Proof of Concept for Tritium-based Accelerated Aging

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Beta Decay of Tritium

- Radioactive decay through emitting an energetic electron

\[ ^{3}_{1}H \rightarrow ^{3}_{2}He^{+} + \beta^{-} + \overline{\nu_{e}} \]

- 12.3 year half-life
  - Tritium storage materials
  - Plasma facing materials in fusion reactors
Helium Effects on Materials

- Insoluble in most materials
- Forms high pressure nanoscale bubbles
- Detrimental Impact on Mechanical Properties
  - Embrittlement
  - Fatigue
  - Swelling

Helium bubbles cause materials to become prone to unpredictable fracture and release of helium
Limitations in Studying Helium Evolution

1. Time consuming
2. Expensive
3. Difficult
   - 12.3 year half life of tritium
   - Complexity of radiological TEM sample preparation

The lack of realistic, validated accelerated aging methods has slowed progress in understanding helium bubble evolution.
Sandia’s Concurrent *In situ* Ion Irradiation TEM Facility

Heavy Ion Irradiation + Gaseous Implantation
Control ratio of dpa and gas species implantation and characterize coupling effects

Direct real time observation of ion irradiation, ion implantation, or both with nanometer resolution
The application of advanced microscopy techniques to characterize synergistic effects in a variety of extreme environments.
Radiation-Solid Interactions
Helium Interacts Strongly with Damage
Au film Before Implantation

- Columnar Grains range from tens of nm to over 300 nm.
- Through-focus imaging did not reveal any pre-existing cavities.
10 keV He into 40 nm Thick Gold Foil

Before Implantation

After Implantation
SRIM Simulation of 430 eV He+ in Au

430 eV He⁺ into Au

He⁺/cm²s

Depth (Å)

Helium Implantation Rate
Damage Rate
Home Made Faraday TEM Stage
Au Film After Room Temperature Implantation
10 keV helium ions in gold foil caused displacement damage (dislocation loops & other defects) with no visible helium bubbles.

430 eV helium ions caused no visible displacement damage, and resulted in high density of helium bubbles.
Self Ion Irradiation and Thermal Aging of Zirconium Alloys
3 MeV Self Ion Irradiation at 310 C

Before Irradiation

After Irradiation
≈ 7 DPA
3 MeV Self Ion Irradiation at 310 C
10 keV He\(^+\) Implantation at 310 C

Before Implantation

After Implantation
Damage, No Cavities
3 MeV Self Ion Irradiation after He$^+$ Implantation

High Density of Defects but No Cavities
He$^+$ Followed by Zr

On Axis
He$^+$ Followed by Zr
He\(^+\) Followed by Zr

Two Beam
g = 0002
Through Focus Imaging of Cavities: 30 Days Later

Under Focus

Over Focus

In Focus
Concurrent D & He Implantation & Zr Irradiation

After Implantation/Irradiation
Damage, No Cavities
Concurrent D & He Implantation & Zr Irradiation

Two Beam
$g = 1\bar{1}01$
Through Focus Images: 30 Days Later

Under Focus

In Focus

Over Focus
Thank You!