High Power Production Target for FRIB

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Target Systems Group Leader

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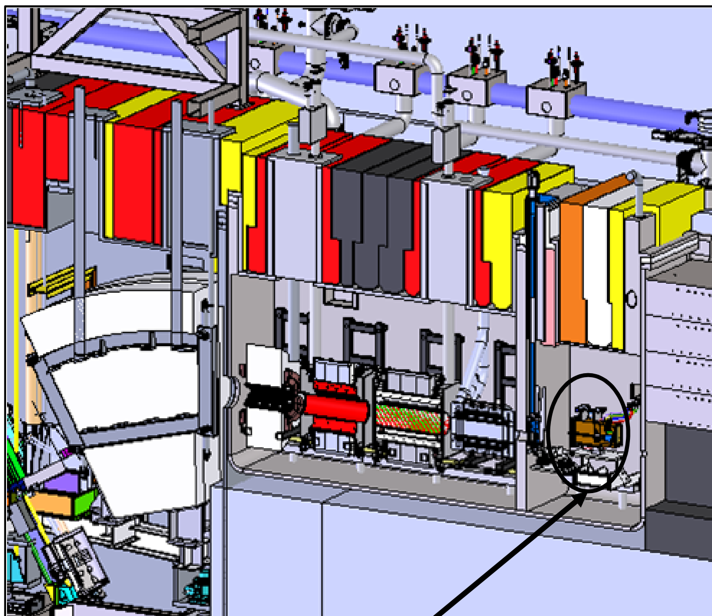
Outline

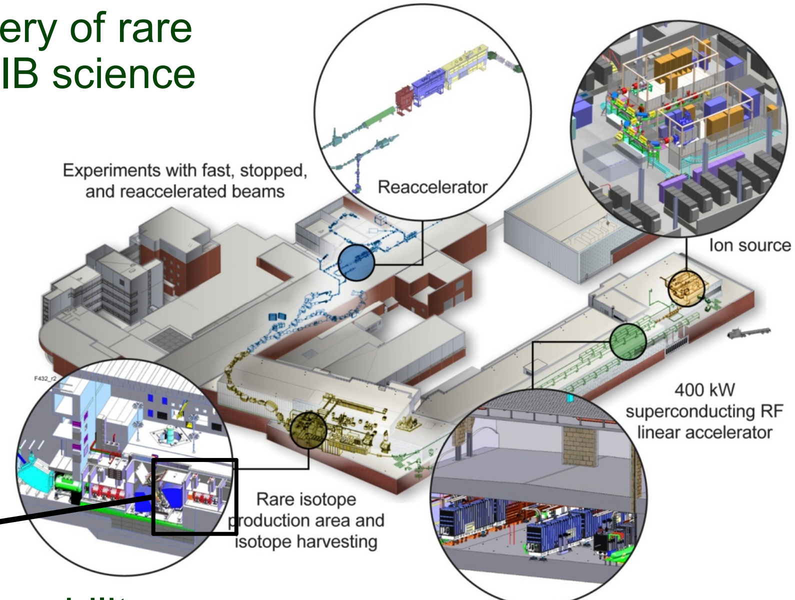
- Technical requirements and scope
- Rotating multi-slice target concept and challenges
- Single slice target development
- Prototyping to validate the concept
- FRIB target module design

FRIB High Power Production Target
Scope and Technical Requirements

- Three stage fragment separator for production and delivery of rare isotope with high rates and high purities to maximize FRIB science reach
- Primary beam power of 400 kW and beam energies of ≥ 200 MeV/u



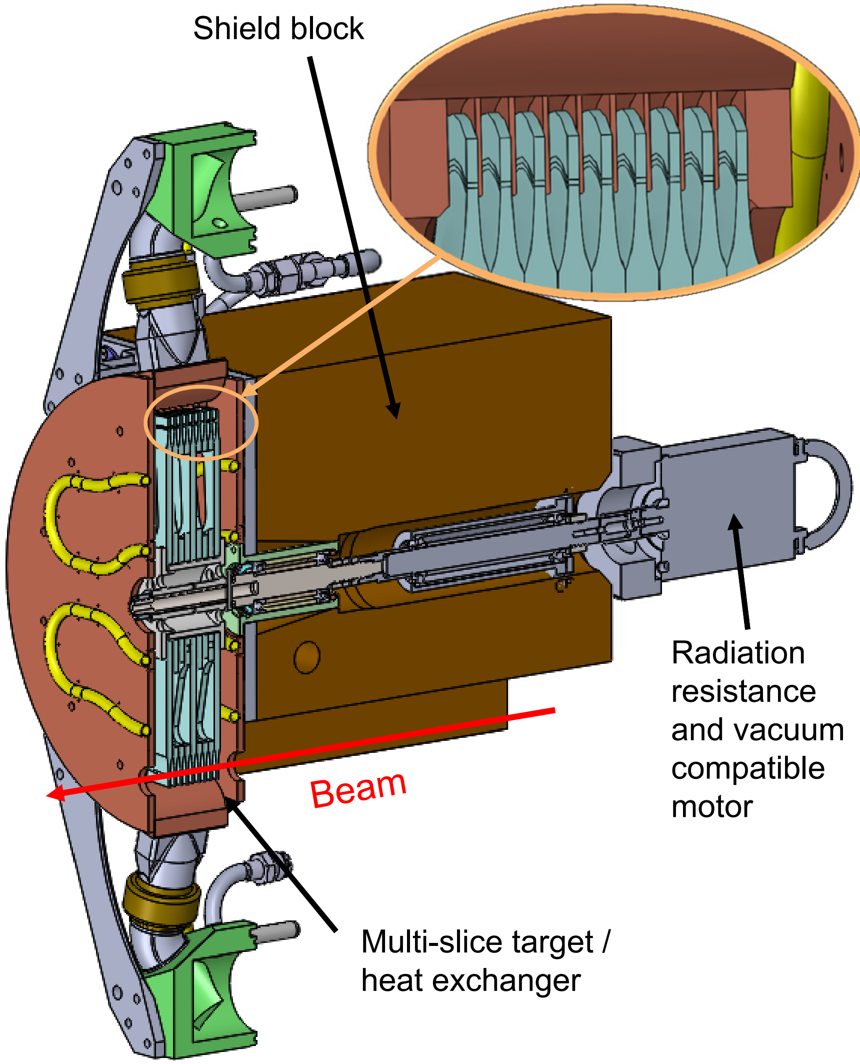
Production Target



- High power capability
  - Up to 100 kW in a ~ 0.3 - 8 g/cm² target for rare isotope production via projectile fragmentation and fission
- Required high resolving power of fragment separator
  - 1 mm diameter beam spot and maximum extension of 50 mm in beam direction
- Target lifetime of 2 weeks to meet experimental program requirements

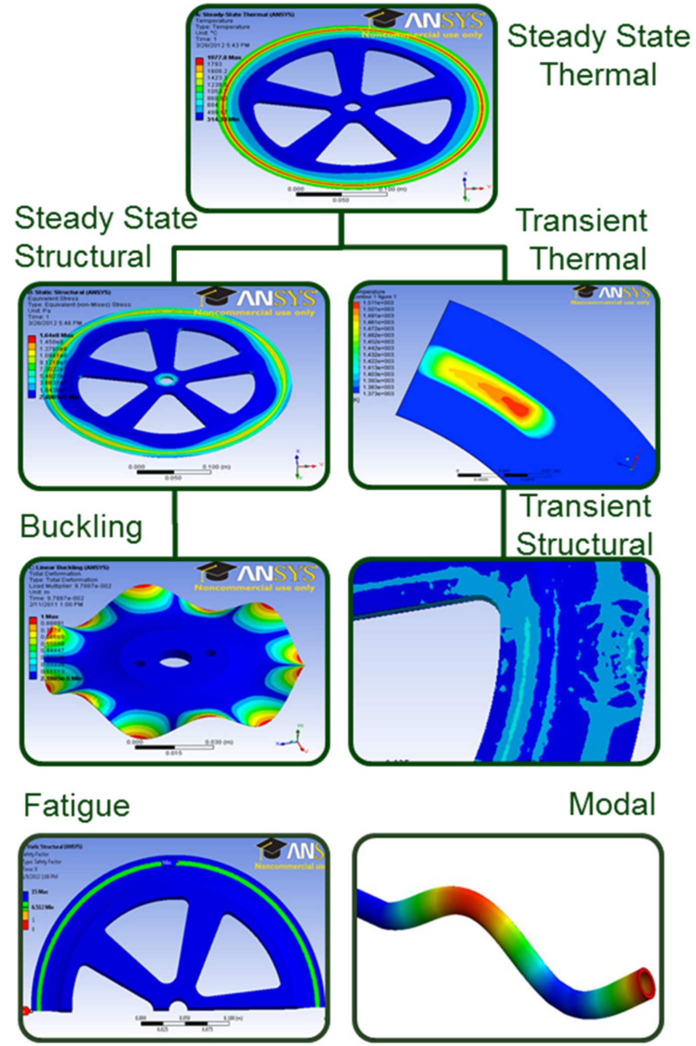
FRIB High Power Production Target
Rotating Multi-slice Graphite Target Design

- Rotating multi-slice graphite target chosen for FRIB baseline
  - Increased radiating area and reduced total power per slice by using multi-slice target
  - Use graphite as high temperature material
  - Radiation cooling
- Design parameters
  - Optimum target thickness is ~ ⅓ of ion range
    - » Each slice thickness 0.15 mm to several mm
  - Maximum extension of 50 mm in beam direction including slice thickness and cooling fins to meet optics requirements
  - 5000 rpm and 30 cm diameter to limit maximum temperature and amplitude of temperature changes



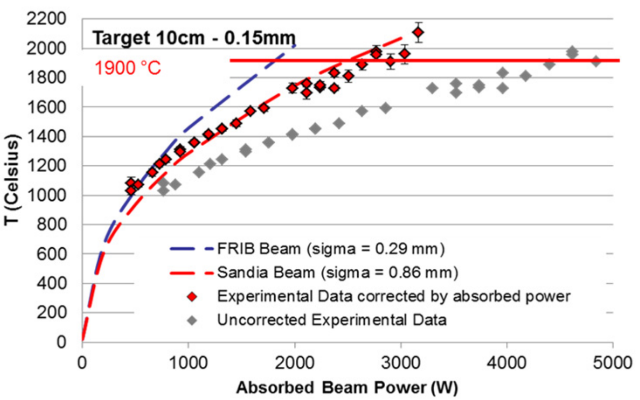
FRIB Production Target
Thermo-mechanical Challenges

- Thermo-mechanical challenges
  - High power density: ~ 20 - 60 MW/cm³
    - » High temperature
      - Maximum 1900ºC to mitigate evaporation of graphite
      - High thermal stress values
      - Deformation of the rim
  - Rotating target: 5000 rpm
    - » Temperature variation
      - Fatigue (Safety factor > 6)
      - Stress wave through the target (less than 10%)
    - » Inertia stress and Vibration
  - Multiple target slices: 2 - 9
    - » Maximum extent of target material is 50 mm in beam direction
      - Deformation of slices and fins needs to be considered

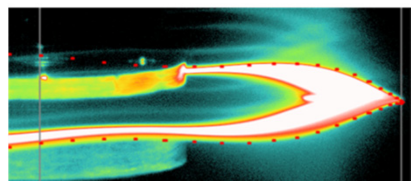


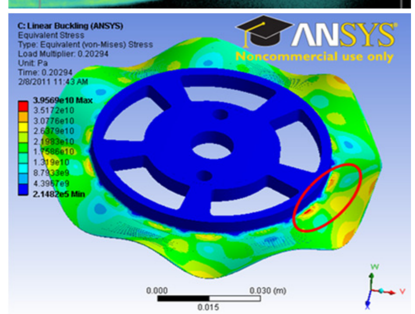
Single Slice Target Studies
Simulations validated and Lesson learned with Low Energy Electron Beam Tests

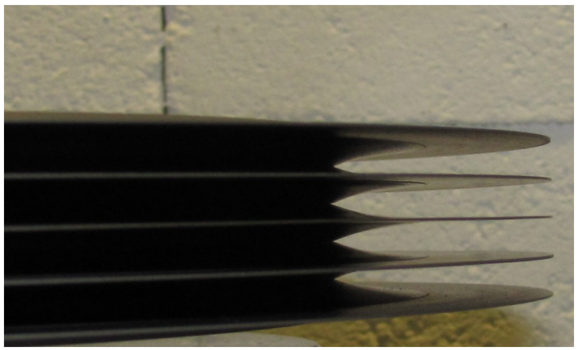
- Successful low energy electron beam tests at Sandia National Laboratories (2010) and SOREQ (2010)
- Based on experimental data and simulation results, target shape was optimized to better withstand the high thermal shock.

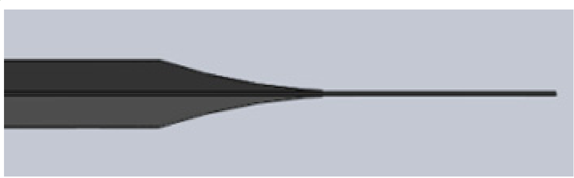


- Thermal simulations validated by experimental data
- Buckling analysis revealed stress concentrator locations in good agreement with experimental observation









SOREQ

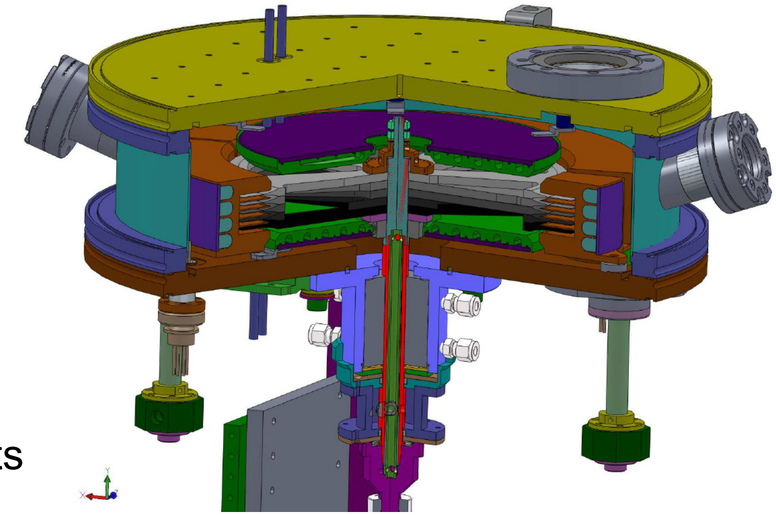
Sandia National Laboratories

F. Pellemoine et al., NIMA 655 (2011) 3-9

F. Pellemoine et al., J. Radioanal. Nucl. Chem. 299 (2014) 933-939

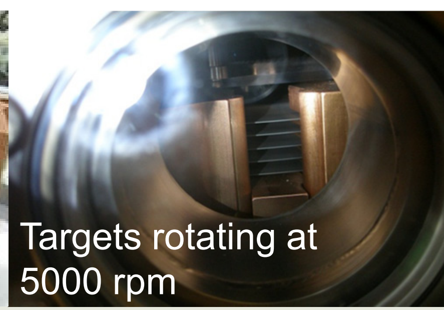
Multi-slice Target Studies
Simulations validated and Lesson learned with High Energy Electron Beam Tests

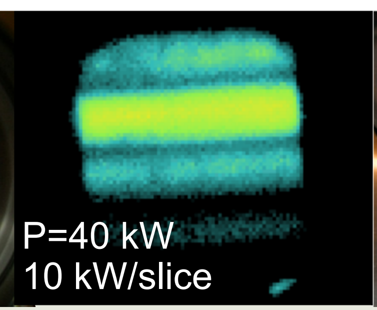
- Prototype for FRIB production target successfully tested with high energy electron beam at BINP-Novosibirsk (2012)
  - 5 slices – 0.5 mm - 5000 rpm - 30 cm diameter
  - Mechanical design validated and vibration optimized during mechanical tests at NSCL
  - Electron test demonstrated that FRIB power densities can be achieved
  - Valuable information input for final design of FRIB production target
    - » Design improvements of heat exchanger and targets themselves to reduce slice deformation
    - » Rim width reduced to 10 mm and increase space between fins of 1 mm

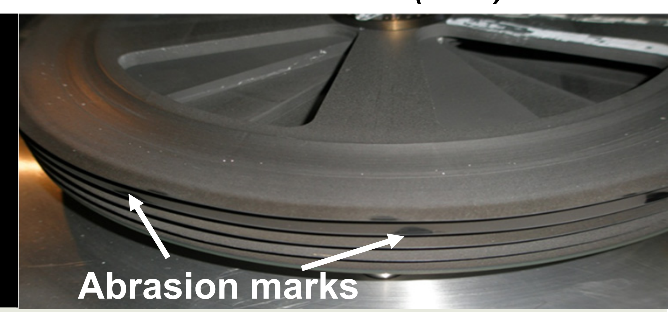


Budker Institute of Nuclear Physics

M. Avilov et al., J. Radioanal. Nucl. Chem. 305 (2015) 817-823

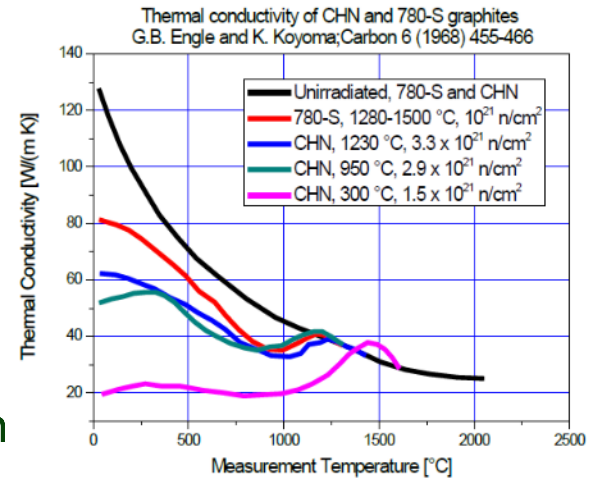






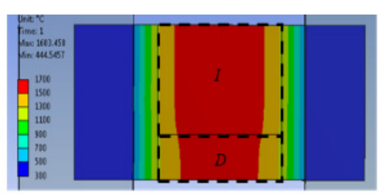
Radiation Damage Studies in Graphite For Better Lifetime Predictions

- Swift Heavy Ion (SHI) effects on graphite
  - $5 \cdot 10^{13}$ U ions/s at 203 MeV/u may limit target lifetime
    - Fluence of ~$9.4 \cdot 10^{18}$ ions/cm² and 10 dpa estimated for 2 weeks of operation



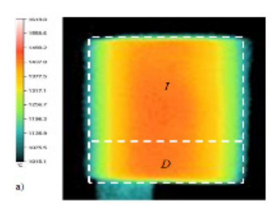
- Radiation damage induce material changes ⇨ decrease target performance
- Swift heavy ions (SHI) damage not well-known and most of the studies were done with neutron and proton irradiation
- How much will annealing help?
- Graphite irradiated with Au-beam 8.6 MeV/u at UNILAC at GSI-Darmstadt
  - Up to $5.6 \cdot 10^{10}$ cm^{-2}.s^{-1}, Fluence up to 10^{15} cm^{-2}
  - Samples heated to different temperature

I = 35 A + beam

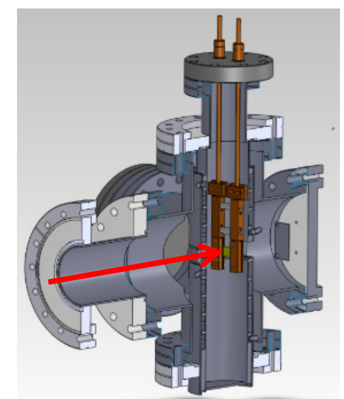


T_{max} = 1600 ºC

I = 35 A

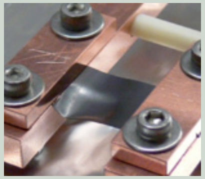


T_{max} = 1480 (± 30 ºC)



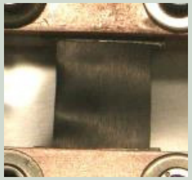
Radiation Damage Studies in Graphite [1]
Annealing of Damage at High Temperature (> 1300ºC)

1 A - 350°C
10^{14} cm^{-2}

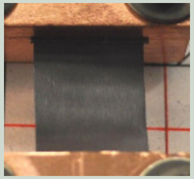


11 A - 750°C
10^{14} cm^{-2}

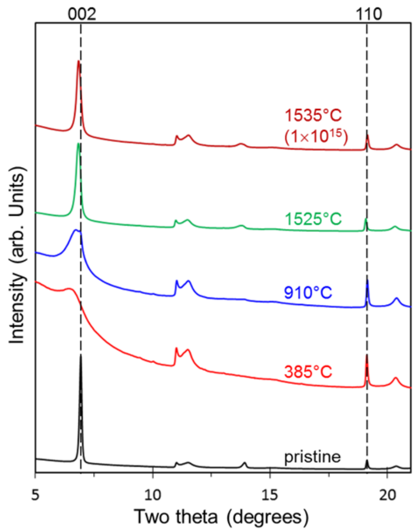
25 A - 1205°C
10^{14} cm^{-2}

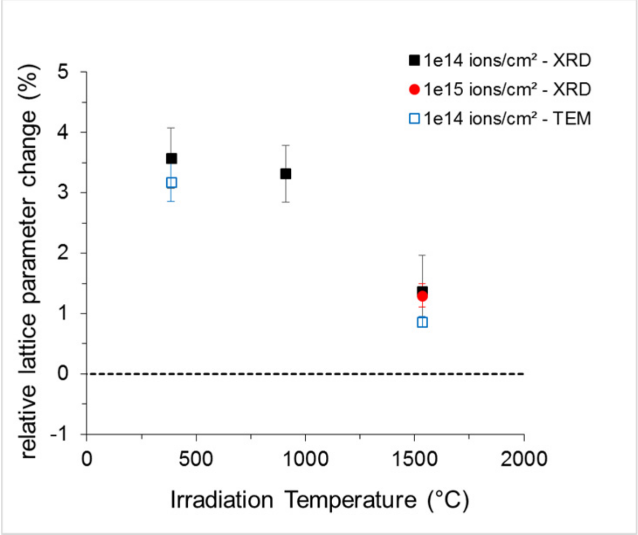


35 A - 1635°C
10^{15} cm^{-2}

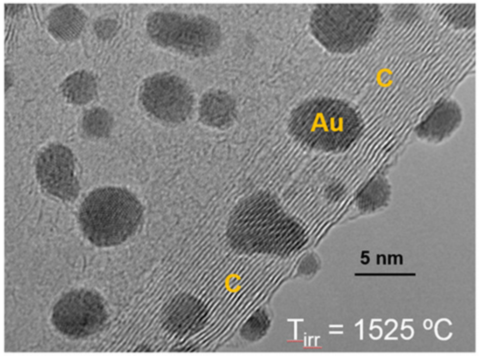


X-Ray Diffraction analyses

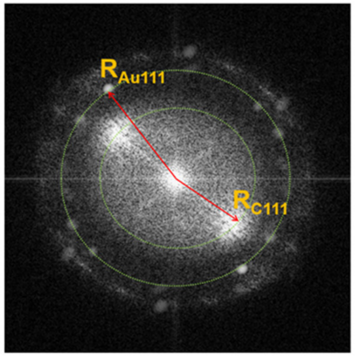




TEM analyses



FFT

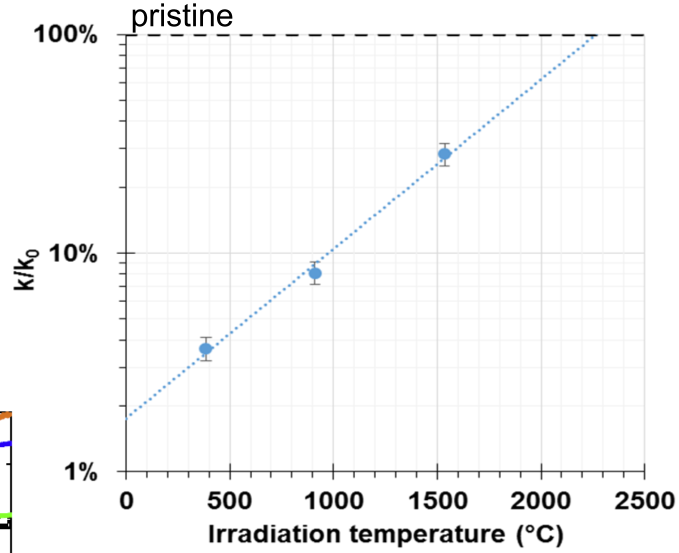


Nearly complete recovery from swelling at irradiation temperatures above ~1500 ºC

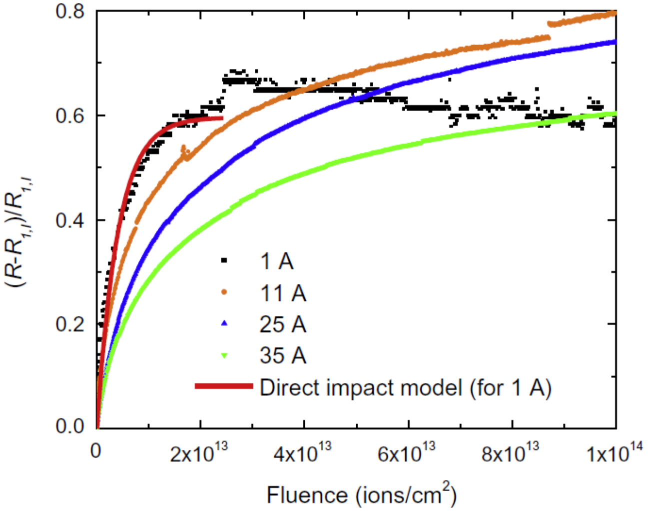
F. Pellemoine et al., NIMB 365 (2015) 522-524

Radiation Damage Studies in Graphite [2]
Annealing of Damage at High Temperature (> 1300ºC)

Thermal conductivity change of irradiated graphite samples - ^{197}Au fluence 10^{14} ions/cm²

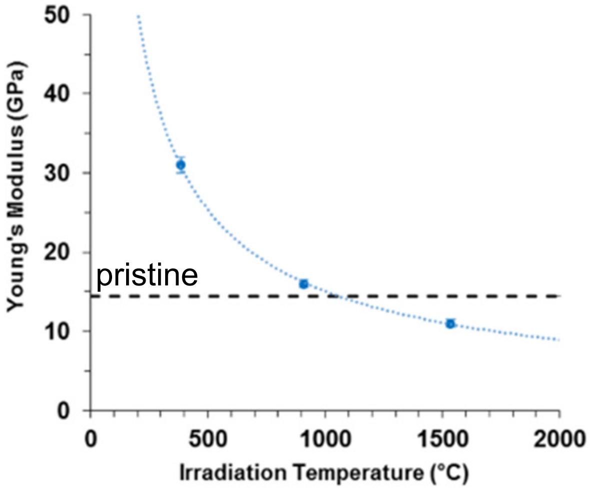


Electrical resistance change of irradiated graphite samples - ^{197}Au



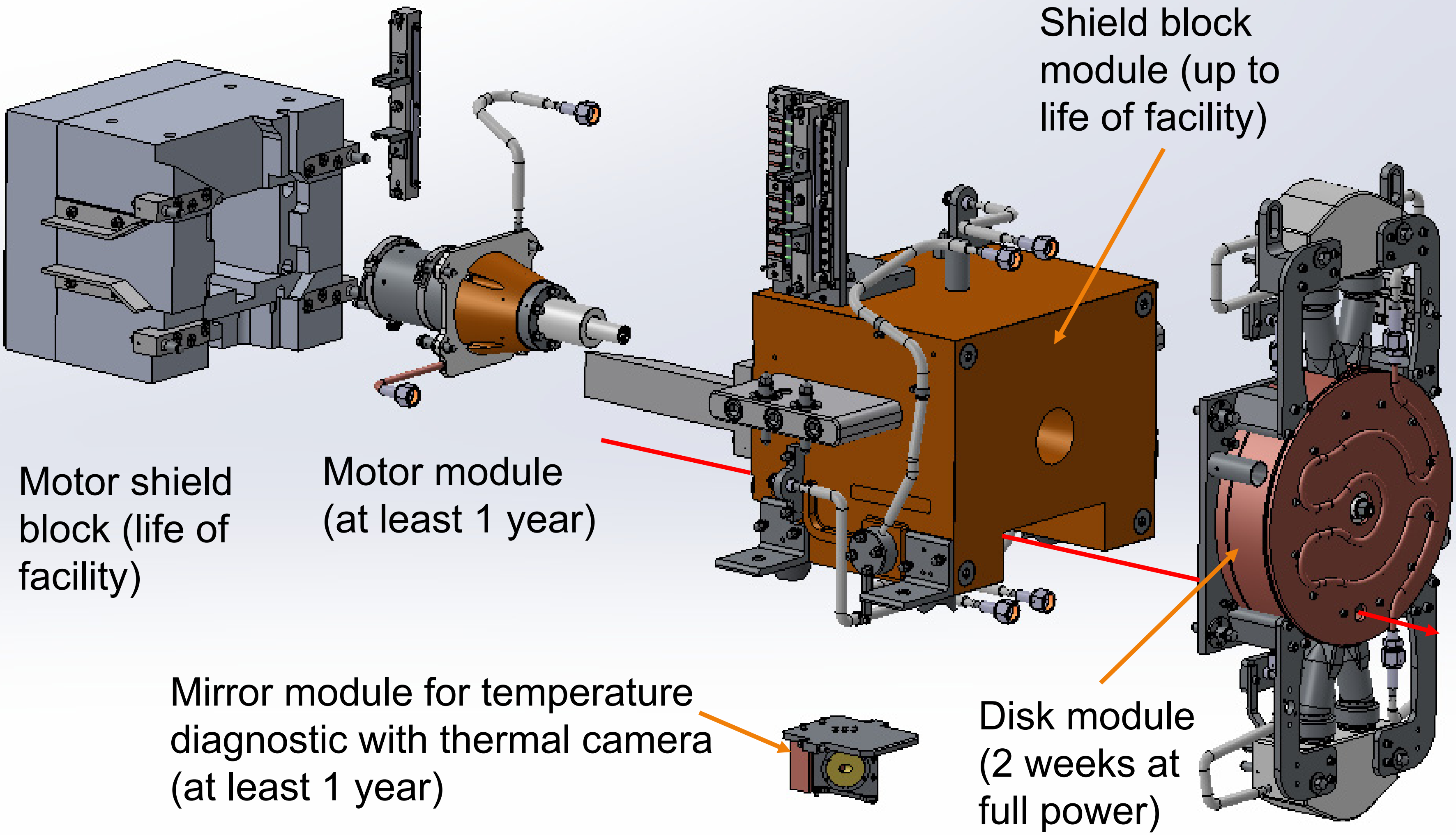
S. Fernandes et al., NIMB 314 (2013) 125-129

Young's Modulus of irradiated graphite samples - ^{197}Au fluence 10^{14} ions/cm²



- Annealing at high temperature confirmed

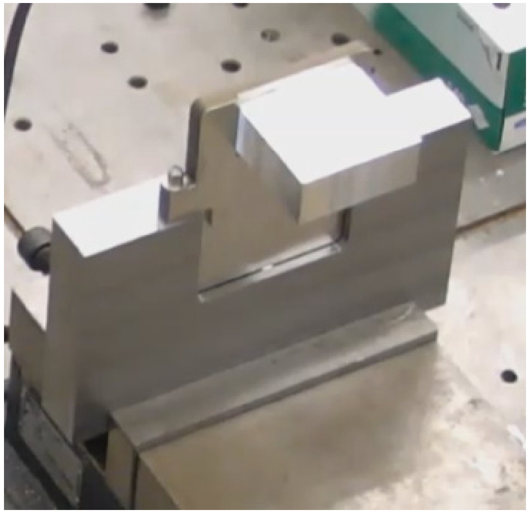
Target Module Design
With Expected Lifetimes at Full Power



Target Design Refinements
Validating Design for Remote Handling

- Full scale wood mock-up and remote handling (RH) fasteners have been fabricated for RH cold testing
- Mockup tests successfully performed using this and other configurations
  - Electrical connector replacement
  - Disk module bearing and shield block interface
  - Mirror module to shield block replacement






Summary

- Thermo-mechanical simulations and testing validate multi-slice target concept and support production target final design
- Production target material studies support final design
  - Graphite radiation damage studies promise a sufficient lifetime for FRIB production target
  - Simulations and design studies for simplification of design – will reduce operational costs
- Near-term
  - Ordering of long lead time items first complete, all remaining orders to be complete by November, 2016
  - Finalize remaining design: lifting frame; in-vacuum shielding; utility connections
- Long-term
  - Procurement underway
  - Assembly completion expected by 5/2017
  - Installation in September 2017

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Thank you for your attention