High Power Production Target for FRIB

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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 \( \geq 200 \text{ MeV/u} \)

- High power capability
  - Up to 100 kW in a \( \sim 0.3 - 8 \text{ g/cm}^2 \) 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
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 $\frac{1}{3}$ 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
Thermo-mechanical challenges

- High power density: ~ 20 - 60 MW/cm³
  - High temperature
    - Maximum 1900°C 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

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

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

Radiation damage induce material changes $\Rightarrow$ 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

$T_{\text{max}} = 1600$ °C

$I = 35$ A

$T_{\text{max}} = 1480$ (± 30 °C)
Radiation Damage Studies in Graphite [1]
Annealing of Damage at High Temperature (> 1300ºC)

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

X-Ray Diffraction analyses

TEM analyses

Nearly complete recovery from swelling at irradiation temperatures above ~1500 °C
Radiation Damage Studies in Graphite [2]
Annealing of Damage at High Temperature (> 1300°C)

- Thermal conductivity change of irradiated graphite samples - $^{197}$Au fluence $10^{14}$ ions/cm²
- Electrical resistance change of irradiated graphite samples - $^{197}$Au
- Young's Modulus of irradiated graphite samples - $^{197}$Au fluence $10^{14}$ ions/cm²

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

- Annealing at high temperature confirmed
Target Module Design
With Expected Lifetimes at Full Power

Motor shield block (life of facility)

Motor module (at least 1 year)

Mirror module for temperature diagnostic with thermal camera (at least 1 year)

Shield block module (up to life of facility)

Disk module (2 weeks at full power)
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