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Design, implementation, and characterization of a triple beam *in situ* ion irradiation TEM facility

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Motivation: Fission & Fusion

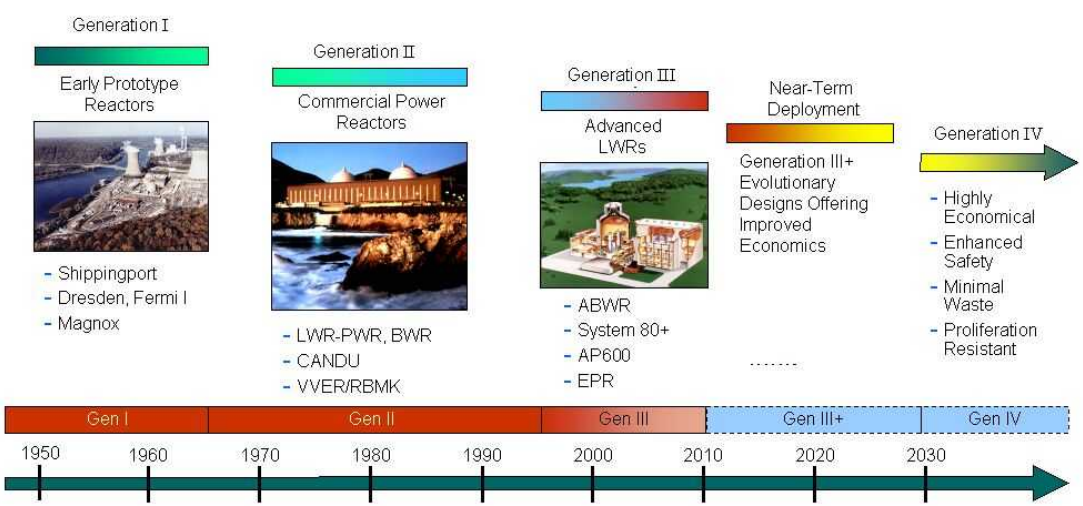
- Neutron damage
  - Displacement
  - Transmutation
- Individual components
- Synergistic effects

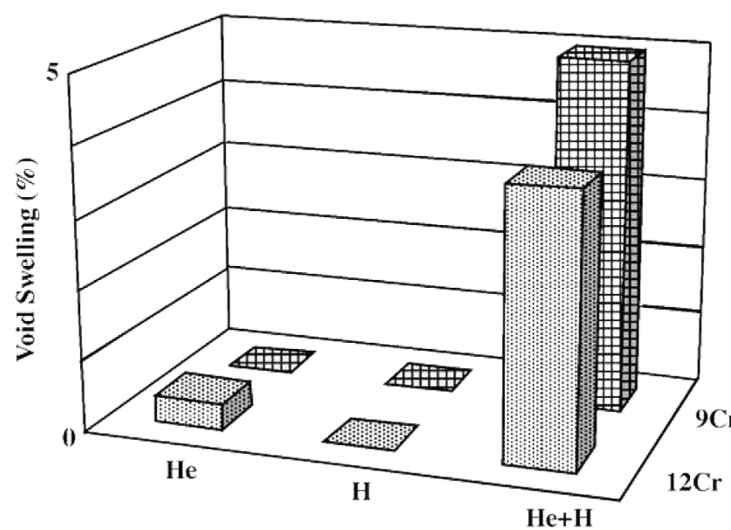
DCB2

	Fission (Gen I)	Fission (Gen IV)	Fusion (DEMO/PROTO)	Spallation (ADS)
Structural alloy T_{max}	<300 °C	300–1000 °C	550–1000 °C	140–600 °C
Max dose for core internal structures	~1 dpa	~30–200 dpa	~150 dpa	50–100 dpa
Max helium concentration	0.1 appm	~3–40 appm	~1500 appm (~10,000 appm for SiC)	~5000 appm/fpy
Max hydrogen concentration			~6750 appm	50,000–100,000 appm/fpy
Neutron Energy E_{max}	<1–2 MeV	<1–3 MeV	<14 MeV	Several hundred MeV

Fluss and King, 2009.

Generation IV: Nuclear Energy Systems Deployable no later than 2030 and offering significant advances in sustainability, safety and reliability, and economics





Tanaka, et al, J Nuc Mater, 2004.

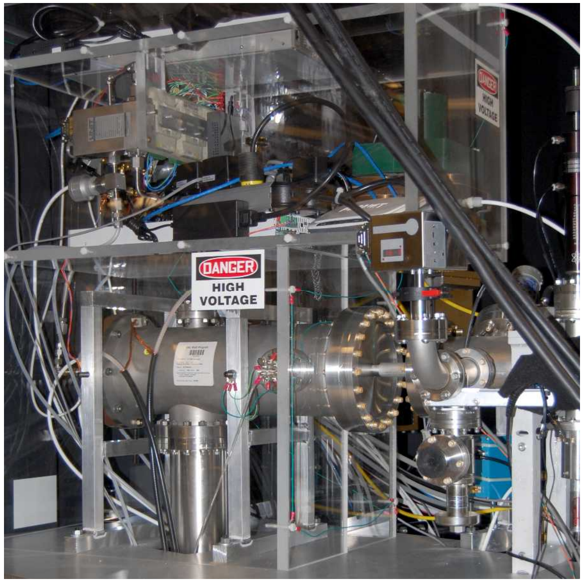
Slide 2

DCB2 Gen1-4 reactor schematic
Bufford, Daniel C, 5/16/2014

Accelerators

- HVE EN Tandem
  - 0.8 – 6 MV/q
  - SNICS, Alphatross, Hiconex 834 sputter, and duoplasmatron sources
    - H, He, most elements except noble gases
  - Displacement damage

- Colutron G-1
  - 0.5 – 10 kV/q
  - Hot filament source
    - Gases
    - He/D_2
  - Implantation



TEM Facility

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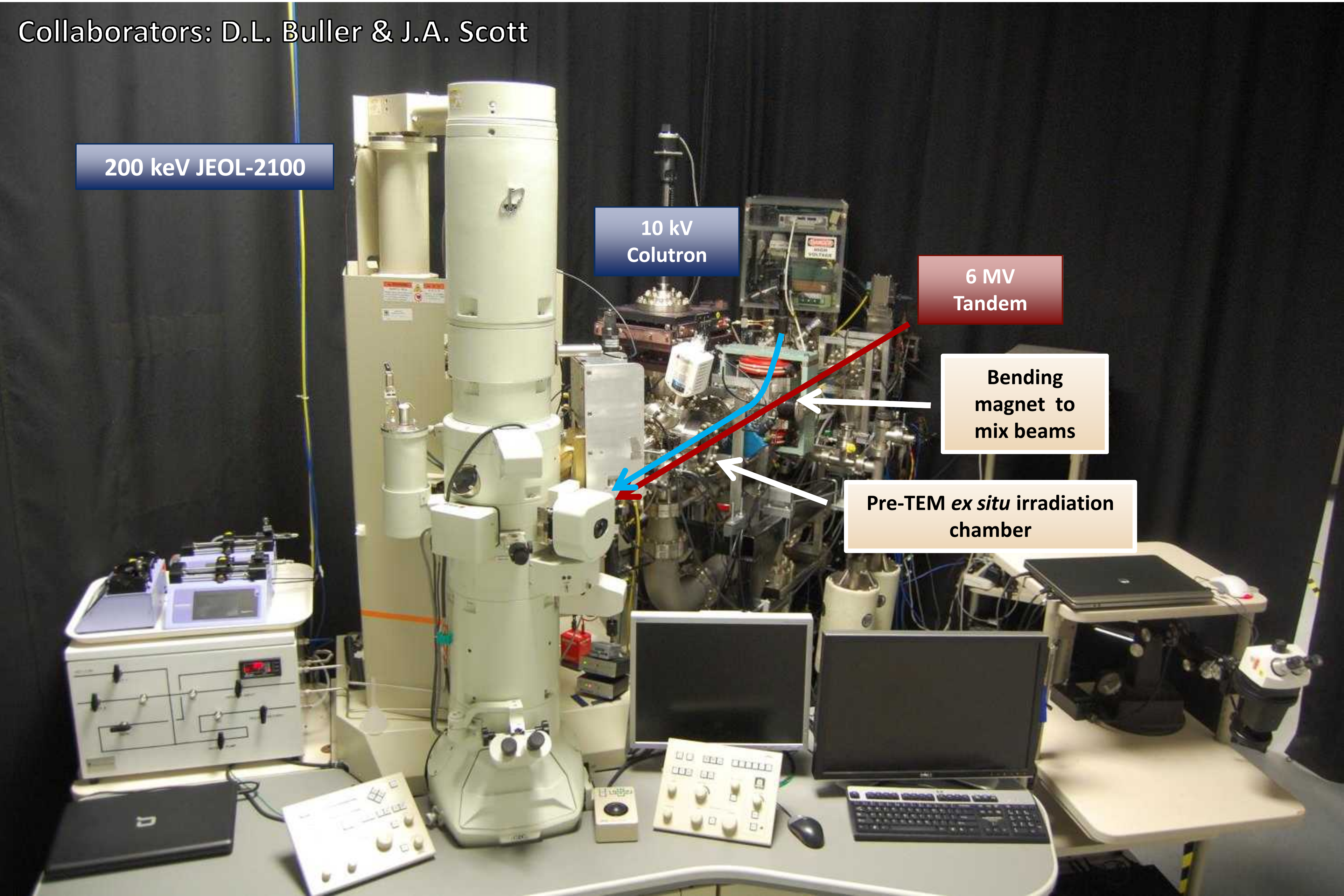
Collaborators: D.L. Buller & J.A. Scott



Mixing the Beams

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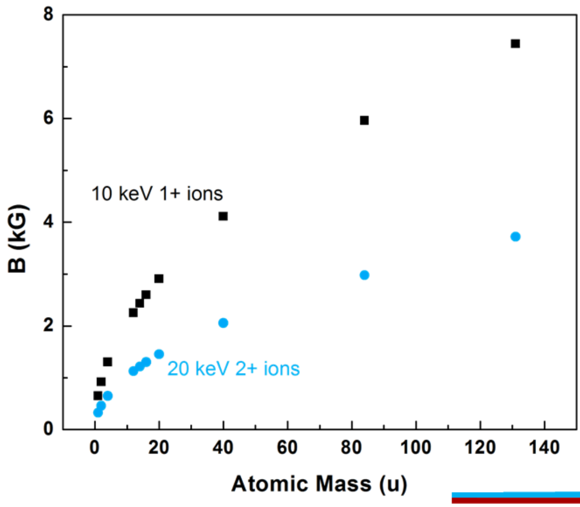

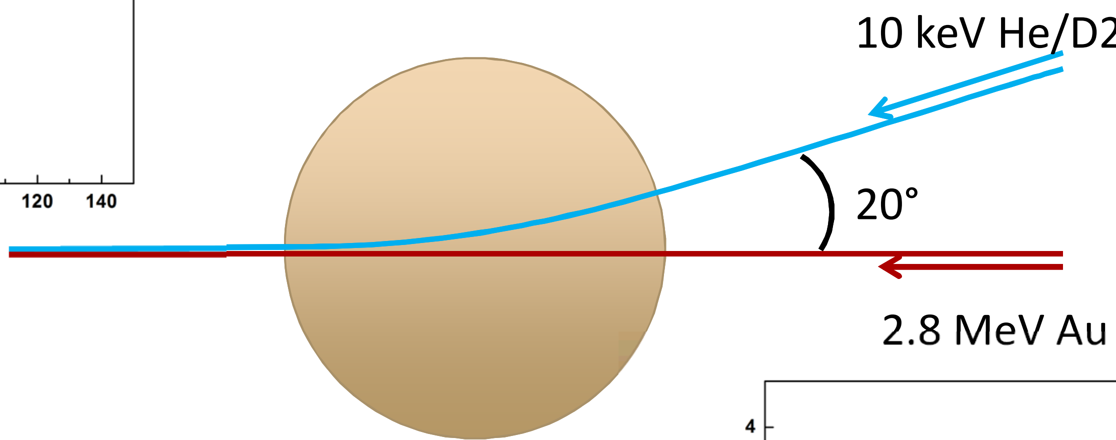

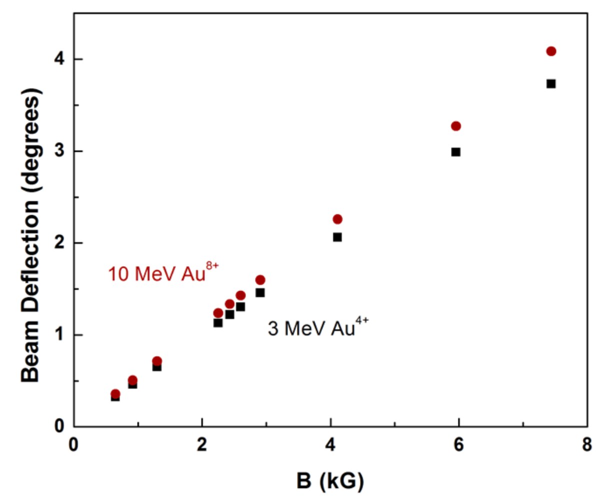

- Deflection can be accommodated for many heavy ion beams

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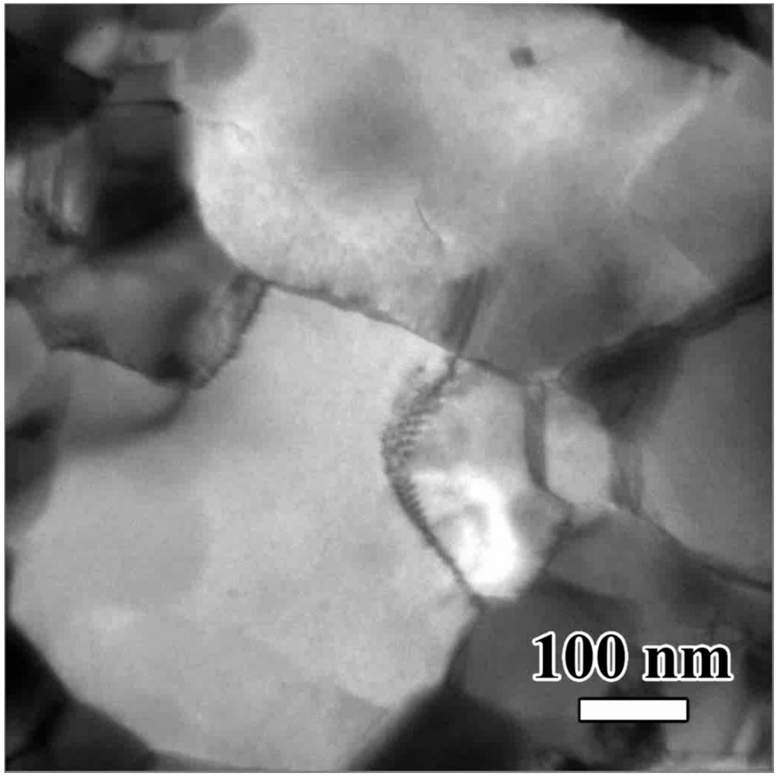
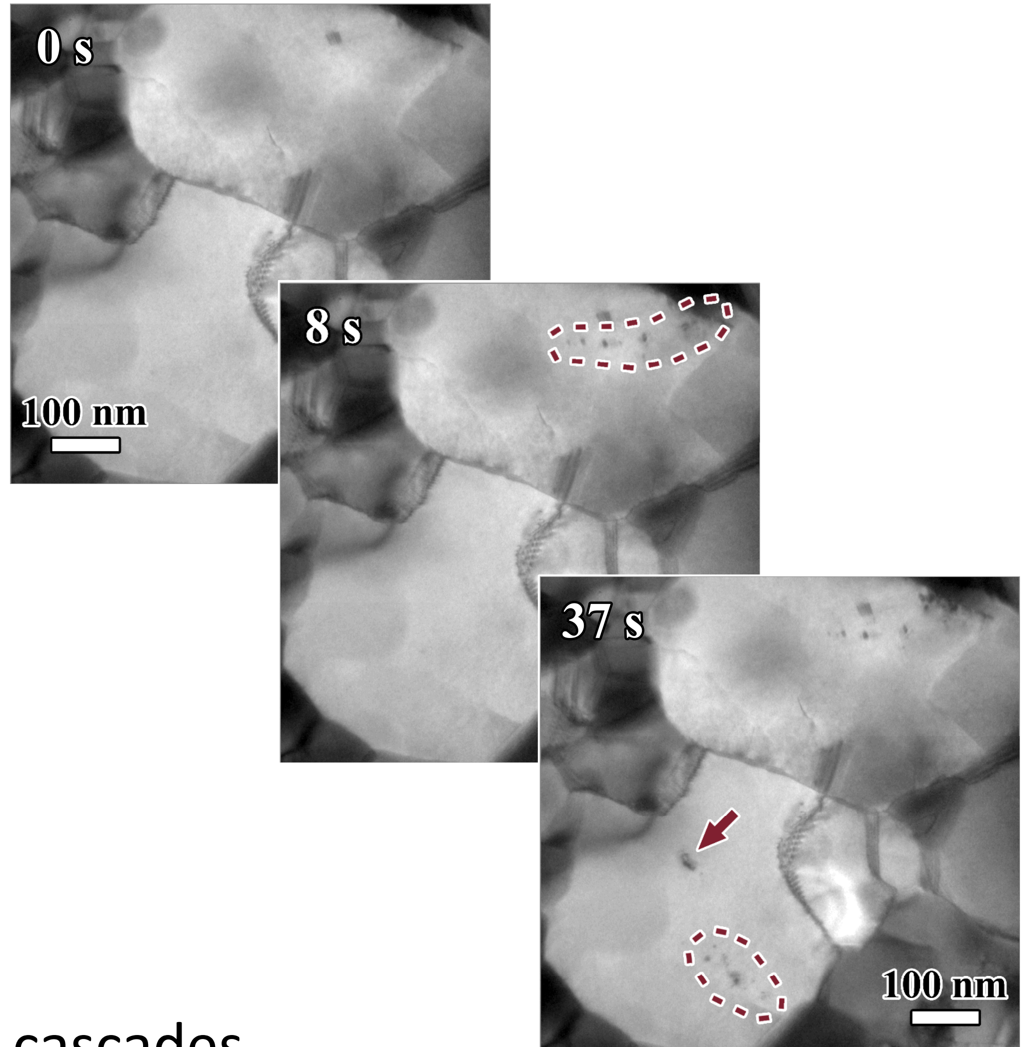
TEM: 2.8 MeV Au^{4+}

Video playback speed x5.

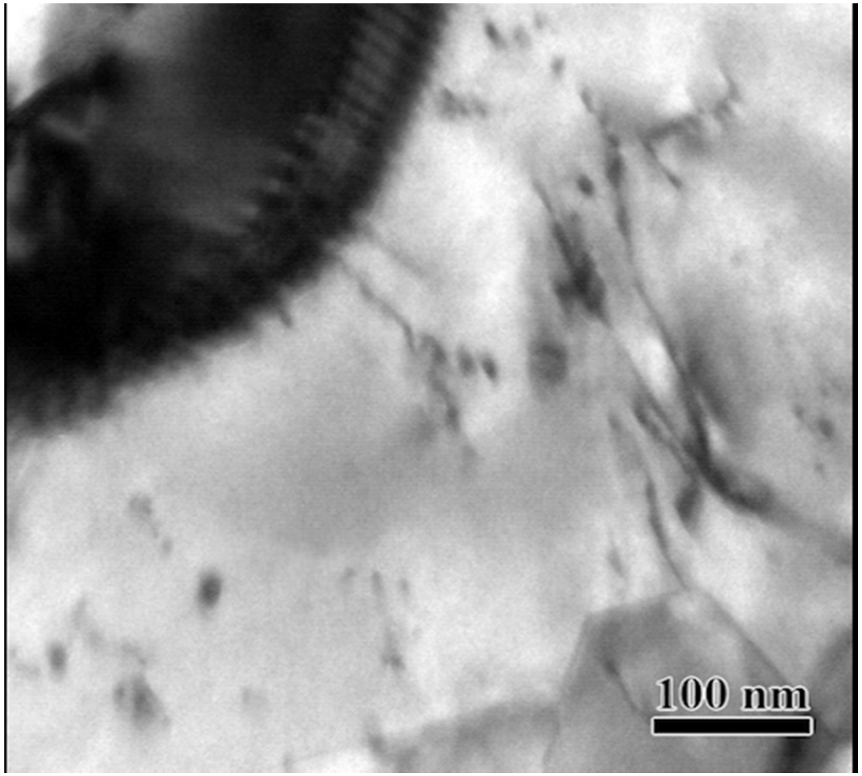


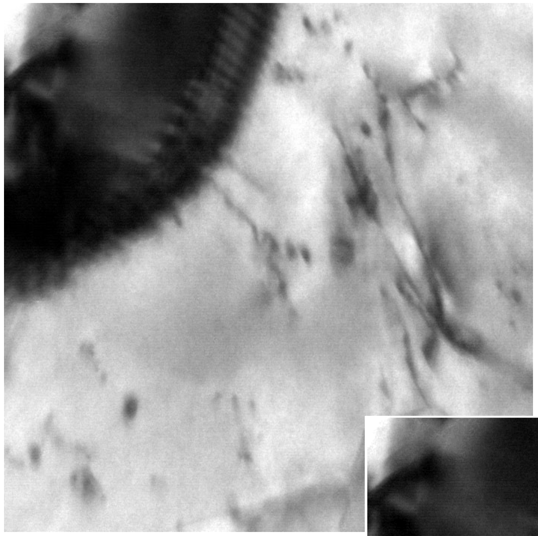


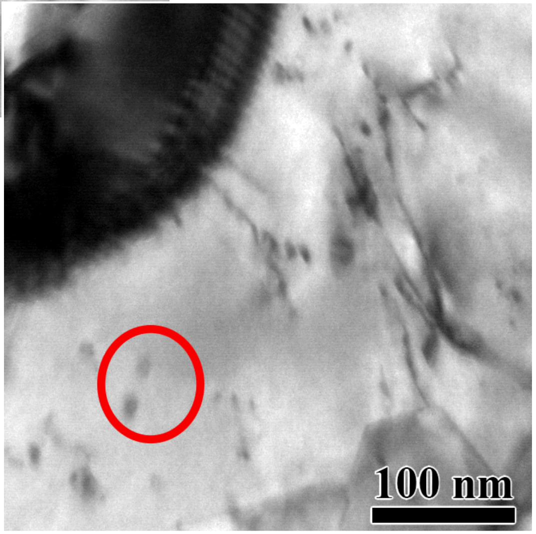
- Single Au ions
- Large defect clusters from cascades

2.8 MeV Au^{4+} + 10 keV He^{+}/D_2^{+}

Video playback speed in real time.



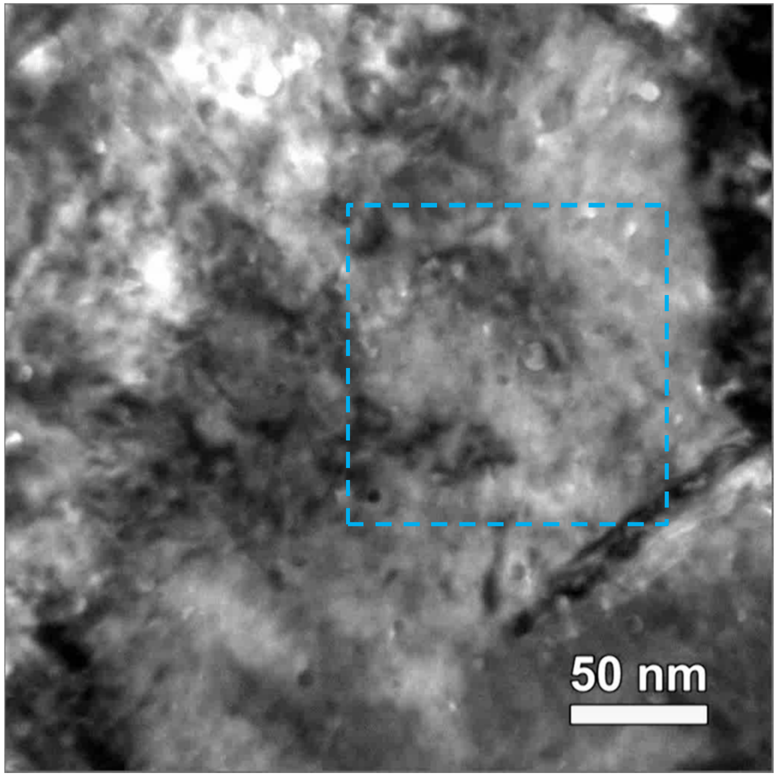


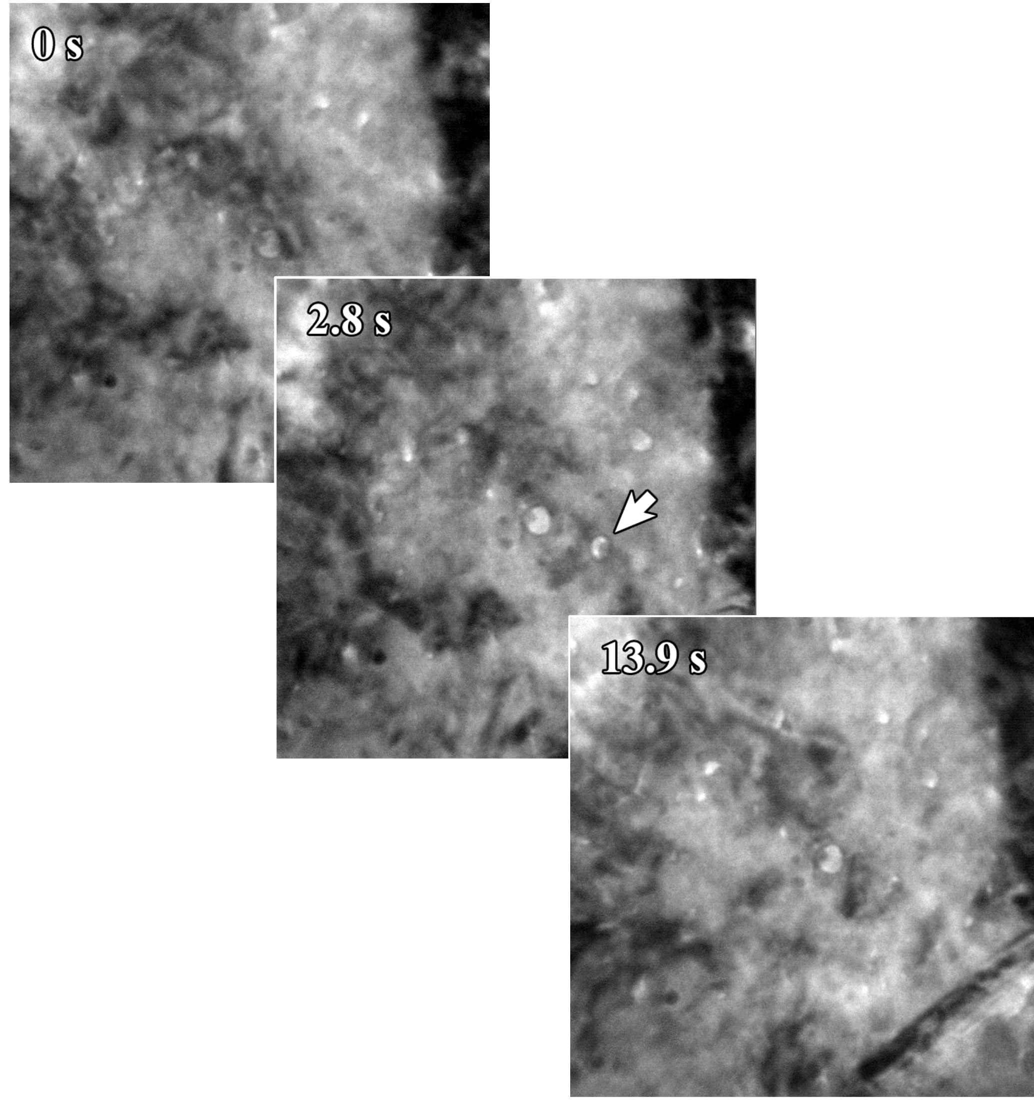


- Dislocation loop moves between two pinning sites
  - ~30 nm

2.8 MeV Au^{4+} + 10 keV He^{+}/D_2^{+}

Video playback speed x1.5.

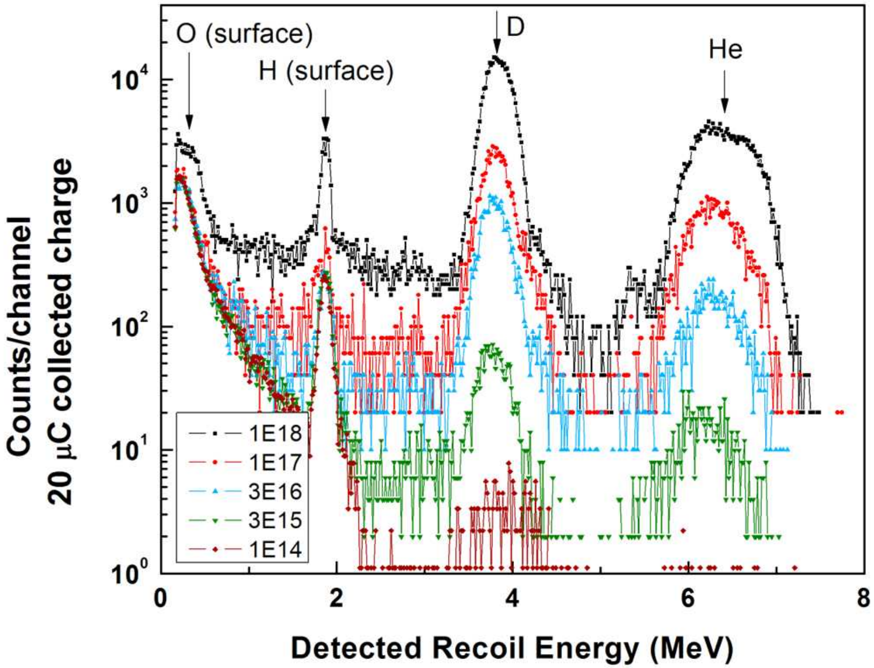


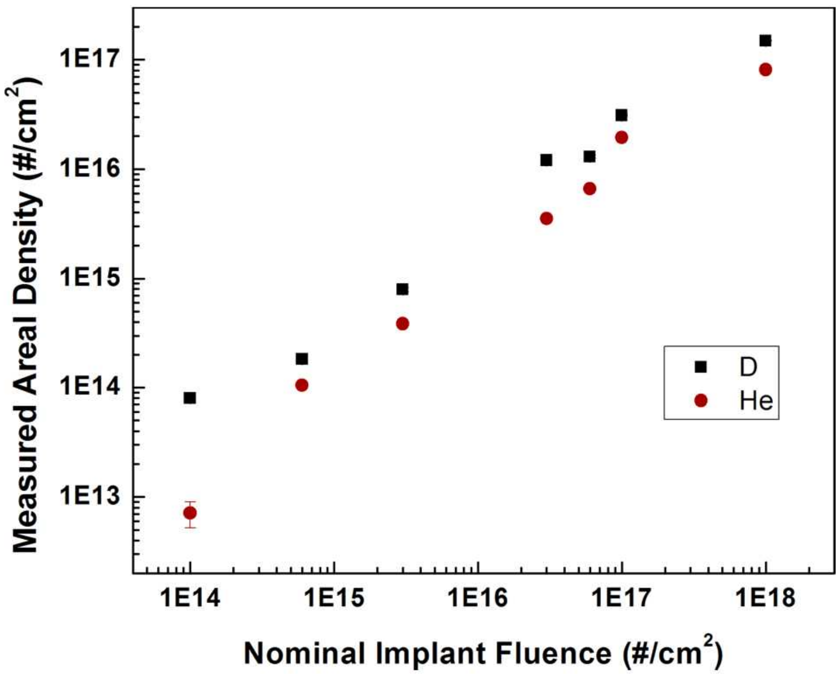


- Approximate fluence:
  - Au 1.2 $\times 10^{13}$ ions/cm^2
  - He 1.3 $\times 10^{15}$ ions/cm^2
  - D 2.2 $\times 10^{15}$ ions/cm^2
- Cavity nucleation and disappearance

ERD

- 10 keV He/D_2 beam into Si wafer





- Confirm that He and D are being implanted
- D/He ratio of ~1.8

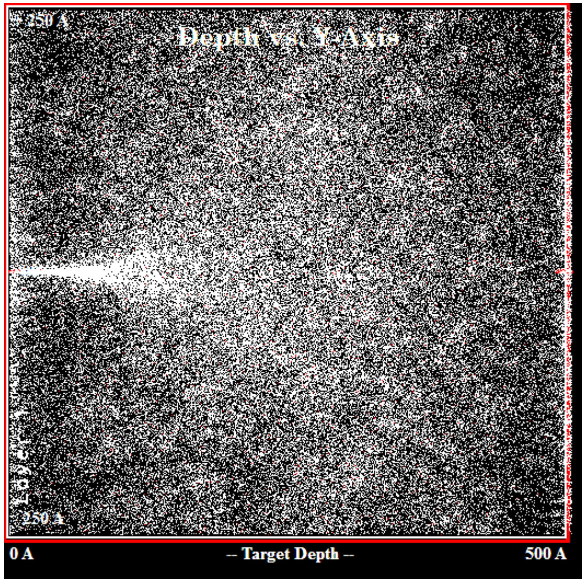
Summary

- Successfully constructed triple beam irradiation facility
- Confirmed beam composition
- Demonstrated results in a model system

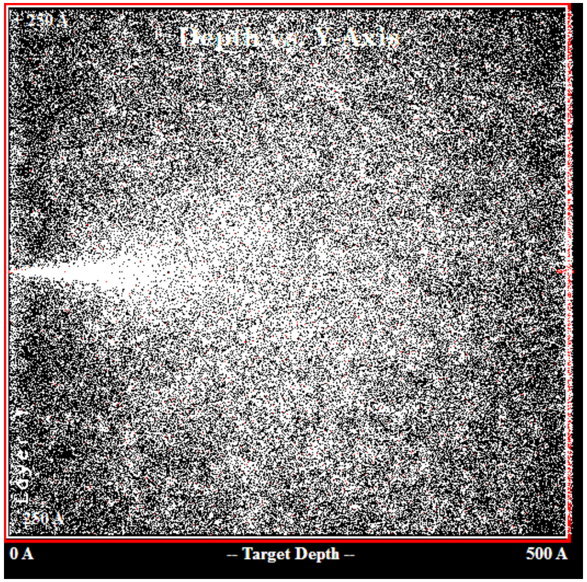
Future Plans

- Faster determination of beam composition
- Enhanced control of beam composition

SRIM range estimation



5 keV D



10 keV He

- Similar predicted end of range
  - 5 keV D: 22 nm
  - 10 keV He: 23 nm
- Well-suited for TEM foil thickness (nominally 50 nm in this work)