

Facility for Rare Isotope Beams: Never the Same Beam Twice

Tom Ginter Radiation Transport Staff Physicist ginter@frib.msu.edu

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Overview

The Facility for Rare-Isotope Beams: Never the Same Beam Twice

Introduction to FRIB

- Radiological environments
- The many beams at FRIB
- Shielding and shielding analysis
- Recent radiation transport case studies from the fragment separator
 - Canyon shielding reevaluated in detail for power ramp up
 - Measured vs calculated rates
 - Employing stable heavy ion as surrogate for its rare isotopes
 - Understanding which beams leave the Target Hall



Work in collaboration with FRIB team: Georg Bollen, Rajarshi Pal Chowdhury, Juan Zamora



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FRIB - Facility for Rare Isotope Beams World-leading Next-generation Rare Isotope Beam Facility

- Rare isotope production via in-flight technique with primary beams up to 400 kW, 200 MeV/u uranium
- Fast, stopped, and re-accelerated beam capability
- Experimental areas and equipment for science with fast, stopped, and reaccelerated beams
- FRIB started operation in May 2022
- Broad science addressed



Properties of nuclei



Tests of fundamental symmetries



Societal applications and benefits





FRIB's Different Radiological Areas Highest Radiation in Target Hall Section of Fragment Separator



Our focus: Fragment Separator where beam power managed and beams multiply



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The Many Beams of FRIB Heavy Ion Primary and Secondary Beams Change Frequently

- FRIB accelerates not just one primary beam, but many heavy ions (stable isotopes) to produce rare isotopes: O-18, Ne-22, Si-28, Ar-36, Ar-40, Ca-48, ..., U-238
 - Energy: Reaching 200 MeV/u for all beams, higher for lower masses

» World-leading linac for heavy ions

- Power: 1 kw (start) → 10 kW (now) → 20 kW (this year)
 → 400 kW (ultimate)
 » World-leading for uranium
- Rare-isotopes produced as secondary beams by in-flight fragmentation/fission of heavy ions

• Rare-isotope beam power on order of 1 W but can be higher

 Experimental science program demands different beams every few days, if not every few hours



View from LISE++: https://lise.nscl.msu.edu/lise.html



Beam Changes → Radiation Level Changes Neutron Monitor Readings

- Plot shows readings from neutron monitors in and around the Fast Beam Area in response to different beams over a few weeks
- Labels show the various primary and rare-isotope beams being run
- Every beam is unique in terms of radiation rankings and intensities at each location





Wide Range of Beams in Different Facility Areas Requires Adequate Shielding as FRIB Power Ramps Up

FRIB approach to shielding

Design basis enables what will be needed at full power

- » Shielding that can't be added later was already addressed during facility construction
 - Enough underground shielding for Linac Tunnel and Target Hall to protect ground water
 - Planning focused on limiting, worst-case scenarios
- » Enough shielding in place at end of construction for early years of operation
- During power ramp-up add shielding based on measurements and further simulations » Only as needed
 - » As informed by operational experience
 - » To address new facility additions
- Current shielding analysis approach
 - Evaluate dynamically and with a more granular view
 - Still a powerful tool: use worst cases to cover the many-beam scenario



Case Studies from the Fragment Separator

- In Target Hall
 - Canyon shielding reevaluated in detail for power ramp up
 - Measured vs calculated rates

In Fast Beam Area

- Employing stable heavy ion as surrogate for its rare isotopes
- Understanding which beams leave the Target Hall





Target Hall Environment Access Needed When Beam is Off



- When beam is on (most of the time) intense prompt fields from dumping multiple kW of beam in separator
- Strong residual fields from highly activated separator parts undergoing remote maintenance

Target Hall generally not a nice place!



Canyon

- A place to hide activated parts and waste to allow access when beam is off
- Requires adequate shielding on top

Views from radiation transport model of Target Hall



Canyon Shielding Revaluated in Detail for Power Ramp Up 1st Target Hall Example

- Original analysis
 - Completed 9 years ago
 - Established shielding thickness, not details
- Recent analysis
 - Confirms early results in context of present plans
 - Supports detailed design of shielding and equipment support stands based on recent experience managing work in the Target Hall
 - Assumed worst-case scenarios for Target Hall use



Must anticipate wide range of beams and resulting part activation over the next 30 years



Measured Rates Compared to Simulation 2nd Target Hall Example

 This beam caught our attention – potent combination of low-Z, high energy

 Measured rates on shielding roof 5x higher than expected based on simulations with full shielding in place





Measured vs Calculated Rates Full Initial Shielding Not Yet Installed!





Measured vs Calculated Rates Corrected Model → Good Agreement





Primary Beam as Surrogate for Its Rare Isotops 1st Fast Beam Area Example – A Strategy for Dealing with Many Beams



FRIB

Caveat: Understand Which Beams Enter Fast Beam Area 2nd Fast Beam Area Example

- Primary beam: Se-82, 215 MeV/u, 10 kW used to produce the rare isotope K-54, 170 MeV/u
 Rate <1.5 particles/s, Exotic!!!
- Higher radiation observed than expected from surrogate
- Reason: in addition to K-54, other fragments left the Target Hall and stopped at the point of reference
 - Had almost same rigidity as K-54
 - ~50% H-3 at 150 MeV/u
 - ~50% H-2 at 310 MeV/u
 - Beam power of 0.2 W!
- These H isotopes significantly worse than Se-82 surrogate at same power in terms of radiation impact
 - Higher average specific energy
 - More chances for nuclear interactions



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| ⁴⁸ Cr | ⁴⁹ Cr | 50 Cr | ⁵¹ Cr | ⁵² Cr | ⁵³ Cr | ⁵⁴ Cr | ⁵⁵ Cr | ⁵⁶ Cr | ⁵⁷ Cr | ⁵⁸ Cr | ⁵⁹ Cr | 80 Cr | ⁶¹ Cr | ⁶² Cr | 63 |
| | | ⁴⁹ V | ⁵⁰ V | ⁵¹ V | ⁵² V | ⁵³ V | ⁵⁴ V | ⁵⁵ V | ⁵⁸ V | 57 V | ⁵⁸ V | ⁵⁹ V | ⁶⁰ V | ⁶¹ V | 62 |
| ⁴⁶ Ti | ⁴⁷ Ti | ⁴⁸ Ti | ⁴⁹ Ti | ⁵⁰ Ti | ⁵¹ Ti | ⁵² Ti | ⁵³ Ti | ⁵⁴ Ti | ⁵⁵ Ti | ⁵⁸ Ti | ⁵⁷ Ti | ⁵⁸ Ti | ⁵⁹ Ti | ⁶⁰ Ti | 61 |
| ⁴⁵ Sc | ⁴⁶ Sc | ⁴⁷ Sc | ⁴⁸ Sc | ⁴⁹ Sc | ⁵⁰ Sc | ⁵¹ Sc | ⁵² Sc | ⁵³ Sc | ⁵⁴ Sc | ⁵⁵ Sc | ⁵⁶ Sc | ⁵⁷ Sc | ⁵⁸ Sc | ⁵⁹ Sc | 60 |
| ⁴⁴ Ca | ⁴⁵ Ca | ⁴⁶ Ca | ⁴⁷ Ca | ⁴⁸ Ca | ⁴⁹ Ca | ⁵⁰ Ca | ⁵¹ Ca | ⁵² Ca | ⁵³ Ca | ⁵⁴ Ca | ⁵⁵ Ca | ⁵⁶ Ca | ⁵⁷ Ca | ⁵⁸ Ca | 59 |
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Conclusion

- Radiation transport work at FRIB takes place in the context of beam conditions that almost never repeat
- These examples show that while it is good to use simplifications wherever possible to address the complexity of many beams – we must understand the limitations
- Other SATIF-16 work from FRIB to address the many-beam challenge
 - Talk "Bayesian Uncertainty Quantification for Radiation Transport Calculations at FRIB" by Juan Zamora (this afternoon)
 - Poster "Applications of Machine Learning in Radiation Shielding at FRIB" by Rajarshi Pal Chowdhury

Thanks for your attention!

