Novel Helium Ion Beam Degrader for the 88-Inch Cyclotron

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Introduction

- Helium generation can cause significant degradation of nuclear structural materials
- Ion beam implantations are widely performed to understand Helium effects in materials
- The volume of material that can be investigated is limited by ion beam energy and current
- Mechanical properties exhibit a strong size effect if samples are not sufficiently large[1]
- Deep ion implantation is needed to bridge experimental length scale gaps

Impact: Understanding Helium effects on nuclear structural materials is necessary to ensure the safety and functionality of current and future technologies. Coupling the Cyclotron with an ion beam degrader enables rapid turnaround testing of bulk-scale nuclear materials.

Objectives: Uniformly implant micro-mesoscale (100 μm) materials (HT-9) with Helium ions:

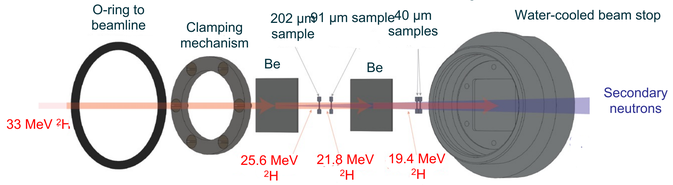
- Implant the samples using 206 discrete energy levels
- Use energy levels to implant at least 0.5 at% He in the sample volume
- Prevent heating of steel samples over 300 ºC
- Implant multiple samples in a single beam run

[1]P. Hosemann, C. Shin, D. Kiener; J. Mater. Res., 30 (2015), pp. 1231-1245

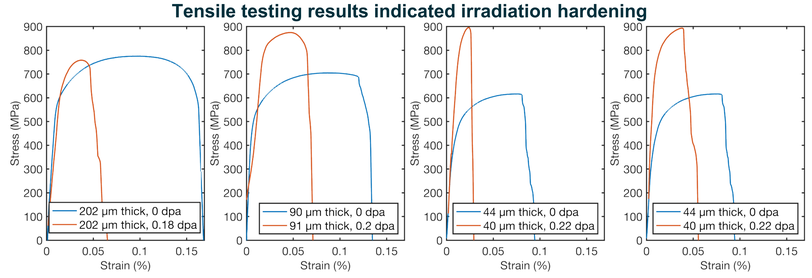
Preliminary Cyclotron Experiment

- 4 HT-9 samples were irradiated with 33 MeV deuterons then tensile tested at UC Berkeley
- This work established the beam stop design and radioactive samples tensile testing protocols

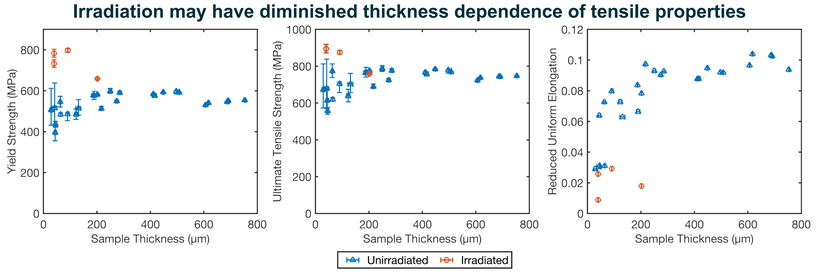
Schematic of the irradiation setup



Tensile testing results indicated irradiation hardening



Irradiation may have diminished thickness dependence of tensile properties

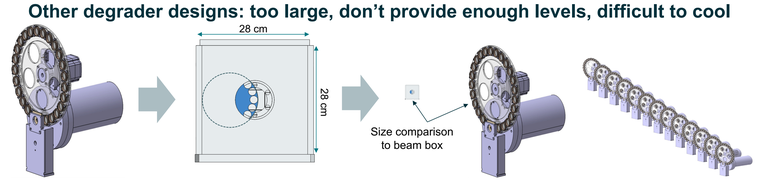


Degrader Design Constraints & Decisions

Design Criteria:

- Compact; fit in 21.5 cm x 28 cm x 28 cm beam box
- Implant 5 samples at once; 20 x 5 mm² beam spot
- Provide water cooling for in-beam components
- Produce >206 discrete energy levels

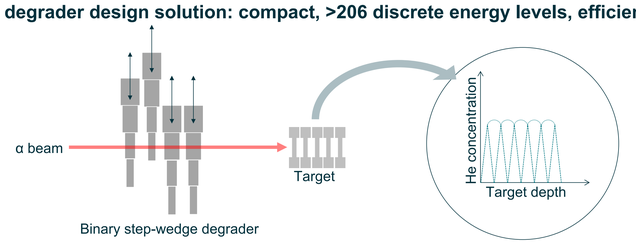
Other degrader designs: too large, don't provide enough levels, difficult to cool



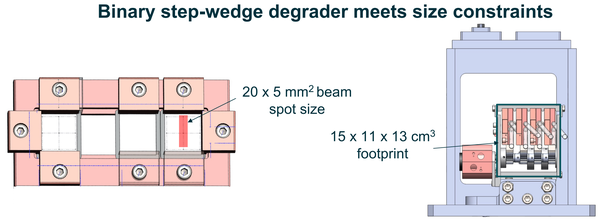
Modulator wheel example[2] | Max wheel diameter to fit in beam box: 13 cm | 1x 1.6 m diameter wheel for 206 levels | 16x 13 cm wheels for 206 levels

[2]Constanzo, J., Vanstalle, M., Finck, C., Brasse, D. & Rousseau, Med. Phys. 46, 2356–2362 (2019).

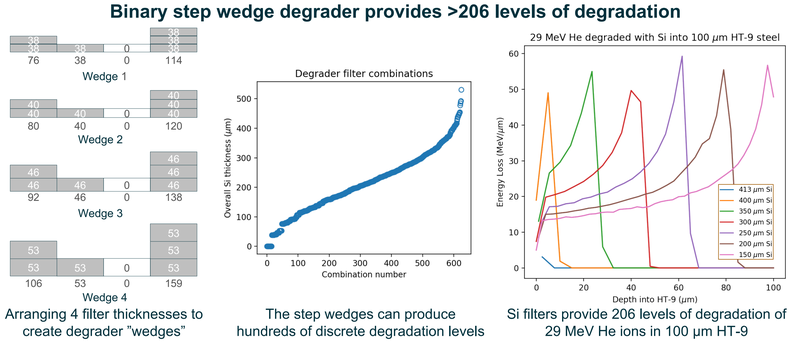
Our degrader design solution: compact, >206 discrete energy levels, efficient cooling



Binary step-wedge degrader meets size constraints



Binary step wedge degrader provides >206 levels of degradation



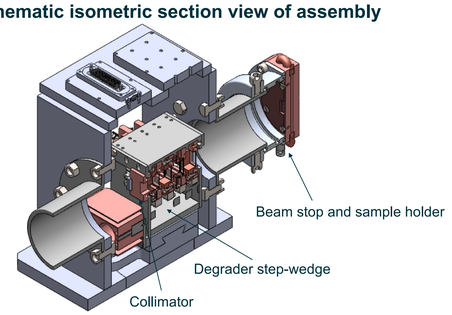
Arranging 4 filter thicknesses to create degrader "wedges"

The step wedges can produce hundreds of discrete degradation levels

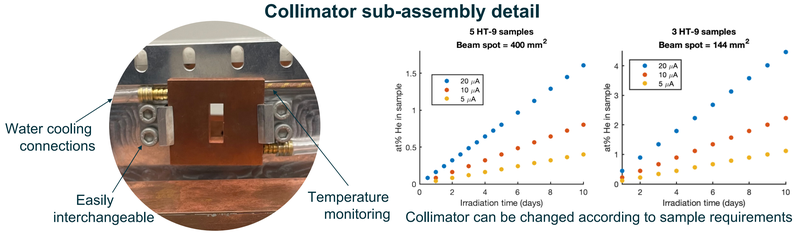
Si filters provide 206 levels of degradation of 29 MeV He ions in 100 μm HT-9

Final Degrader Design

Schematic isometric section view of assembly

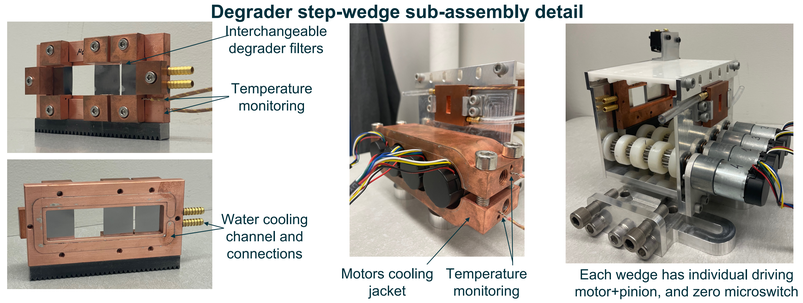


Collimator sub-assembly detail



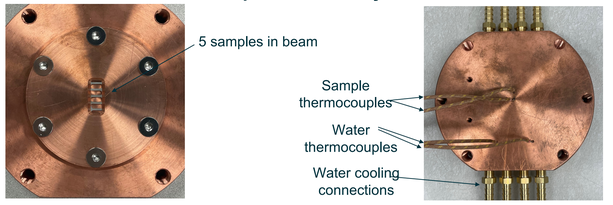
Collimator can be changed according to sample requirements

Degrader step-wedge sub-assembly detail



Each wedge has individual driving motor+pinion, and zero microswitch

Beam stop sub-assembly detail



Conclusions

- A novel ion beam degrader has been designed for uniform Helium implantation
  - Allows for the study of bulk Helium effects of a variety of materials and sample sizes
  - Fits in an average Cyclotron beam box, ~1ft³
  - Water cooled to prevent annealing of samples and in-beam components
  - Instrumented to monitor sample and in-beam component temperature

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National Nuclear Security Administration