# Irradiation Effect on Ferro Fluid Rotary Feedthrough and Permanent Magnet Performance

Frederique Pellemoine on behalf of FRIB

RaDIATE Collaboration Meeting – Nick Simos Memorial Session

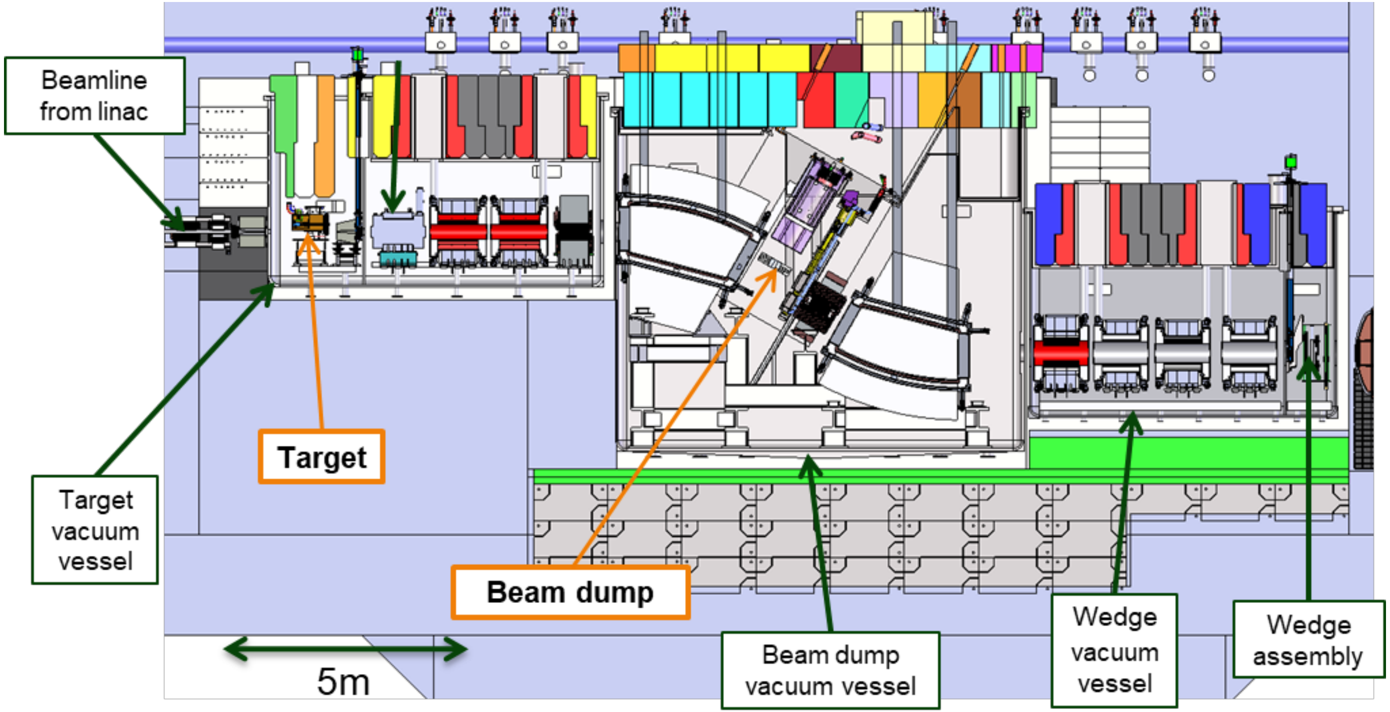
27 June 2023

# Outline

- Context of the studies back in 2011
- Ferrofluidic study
- Permanent magnet study

# Facility for Rare Isotope Beams - status in 2012

- Rare isotope production targets and beam dumps compatible with beam power of 400 kW at 200 MeV/u for $^{238}U$ (>200 MeV/u for lighter ions)

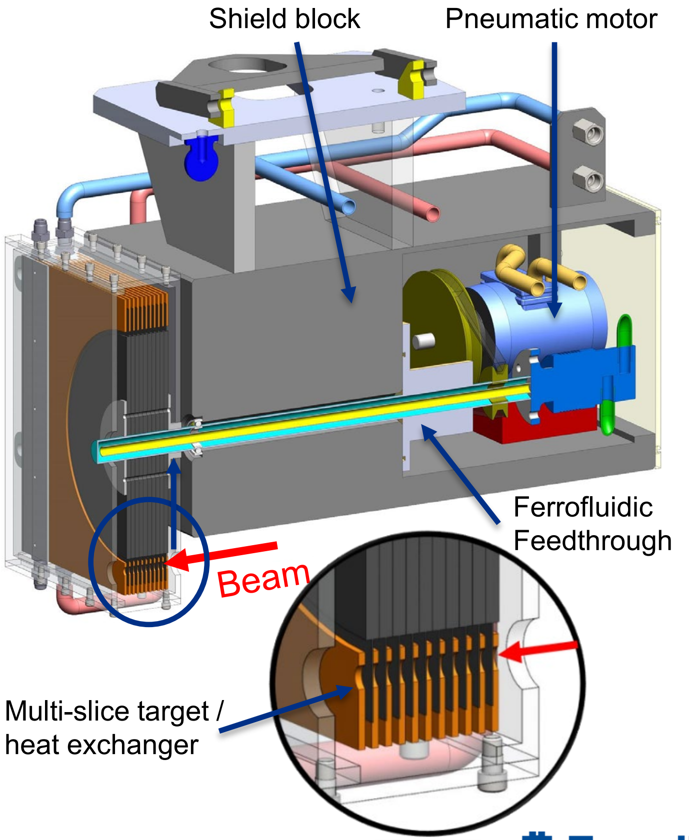




Facility for Rare Isotope Beams at Michigan State University
Fermilab

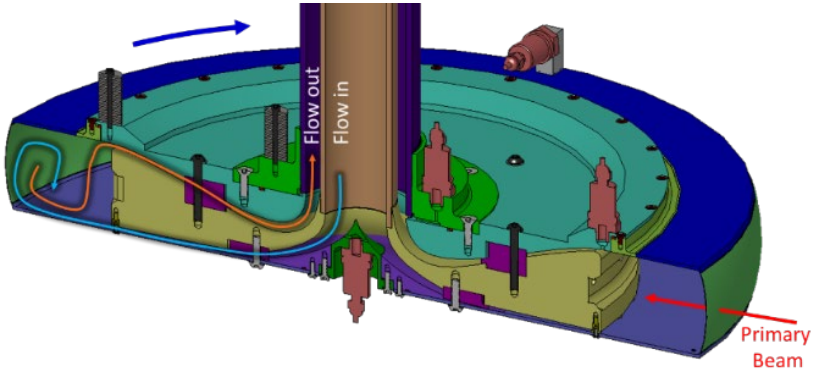
# FRIB Production Target
# Rotating Multi-slice Graphite Target Design

- Rotating multi-slice graphite target chosen for FRIB baseline
  - Multiple rotating target slices
  - Thermal radiation cooling
- Target requirements
  - Up to 100 kW power deposition in 1 mm diameter beam spot
  - Target lifetime 2 weeks to meet experimental program requirements
- Target parameters defined by thermo-mechanical simulations
  - 5000 RPM and 30 cm diameter to limit maximum temperature and amplitude of temperature changes
    - » High temperature: ~ 1900ºC
      - Evaporation of graphite mitigated



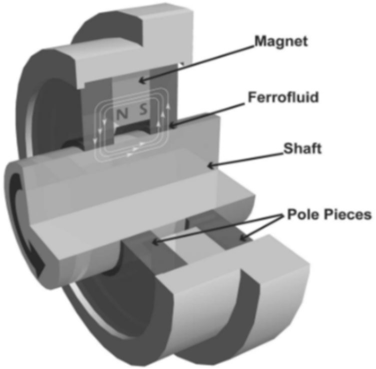
# FRIB Beam Dump
# Water-filled rotating drum beam dump concept

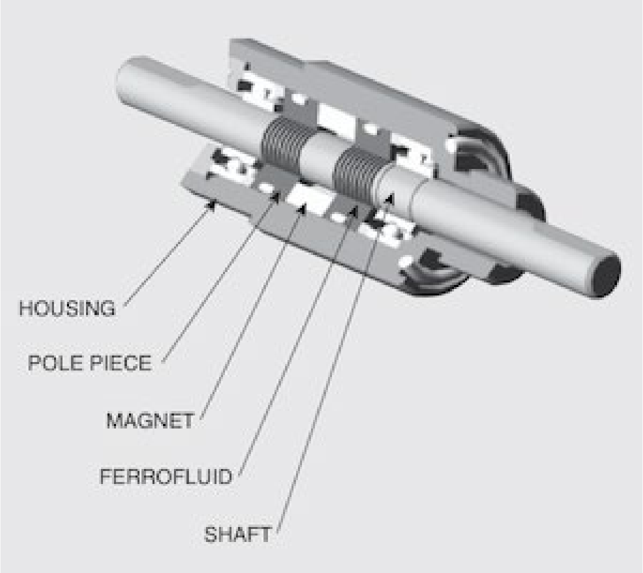
- Water-filled rotating drum beam dump chosen for FRIB baseline
- Parameters defined by thermo-mechanical simulations
  - 400 RPM rotational speed and 70 cm diameter to limit maximum temperature and amplitude of temperature changes
- Understanding Swift Heavy Ion (SHI) effects on Ti-alloy that can limit beam dump lifetime
  - Sputtering
  - Radiation damage on material
  - Combined effects – corrosion combined with radiolysis, thermal and irradiation creep
- No heavy ion beam facility exists that allows us to test all challenges combined together
  - Perform studies that combine some material challenges using existing facilities
    - » Electron beams, neutron beams, SHI beams
    - » Radiation damage, corrosion, creep



# Design Support for Target and Beam Dump Radiation Effects in Ferrofluidic Feedthroughs

- Ferrofluidic Feedthrough will be used in both units (target and beam dump)
  - Several ferrofluid “O-rings” maintained in place by 1 permanent magnet and 2 pole pieces




- Maximum dose to Ferrofluidic Feedthroughs
  - Target (2 weeks of operation)
    - » 1 MGy ($^{18}O$ beam at 266 MeV/u with 15” cast iron shielding)
    - » Estimate 7.5 MGy without shielding
  - Beam dump (1 year of operation)
    - » 3.5 MGy ($^{18}O$ beam, 637 MeV/u (conservative upgrade-energy assumption) with 5” of steel shielding)

# Nick involvement

- Nick offered his help to perform irradiation study of Ferrofluidic feedthrough
  - ➢ The idea was to irradiate on FFFT at BLIP up to 20 MGy
- It ended with 2 great studies and 2 papers

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Performance degradation of ferrofluidic feedthroughs in a mixed irradiation field

Nikolaos Simos[a,*], S. Fernandes[b], Wolfgang Mittig[b,c], Frederique Pellemoine[b], M. Avilov[b], M. Kostin[b], L. Mausner[a], R. Ronningen[b], M. Schein[b], G. Bollen[b]

[a] Brookhaven National Laboratory BNL, Upton, NY 11973, USA
[b] Facility for Rare Isotope Beams (FRIB), Michigan State University, East Lansing, MI 48824, USA
[c] National Superconducting Cyclotron Laboratory NSCL, Michigan State University, 640 South Shaw Lane, East Lansing, MI 48824-1321, USA

Nuclear Instruments and Methods in Physics Research A 841 (2017) 144–155

*Simos et al: ID_TMAG-16-09-0726*

**Demagnetization of $Nd_2Fe_{14}B$, $Pr_2Fe_{14}B$ and $Sm_2Co_{17}$ permanent magnets in spallation irradiation fields[$]**

N. Simos[1*] and S. Ozaki[1]
N. Mokhov[3], A. Zeller[2], W. Mittig[2] and F. Pellemoine[2]

(1) Brookhaven National Laboratory BNL, Upton NY 11973, USA
(2) Facility for Rare Isotope Beams (FRIB), Michigan State University, East Lansing MI 48824, USA
(3) Fermi National Accelerator Laboratory, Batavia, IL 60510, USA



Facility for Rare Isotope Beams at Michigan State University

Fermilab

# Radiation Effects in Ferrofluidic Feedthroughs

- FFFT irradiation tests at BNL in June 2011
  - 0.2, 2, 20 MGy mixed proton, neutron and gamma irradiation from stopped proton beam

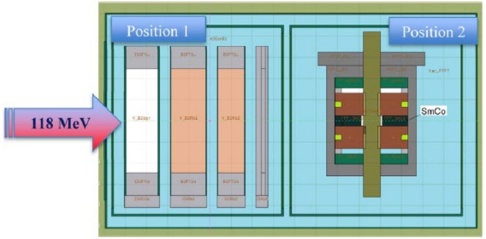


Fig. 2. Detailed FLUKA model of irradiation station layout at BLIP including upstream spallation target configuration and FF orientation.

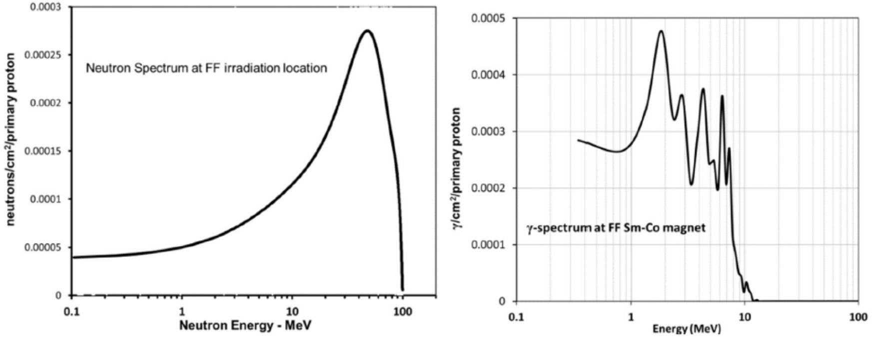


Fig. 5. Neutron and γ energy spectra at the upstream face of the Sm-Co magnet of the irradiated FF.

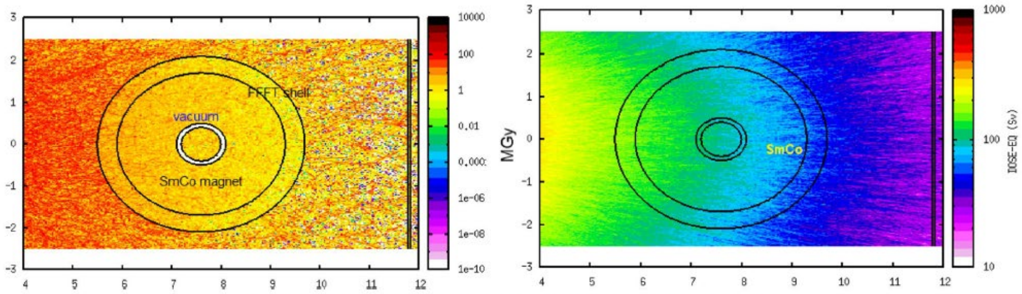


Fig. 4. Dose profile for the Sm-Co-type FF seal (peak dose 20 MGy) and equivalent dose (Sv).

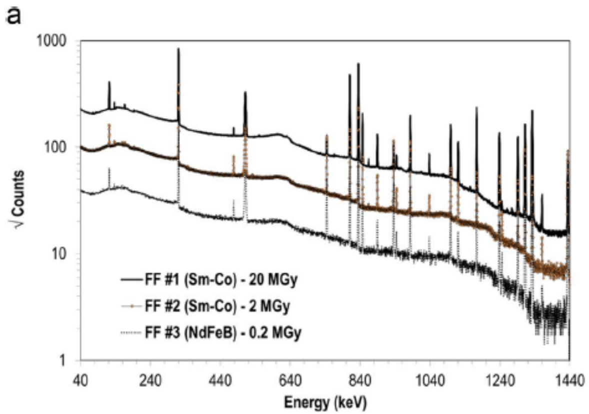
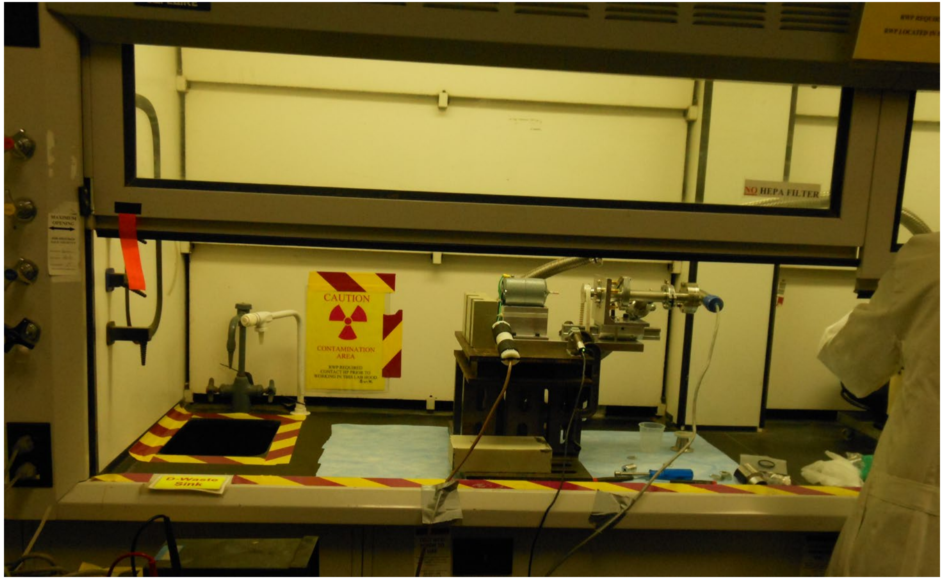
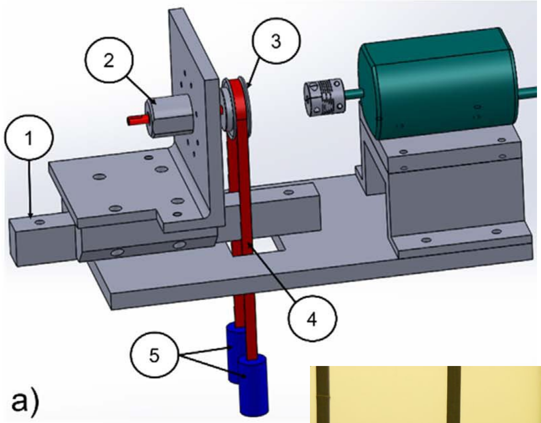


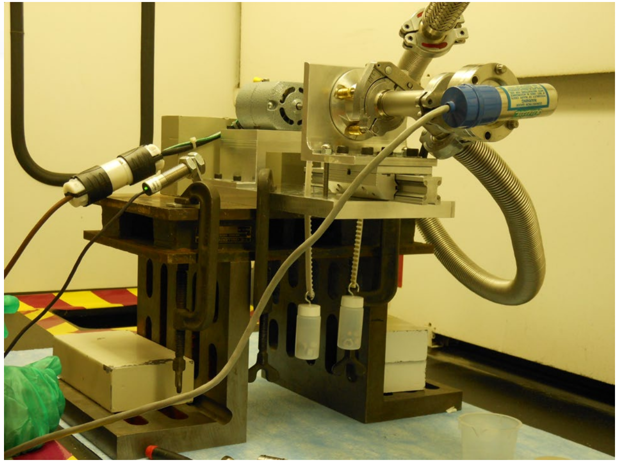
Fig. 6. Photon spectra measured from the entire FF seal following irradiation.

# Static Torque Test

- Torque tests performed in Nov 2011 and Feb 2012
  - Static torque expressed as a function of $1/t_d$
    - $t_d$: time required to reach a specified distance d under a gradually increasing imbalance of counterweights



# Static Torque Test

- Torque tests performed in Nov 2011 and Feb 2012
  - No significant change in FFFT breakaway value observed up to a total dose of 2 MGy

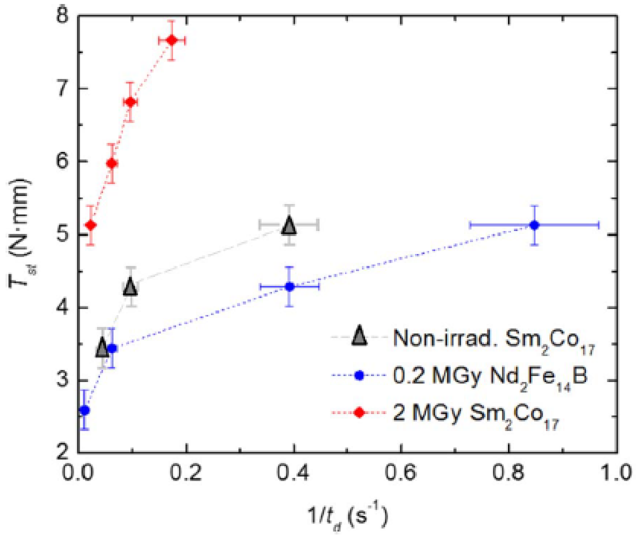



**Fig. 12.** FF static torque $T_{st}$ vs. the inverse of displacement time $(1/t_d)$ following rotational speed cycles up to 5000 rpm.

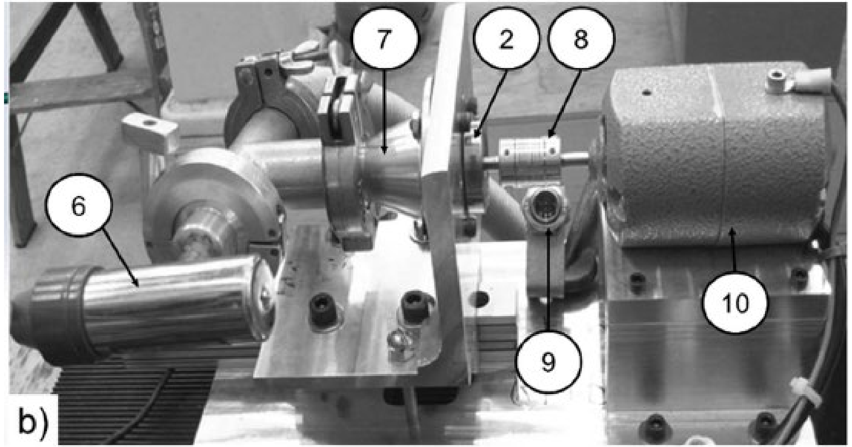
**Table 2**
Measured FF breakaway torque values for different irradiation conditions.

| Magnet composition | Dose (MGy) | Breakaway torque (N-mm) | Experimental conditions |
|---|---|---|---|
| $Sm_2Co_{17}$ | 0 | 4 ± 0.4<br>3 ± 0.3 | Non-irradiated<br>following a rotational speed cycle |
| $Nd_2Fe_{14}B$ | 0.2 | 17 ± 3 | Post- irradiation, no previous rotation |
| | | 7 ± 2 | After 1st rotational speed cycle |
| | | 5 ± 0.5 | After 2nd rotational speed cycle |
| | | 2.5 ± 0.2 | After 3rd rotational speed cycle |
| $Sm_2Co_{17}$ | 2.0 | 5 ± 0.5 | After 1st rotational speed cycle |

# VacuumTest

- Vacuum tests performed in Nov 2011 and Feb 2012
  - No significant change in FFFT performance observed up to a total dose of 2 Mgy
  - Feedthrough blocked for a total dose of 20 Mgy
  - No significant leaks found

Brookhaven National Laboratory



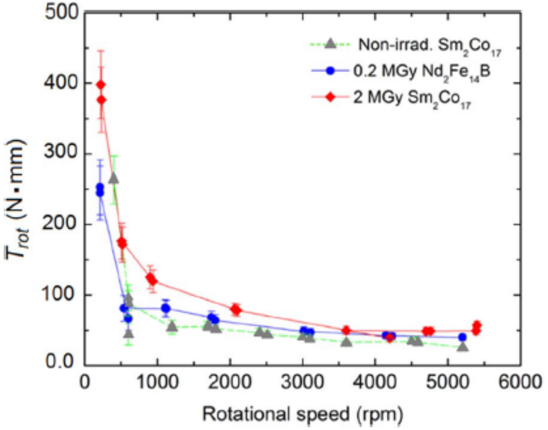
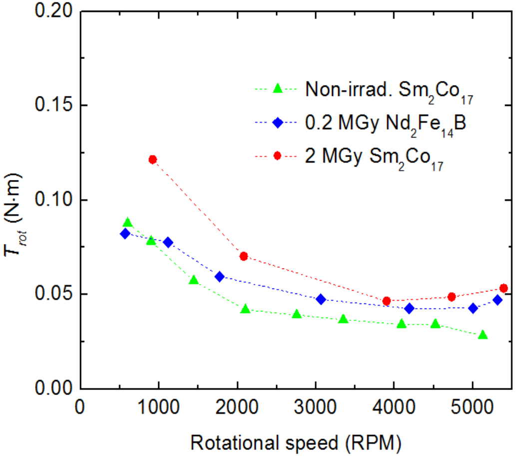
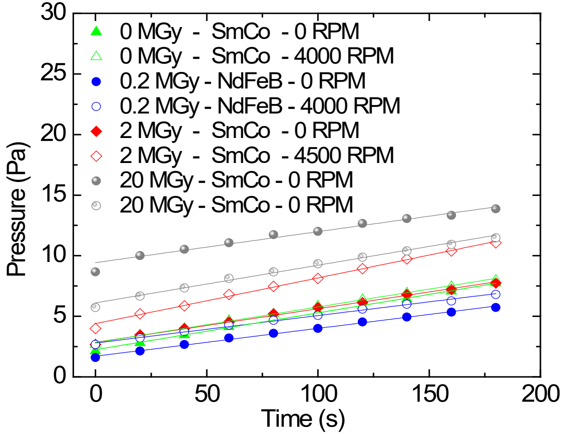




**Fig. 13.** FF rotational torque vs. the rotational speed as a function of radiation dose.



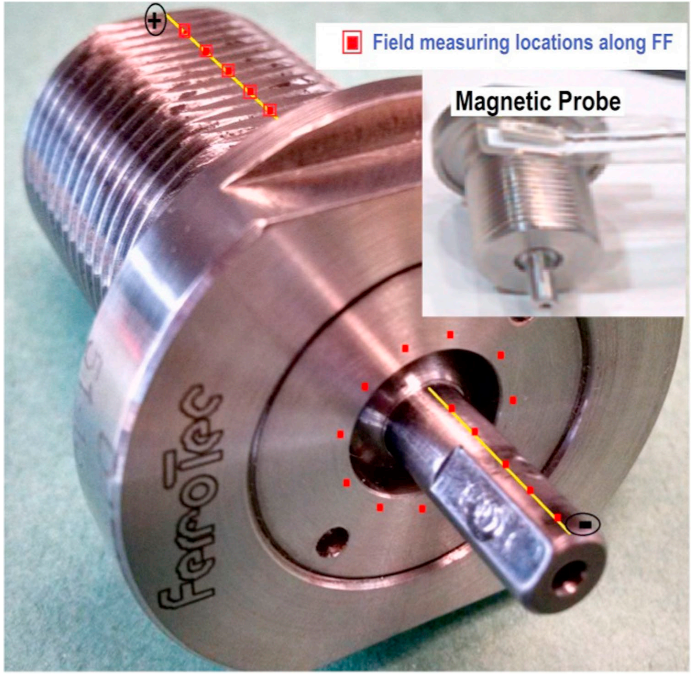



Facility for Rare Isotope Beams at Michigan State University

Fermilab

# Magnetic Field measurement

- “Data show a striking similarity of the magnetic field intensity variation despite the wide range of dose. The findings indicate that minimal, if any at all, de-magnetization was experienced by both types of magnets integrated into the FF seals.”



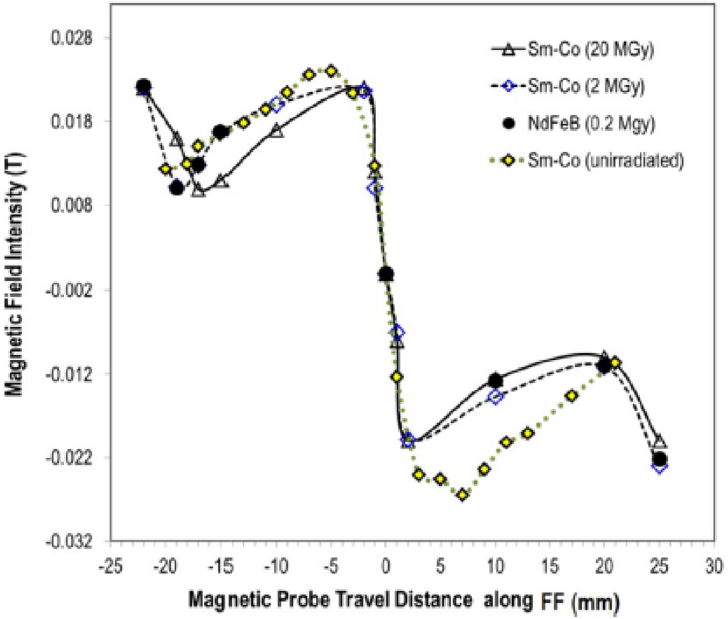




Fig. 8. Measured magnetic field intensity versus magnetic probe travel along the flattened shaft of the irradiated FF seals shown in Fig. 7. Position 0 mm defines the magnet center plane.

# And What Now?

- Snowmass 21 LOI

## Development of High Power Targetry Systems at FRIB

Jian Gao, Wolfgang Mittig and Jie Wei
Facility for Rare Isotope Beams, Michigan State University, MI USA 48824
Email: gaoj@frib.msu.edu

Since the rotating beam dump system is installed in the vacuum vessel, the radiation resistant sealing on the interface between high pressure water and high vacuum is required. TBSG is developing a seal design via using Ferrofluid Feedthrough/ Garlock seal as an intermediate seal that can be tested offline. Due to the complex flow field inside the rotating

Thank you Nick, your legacy continues to help us and has a great impact in HPT R&D now and in the future