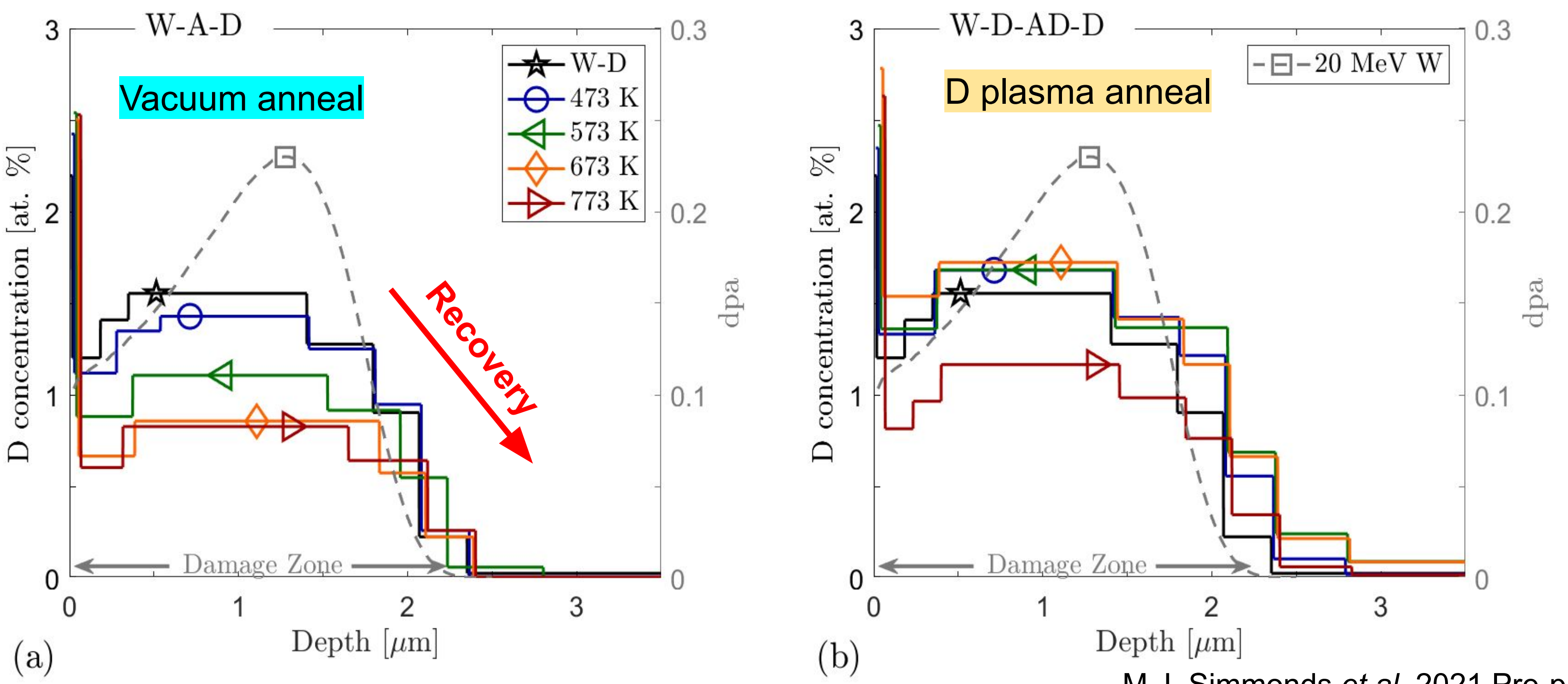




M. Pečovnik *et al.* 2021 JNM 550

- Repeated (W-D) cycles leads to new saturation ~4 at.%
- Further study with high D solute may surpass saturation
  - **Simultaneous** D exposure and heavy-ion irrad.
  - Current proposal for PISCES-RF to be coupled to an accelerator is awaiting DOE funding

Defect recovery reduced for D plasma anneal



Vacuum anneal

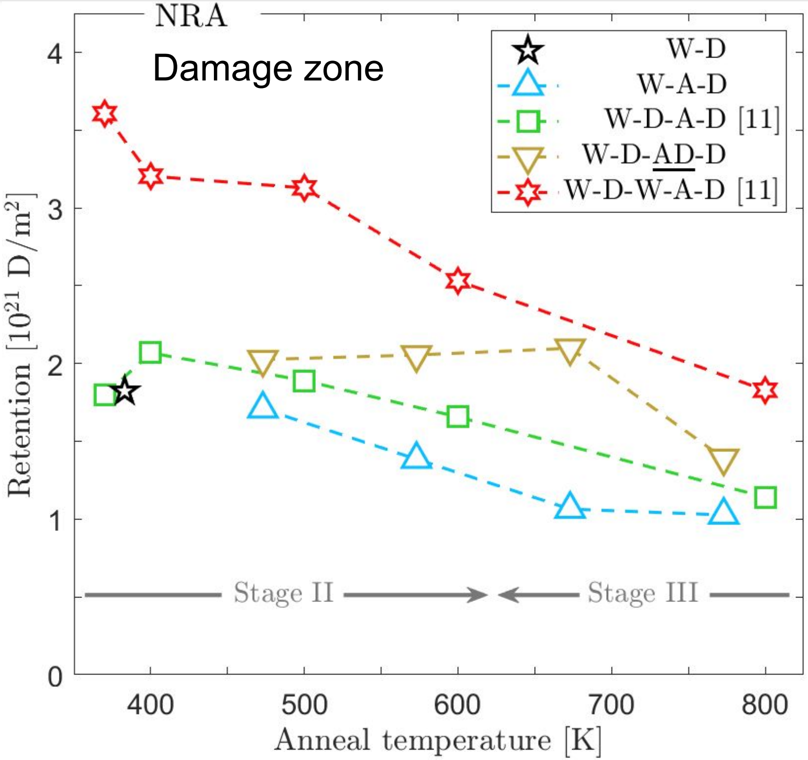
Recovery

D plasma anneal

M.J. Simmonds *et al.* 2021 Pre-publication

- H present in defects during post-damage annealing reduced recovery
- Continuous H implantation (i.e. plasma) ensured H filled defects ➡ inhibit recovery

Defect annealing/recovery reduced with H present



M.J. Simmonds *et al.* 2021 Pre-publication

[11] M. Pečovnik *et al.* 2020 NF 60 106028

Retention from lowest to highest:

- **W-A-D** : Vacuum anneal with no D present
- **W-D-A-D** : Vacuum anneal with prev. D exposure
- **W-D-AD-D** : D plasma exposure during anneal
- **W-D-W-A-D** : Vacuum anneal with previous D exposure and second W damage

- Clever seq. schemes can still study synergisms without fully simultaneous capabilities

Conclusion

- H retention in **heavy-ion damage** studies can be performed in collab with smaller facilities
    - Primary diagnostics - TGS, NRA, TDS
    - Narrow field of viable W alloys/composites (smaller linear devices)
    - Fill out **FPP relevant** parameter space of retained fraction vs. fluence
    - Perform studies as control/narrow field prior to using n^0 activated material in MPEX
        - Test divertor-like conditions (w/ and w/o detachment)
        - He nano-bubble/fuzz formation (oblique incidence, He%, Temperature?)
        - Repeat with n^0 damage on same machine for one-to-one comparison

- Experimental schemes utilizing sequential steps may reveal **synergistic** mechanisms
    - If funded, fully simultaneous damage/decoration experiments can guide schemes
    - High H flux may exacerbate synergisms that are H solute dependent (MPEX)
    - Thermal cycling/annealing with high plasma flux (blisters/cracks)

Backup Slides

Need to study realistic PMI

- Purely sequential and isolated experiments may miss synergies
  - Experiments with **no** H present
    - Heavy-ion damage leads to increased defects until saturation
    - Annealing significantly recovers defects

- Vacancy-interstitial recomb. inhibited when vacancy occupied by H
  - Studied with sequential experimental steps (ensured H present)
  - W damage and H decoration cycles exceeded saturation (T. Schwarz-Selinger*)
  - W damage and H decoration during annealing inhibited recovery (M.J. Simmonds*)

- Material properties under fully simultaneous (FPP-like) conditions?
  - What happens with concurrent damage, decoration, and elevated temperature?
    - Proposal for PISCES-RF to be coupled to an accelerator awaiting DOE funding

*See heavy-ion damage talk tomorrow

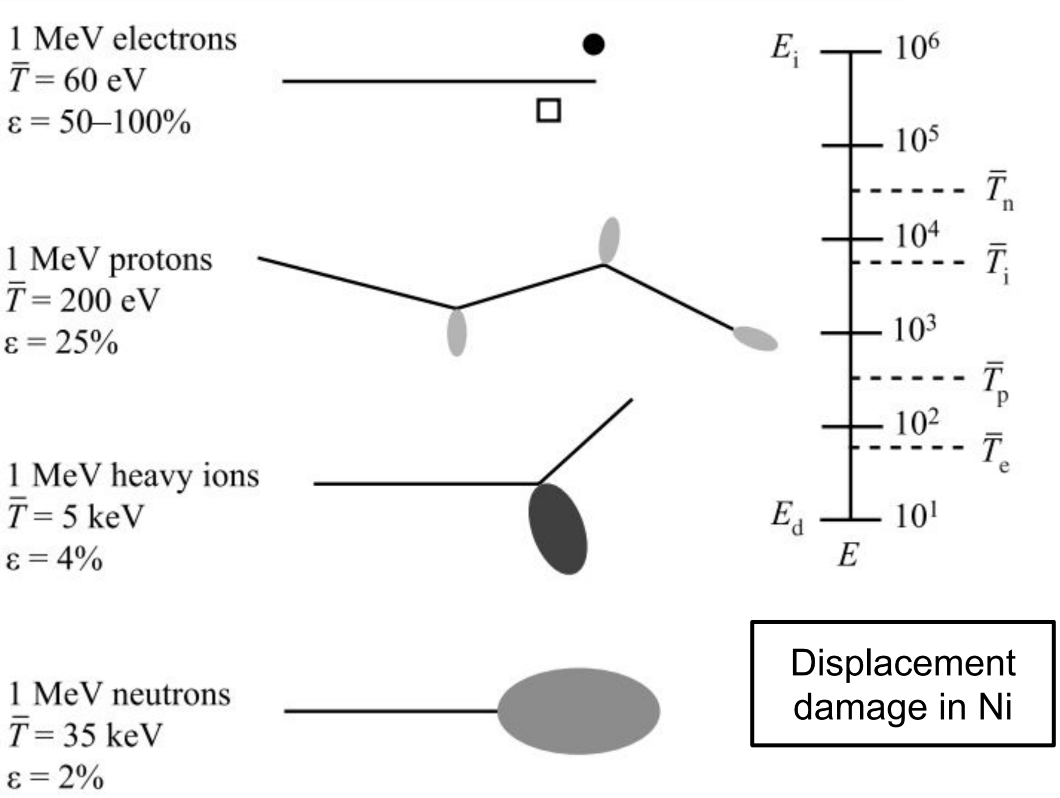
Heavy-ion damage as proxy for n^0 damage

Advantages to heavy-ions

- High dpa rate
    - Short irrad. time
- High ave recoil energy (T)
- Large collision cascade
- No activation of material

Differences

- High dpa rate (too quick)
- Mainly low recoil energy (T)
- Peaked damage (not uniform)
- Near surface (~µm)
- Impurity alloying at high dpa
- No transmutation products

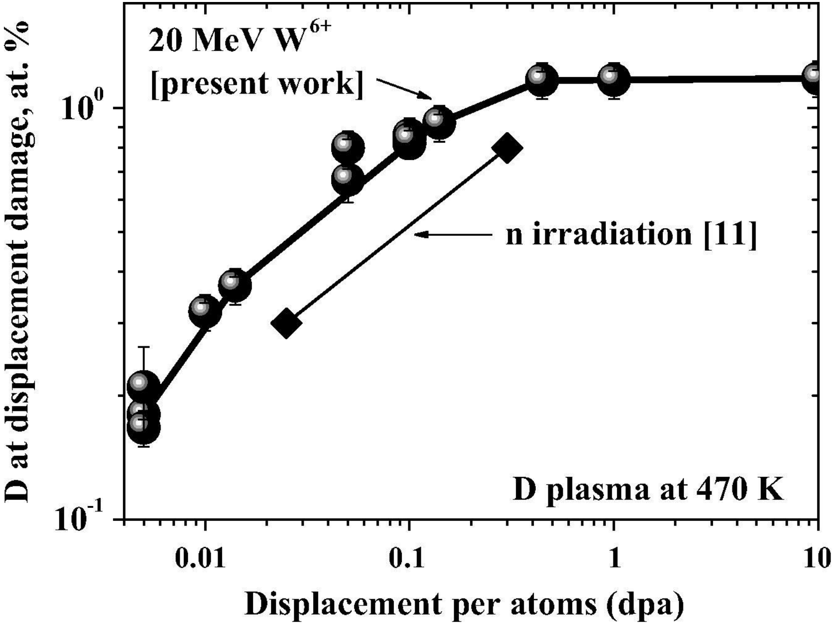


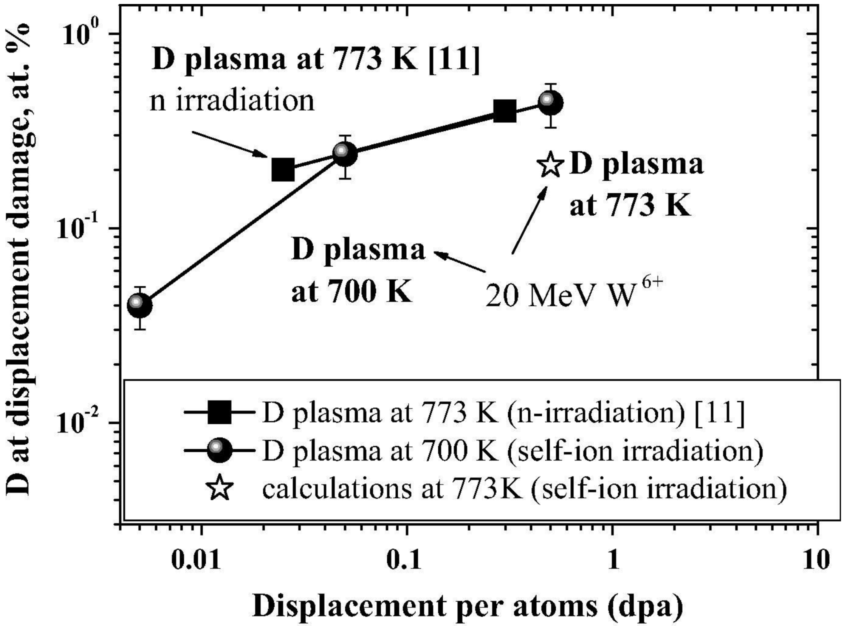
Displacement damage in Ni

G. Was, Fund. of Rad. Materials Science (Springer 2007) pg.118 and 132

Similar D concentration up to 0.3 dpa (n^0 vs. W-ion)

PISCES



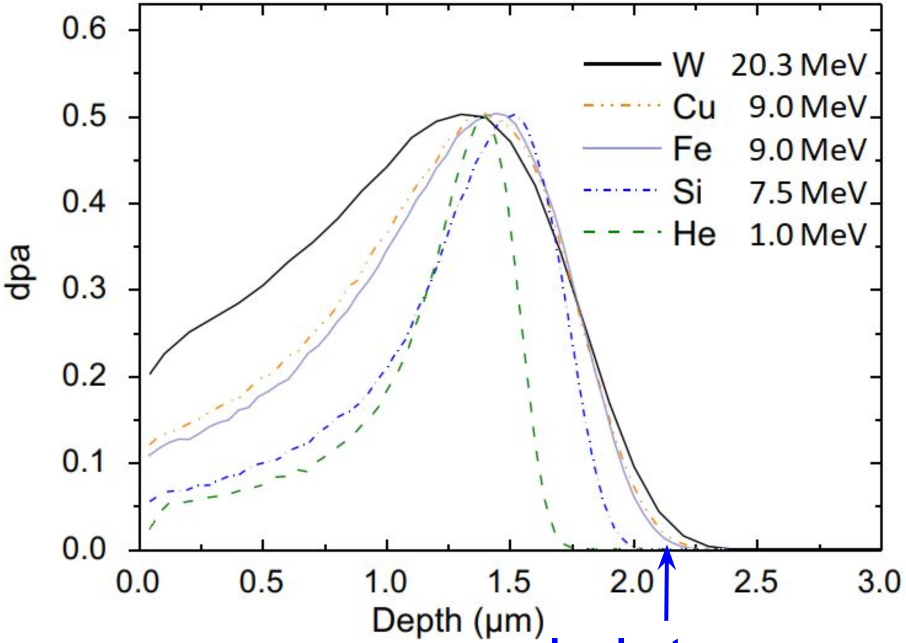


O.V. Ogorodnikova *et al.* 2015 JNM 460 60-71

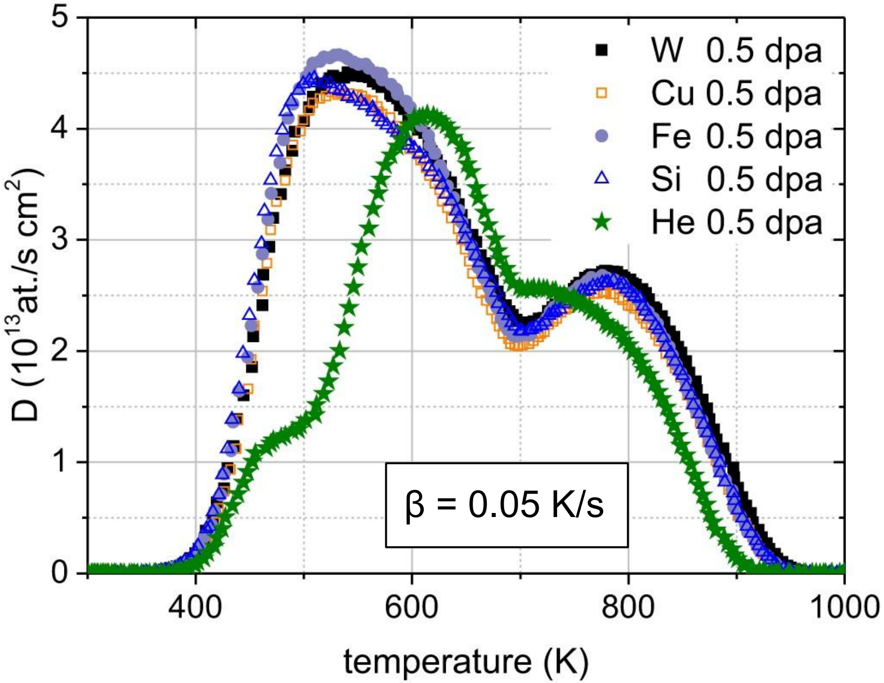
[11] Y. Hatano *et al.* 2013 NF 073006.

- Further study and characterization of n^0 vs. W-ion damage needed (on same device)

Mid- to heavy-ion damage similar (below alloying)



Implant zone



B. Wielunska *et al.* 2020 NF 60 096002

- Light-ion damage (i.e. He) creates different concentration of defects
- Damaging ions implanted beyond damage zone (little effect on retention)
- Effect of Re/Ta implantation within the damage zone (varied E) unknown