Isotope Exchange Experiments: Tungsten with Ion Induced Damage in PISCES

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Motivation

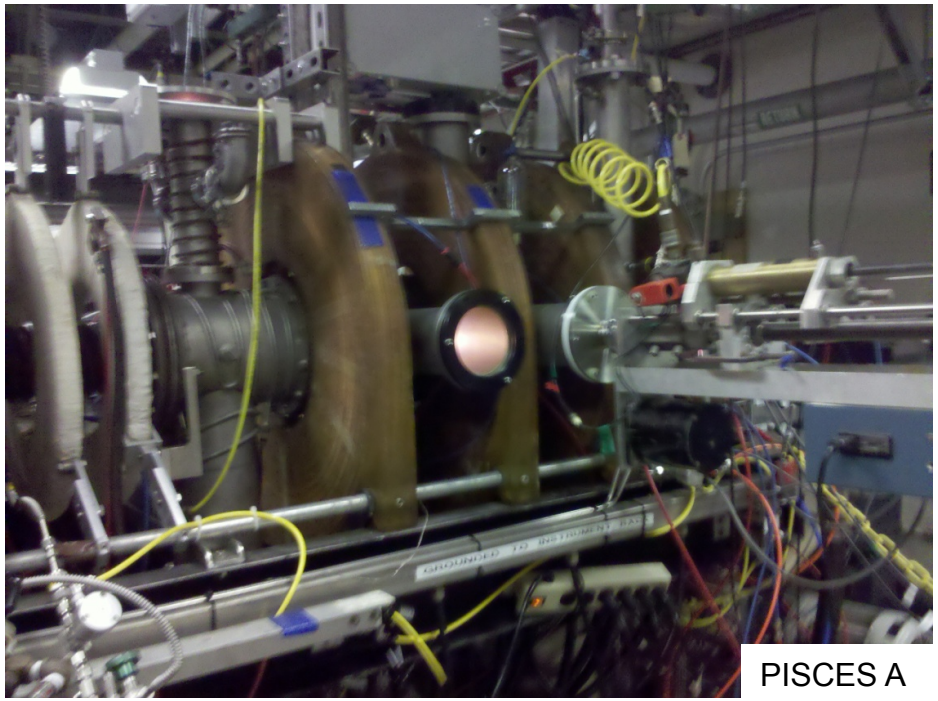
- Tritium retention needs to be minimized for safety reasons and for tritium self-sufficiency in a reactor
- Techniques to reduce tritium loss into materials and to recover tritium already in materials are thus of interest
- Questions:
  - When divertor material is saturated with a large dose of tritium and then subsequently exposed to a hydrogen plasma, how well does H bombardment displace or exchange with tritium retained in the metal?
  - Can this be a viable tritium removal technique?

Objectives

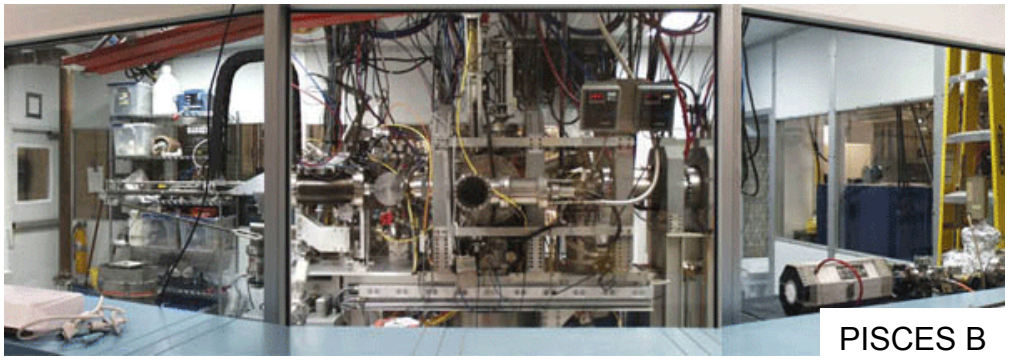
- Explore a process for tritium displacement
  - Simulate hydrogen isotope exchange with hydrogen replacing deuterium in tungsten
- Simulate neutron damage with high Z ion irradiation
- Gain an understanding of D concentration depth profiles and bulk retention

D&H Plasma Exposures in PISCES

- Linear plasma devices PISCES A and B simulate plasma fluxes relevant to those encountered by divertor and first wall materials in proposed magnetically confined fusion reactors
- Plasma is generated by heating LaB_6 and an electric potential is applied between the source and the vacuum chamber walls, which showers electrons onto neutral gas flowing into the chamber



PISCES A



PISCES B

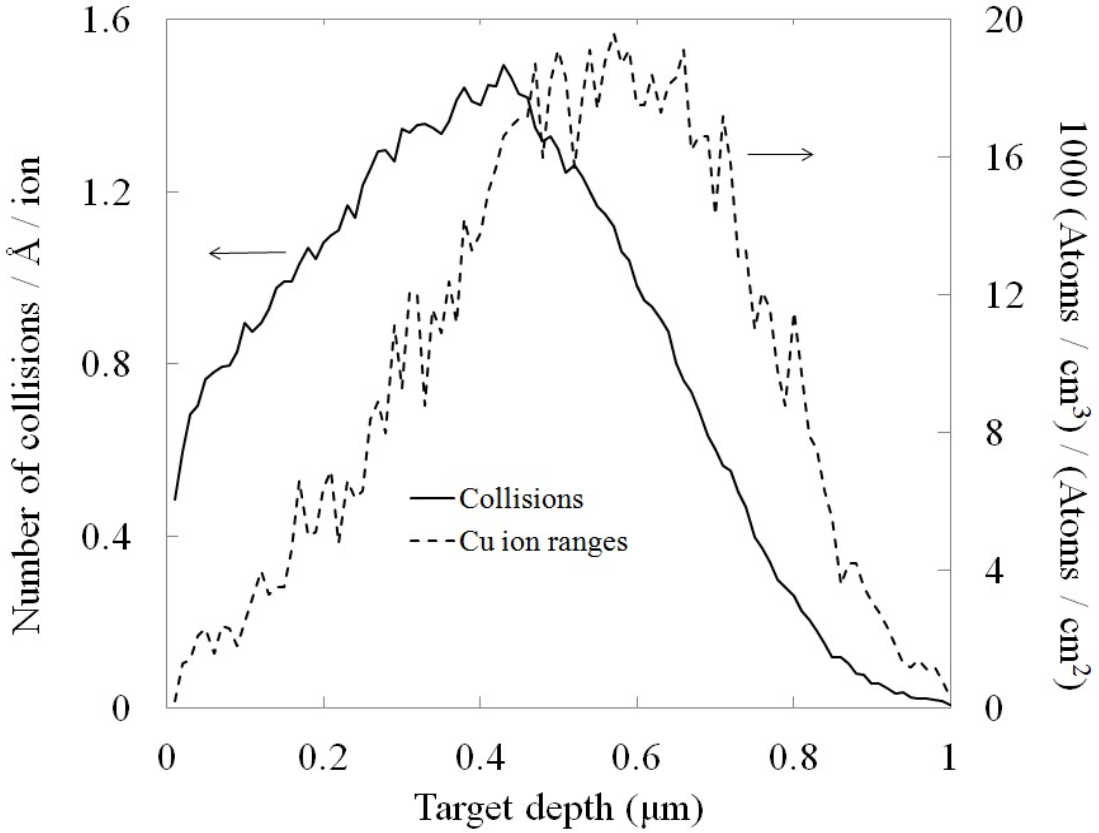
- Each device can reach relevant ion density and flux specifications:

Plasma Densities 10^{18}- $10^{19}/m^3$

Fluxes >10^{22} ions/m^2/s

Ion Beam Displacement Damage

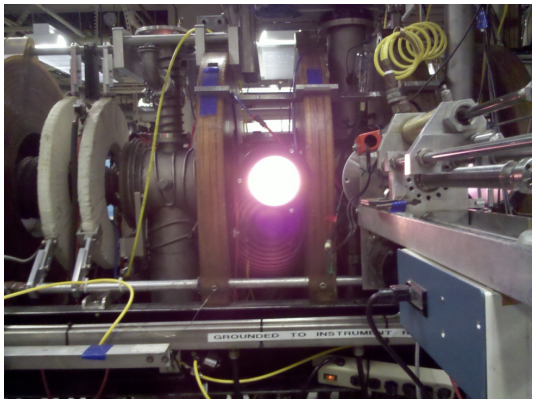
- 2.5 MeV Cu^{2+} ion beam
  - 1.25 x $10^{18,\ 19,\ \text{and}\ 20}$ ions/m^2 calculated to give 0.4, 4, and 40 dpa (SRIM-2012 simulation



Isotope Exchange Experiment

PISCES

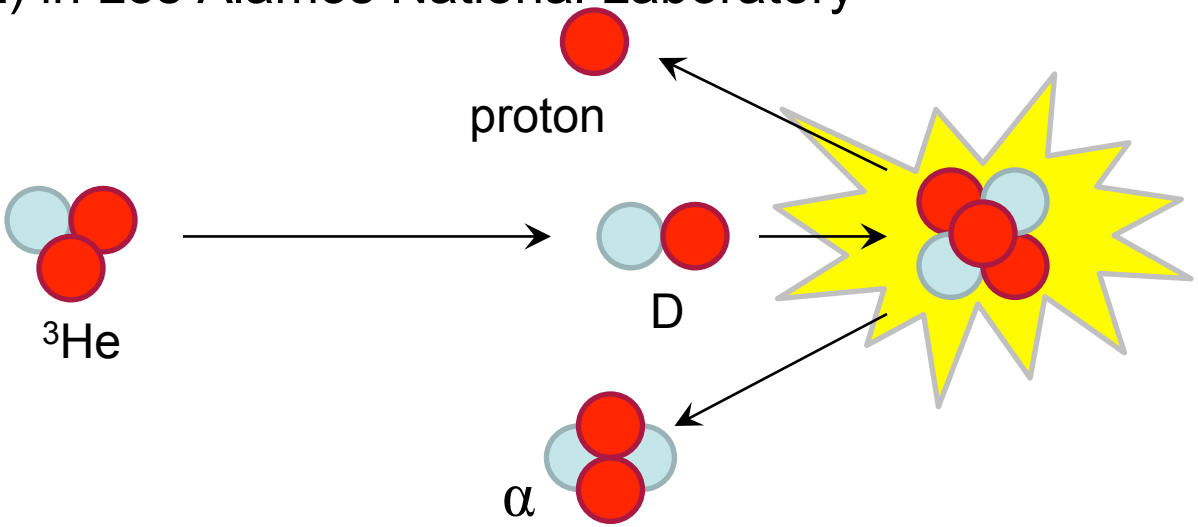
- Polished Plansee ITER grade W samples (6 mm diameter) were exposed in PISCES A
- Unpolished plasma sprayed Be samples exposed in PISCES B in a similar fashion



Procedure		
D plasma phase:	Flux	1-2 * 10^{22} ions/m^2/s
	Sample Temperature	< 373 K
	Ion Energy	100 eV
	Fluence	10^{26} ions/m^2
Pump down ~100 seconds		
H plasma phase:	Flux	0.9-1.3 * 10^{22} ions/m^2/s
	Sample Temperature	< 373 K
	Ion Energy	100 eV
	Fluences	0, 8.4*10^{23}, 6.6*10^{24}, 5*10^{25}, 10^{26} ions/m^2

Post-exposure Measurements

- **Nuclear Reaction Analysis** (Surface vs Bulk retention)
  - Concentration of D in W up to 3.5 μm with a D(^{3}He,p)α reaction
  - NRA was conducted at the Ion Beams Materials Laboratory (IBML) in Los Alamos National Laboratory



- **Thermal Desorption Spectroscopy** (Total retention)
  - Measures desorbed H_2, HD, and D_2

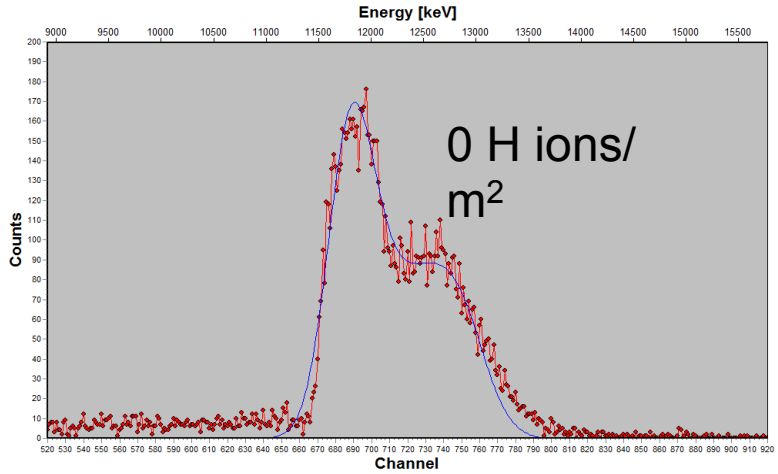
Nuclear Reaction Analysis

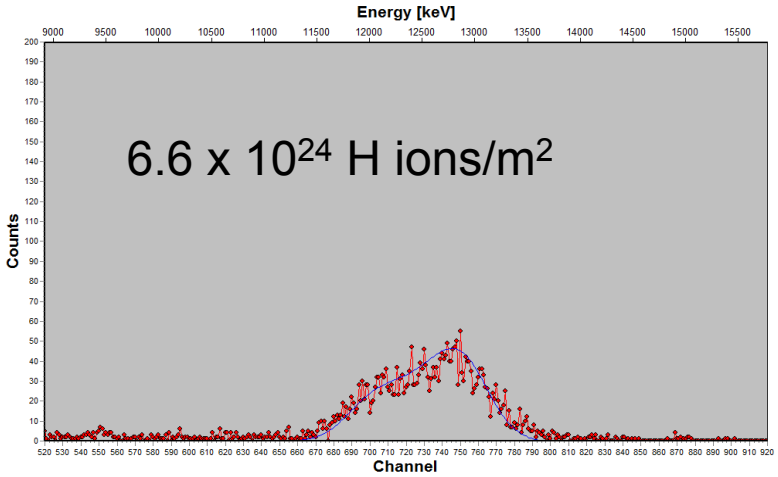
(Experiment)

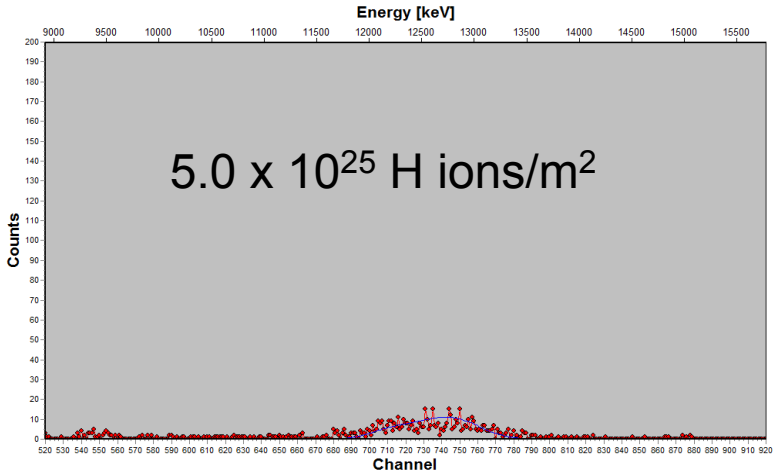
- NRA analysis beam of 2.5 MeV ^{3}He ions
  - Resolution affected in first few microns, but our analysis of examining integrated near surface vs bulk retention is unaffected
- Yield vs Energy spectra of the protons measured with a 300 mm^2 silicon surface barrier detector close to the sample (46.5 mm)
  - Detector angle 150^{o}
- Depth profiles examined with SIMNRA:
  - **Two concentration layers simulated (near surface and bulk)**

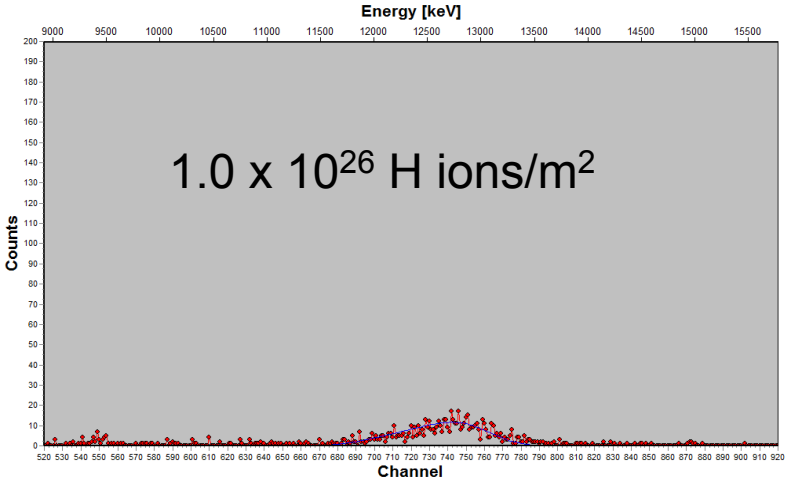
Measured and Simulated Proton Energy from the D(^{3}He,p)α reaction

PISCES

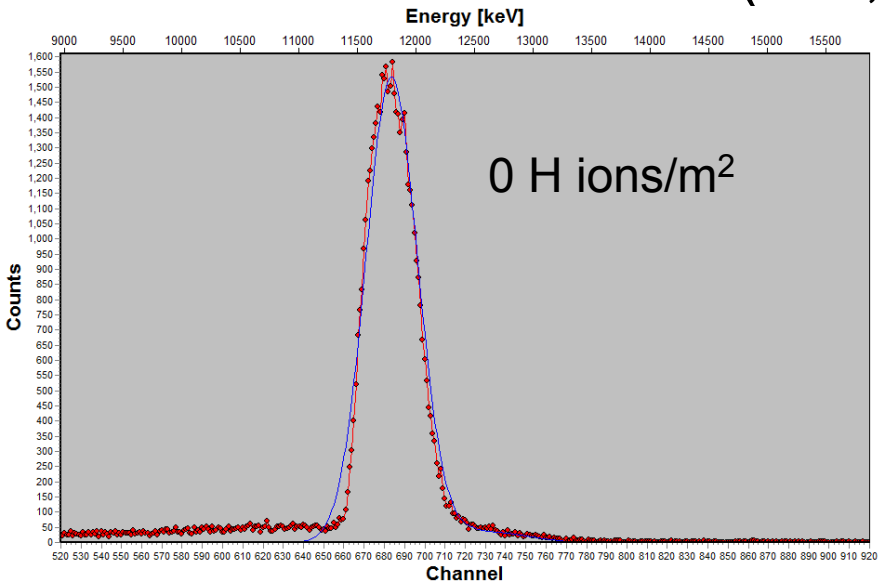




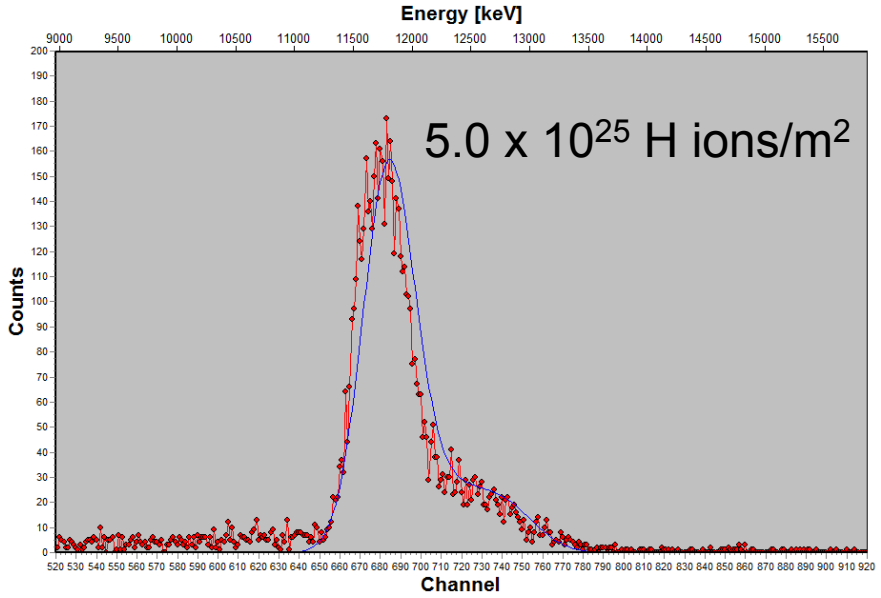


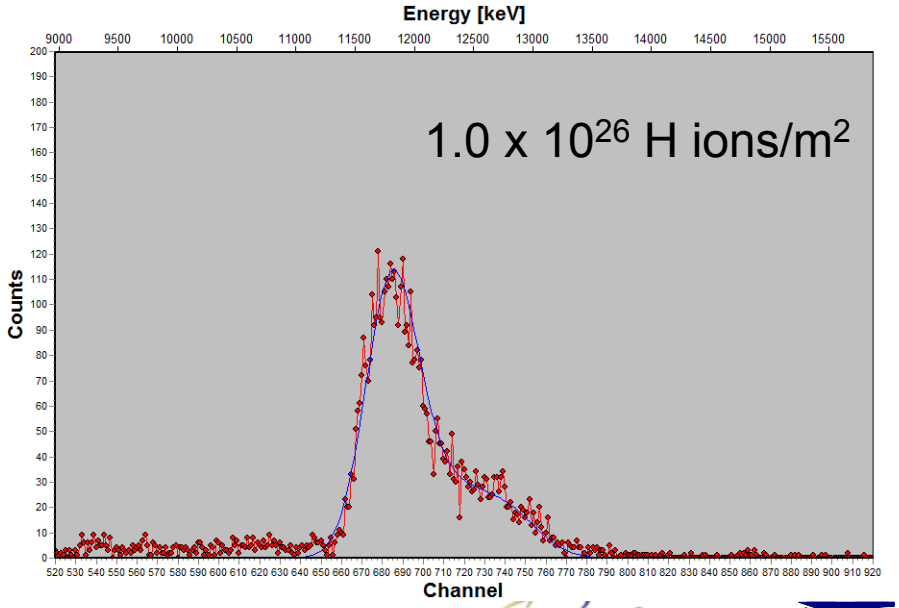


Measured and Simulated Proton Energy from the D(^{3}He,p)α reaction

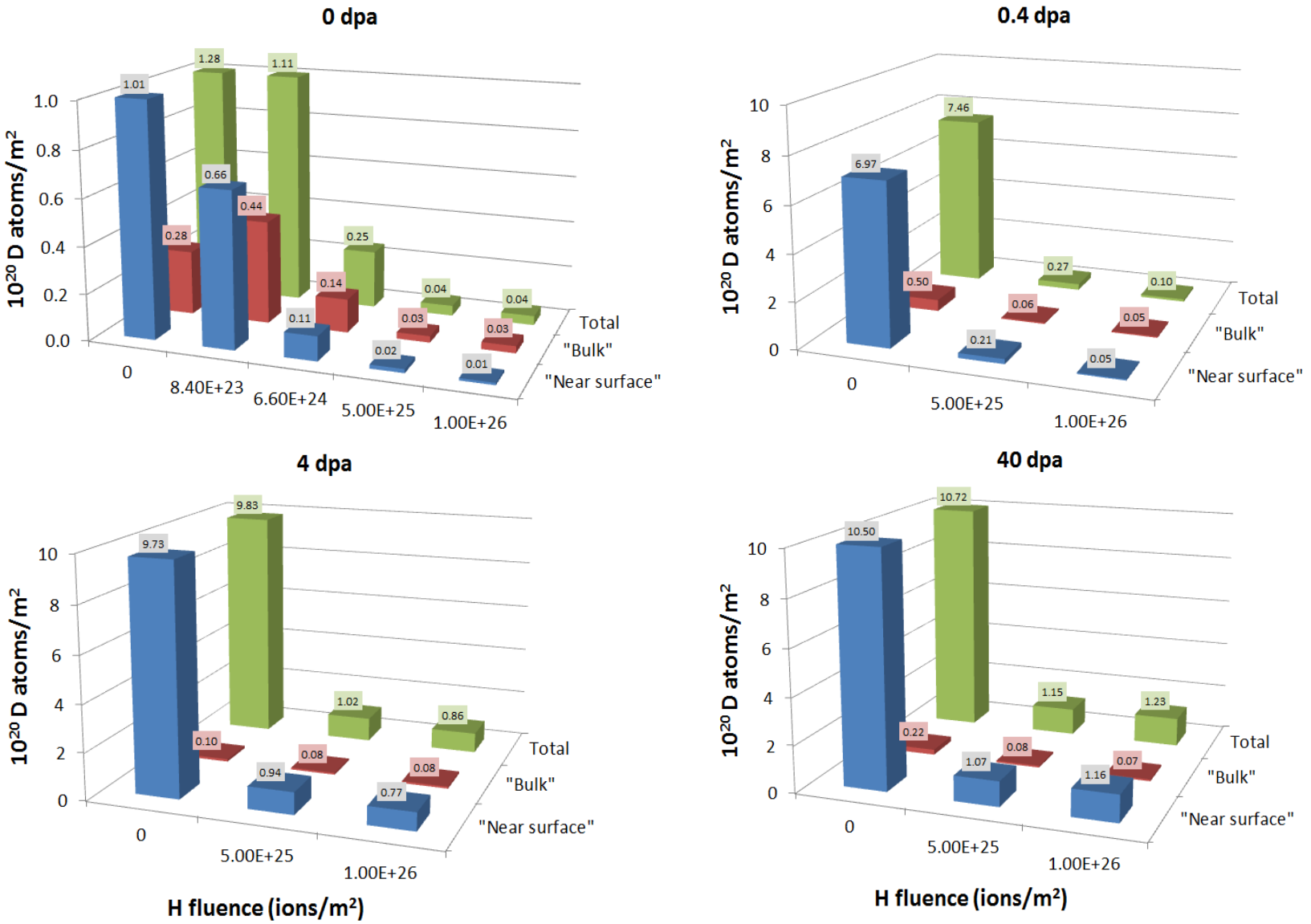


- Samples have 4 dpa
- Note difference in scales





NRA Depth Concentrations

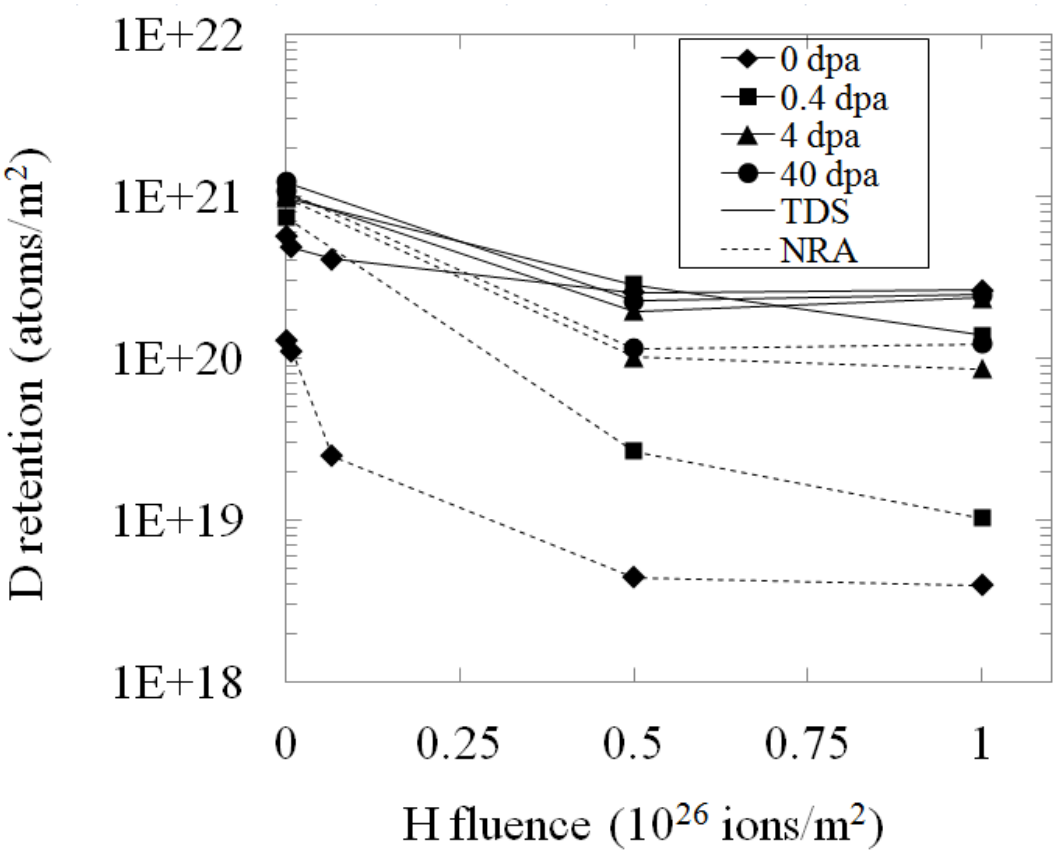


NRA Depth Concentrations

- Isotope exchange mainly affects the surface
- Depleting bulk inventory requires longer plasma exposures on par with diffusion time scales
- Displacement damage yields increased retention
  - Increased near-surface trap site density gives more D retained near the surface
  - Bulk inventory changes little
  - Although there is a higher D inventory in the surface, isotope exchange less efficient due to re-trapping, re-exchanging, etc. in damage zone
  - Neutron damage will be more uniformly distributed

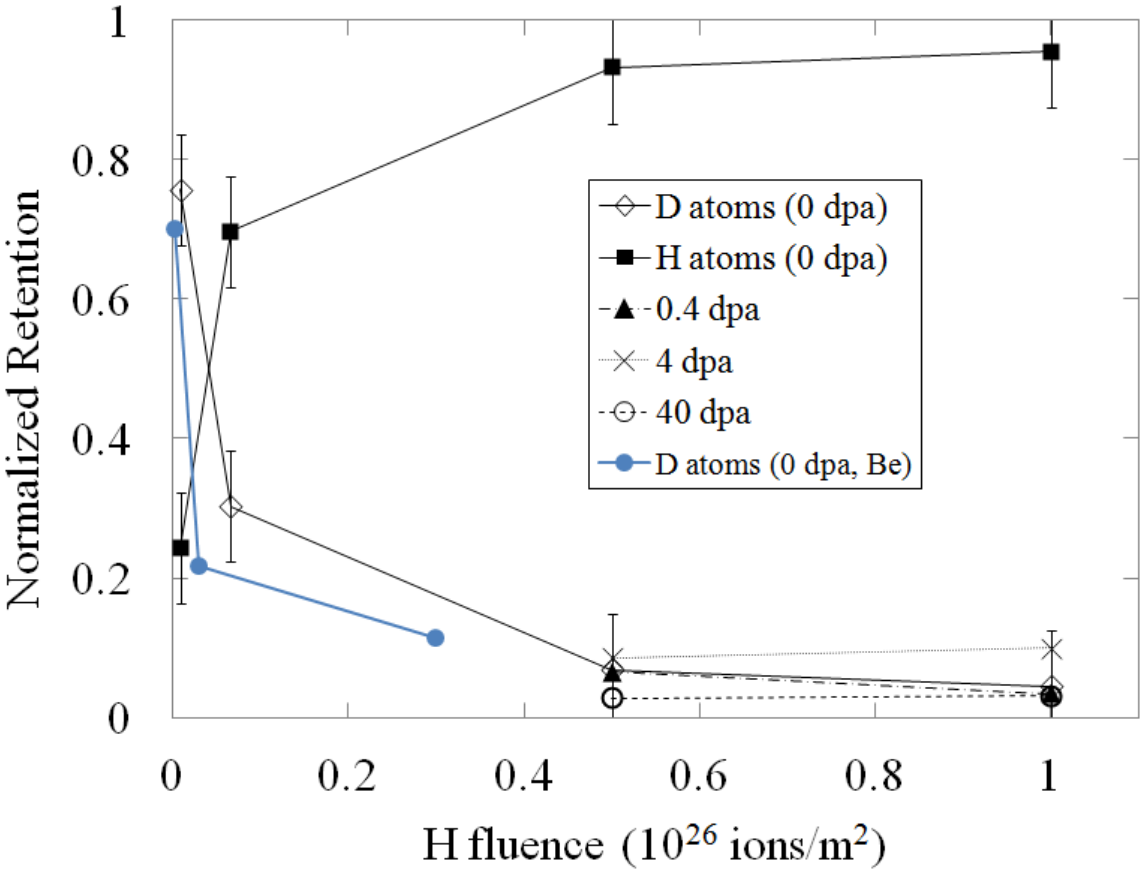
Thermal Desorption Spectroscopy

- NRA data appear more affected by H replacement than TDS results at elevated H fluence levels
- NRA retention values closer to TDS results as damage levels increase
  - Damaged gives increased near-surface retention
  - Near-surface D more easily released in TDS
- The larger discrepancy at low dpa could be from D inventory beyond 3.5 μm



Thermal Desorption Spectroscopy

- Fractional retention: retained D inventory normalized by the total D inventory in sample



- Used to compare W and Be isotope exchange rates since both metals have different retention properties
- The fractional retention in both tungsten and beryllium is decreased to ~20% for a 10^{25} H/m^2 fluence (1000 seconds)

Summary

- H-D isotope exchange
  - Undamaged W samples show **significant exchange in the near surface region;** also observe exchange in **bulk** but at a slower rate due to diffusive time scales
  - **W and Be** both show **similar fractional retention** as a function of H fluence
  - **Isotope exchange not practical for day-to-day D/T Removal** (esp. in bulk) because of the long plasma exposures required
    - May be useful before major vent
- Radiation damage in W
  - Results in increased D retention near the surface
  - Although there an increased inventory in the near surface, the increased number of trap sites decrease the efficiency of isotope exchange because of re-trapping

Summary

- Future Work
  - H-D exchange is a great method to study hydrogenic migration in materials
    - As of now, it is not a feasible method for Tritium removal
  - Model thermal desorption data in order to understand the release energies of these H traps to have a more quantitative picture of H isotope migration: *TMAP-7 code*
  - D molecules in blisters act as higher energy traps may decrease isotope exchange efficacy