



The Facility for Rare Isotope Beams: Radiation Transport Supporting Power Ramp-Up

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October 2026



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U.S. DEPARTMENT
of ENERGY

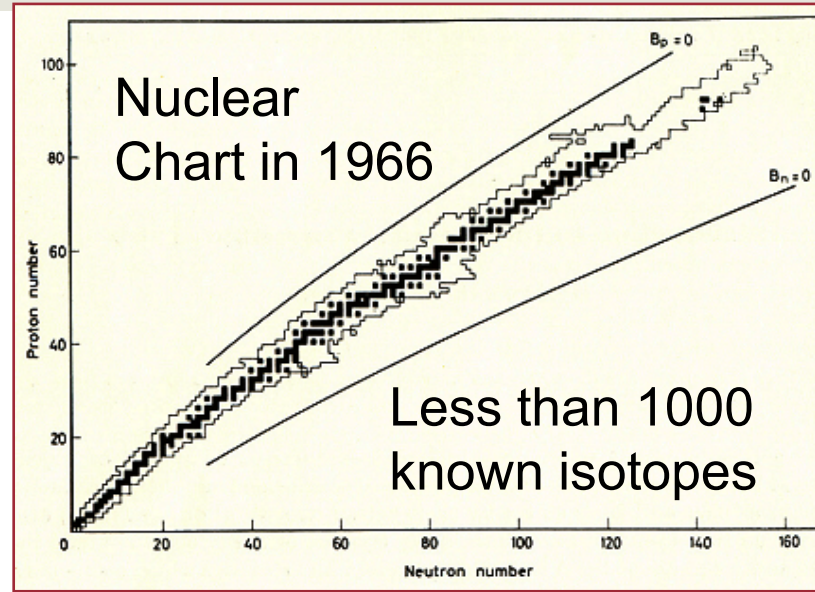
Office of
Science

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB) Operations, which is a DOE Office of Science User Facility under Award Number DE-SC0023633.

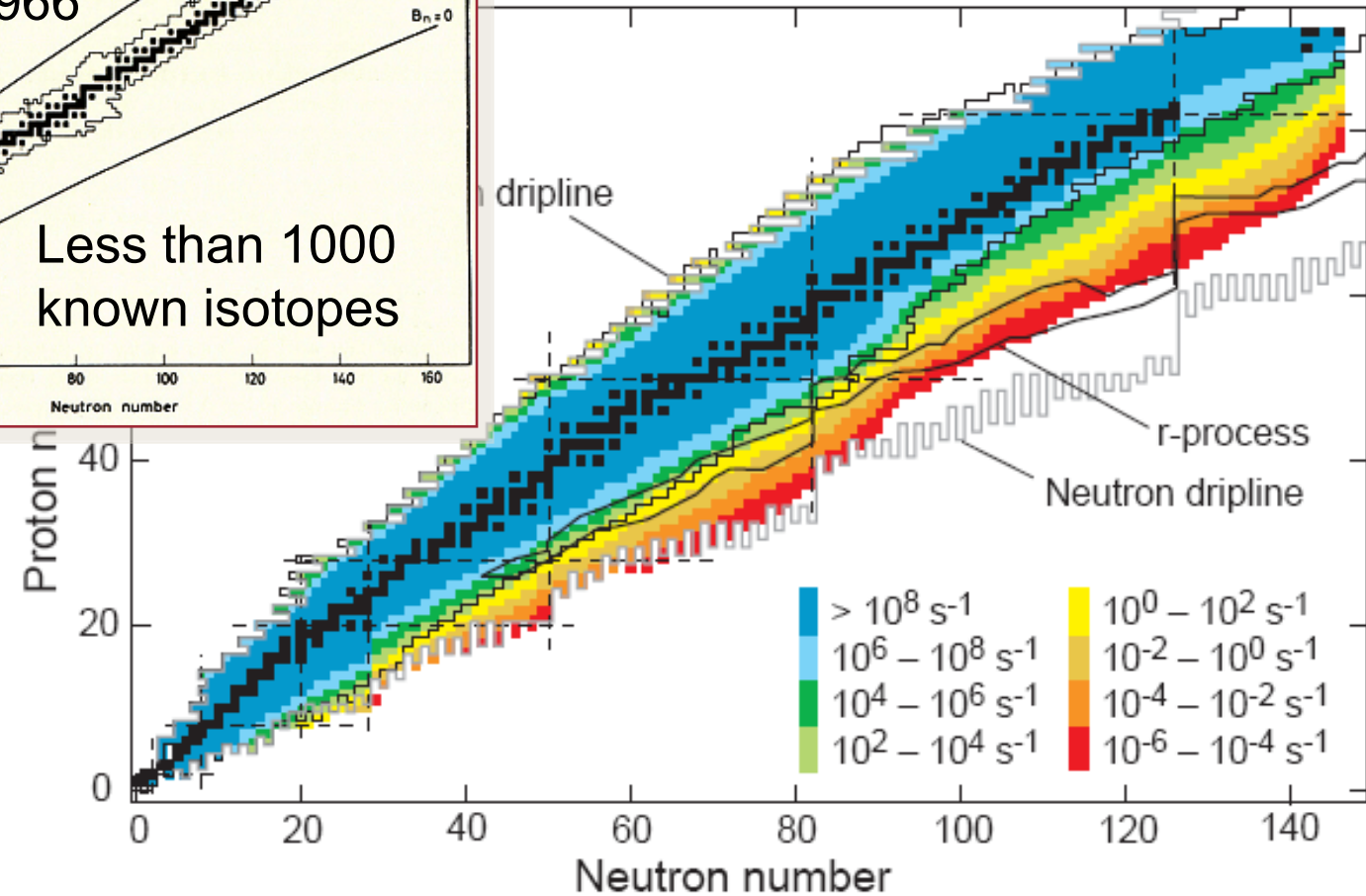
Nuclide Production at New Generation Facilities

High Power Drives Discovery

- More than 3000 isotopes synthesized in laboratories
- Theory predicts the existence of about 7000 isotopes
- Broad science scope ahead
 - Understanding nuclear existence
 - Nature of nuclear many-body systems
 - Astrophysical modeling
 - Fundamental interactions
 - Applications



FRIB reach with 400 kW beam power

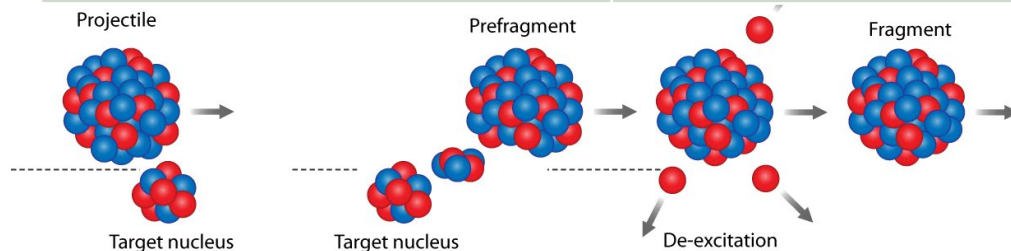


FRIB - Facility for Rare Isotope Beams

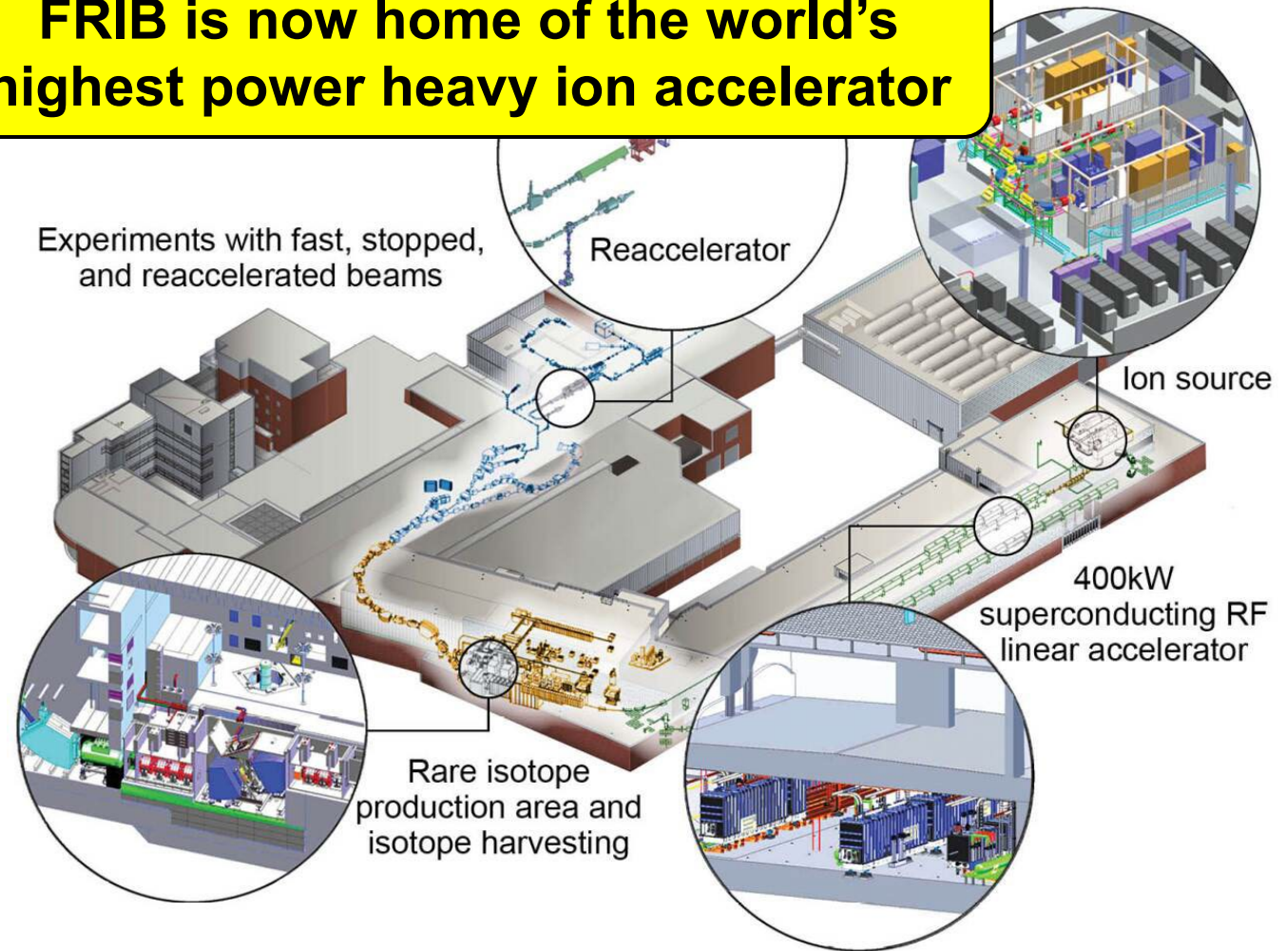
DOE-SC National User Facility

- Started operation in 2022
- Energy ~ 200 MeV/u (upgradable 400 MeV/u)
- Fragmentation for primary beam makes rare isotopes
- Magnet in-flight separation and atom-by-atom identification of A, Z, q

Year	Beam Power
2022 (start of FRIB)	1 kw
2026 (now)	20 kW
... In a few years	400 kW



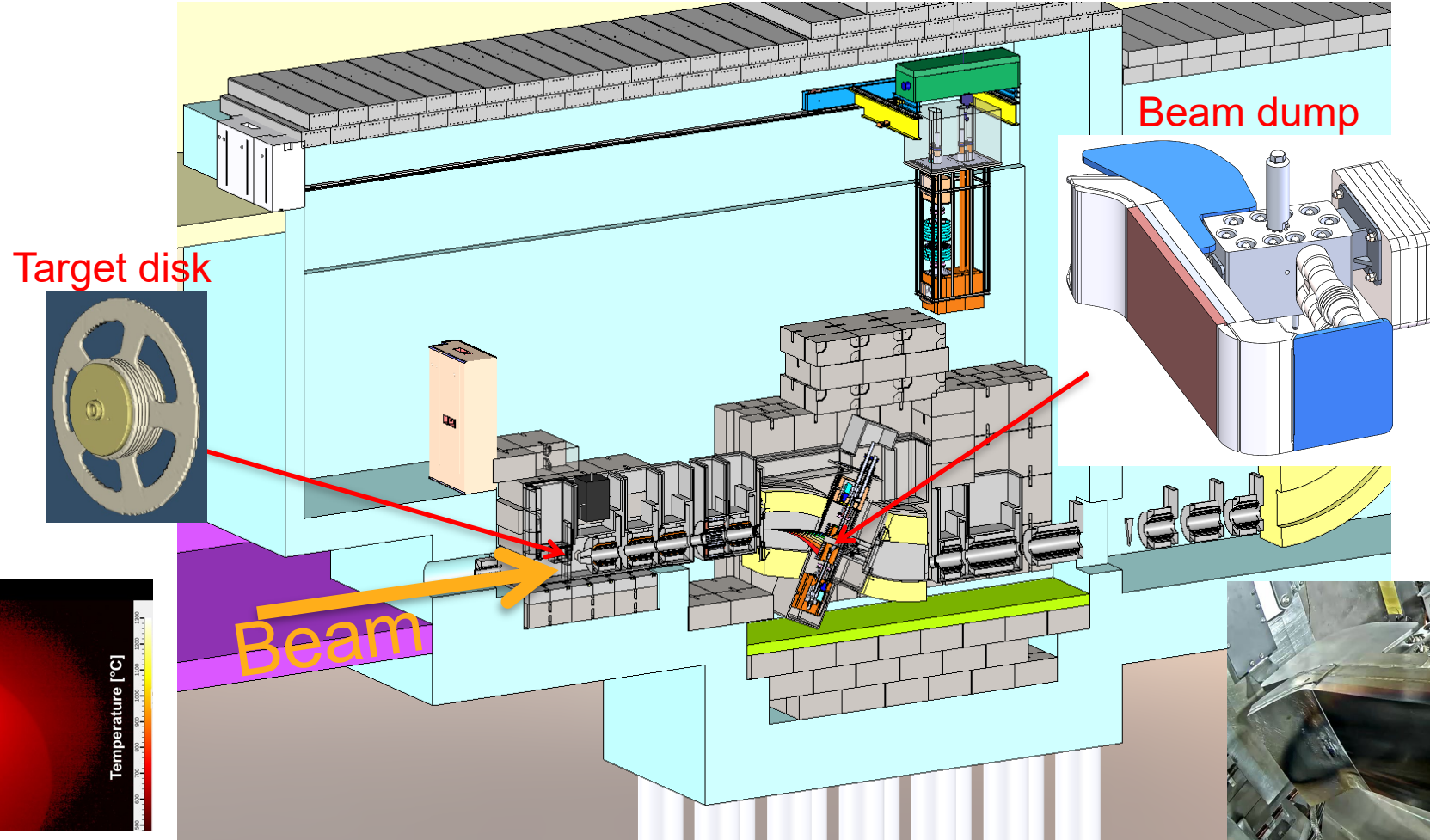
FRIB is now home of the world's highest power heavy ion accelerator



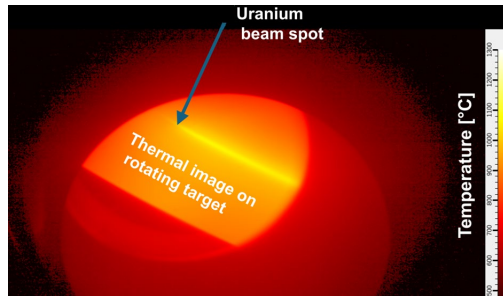
FRIB's Target Hall and Fragment Separator

Areas of High Radiation and Activation

Absorbs ~ 25% beam power;
accommodate small (~ 1 mm diameter) beam size



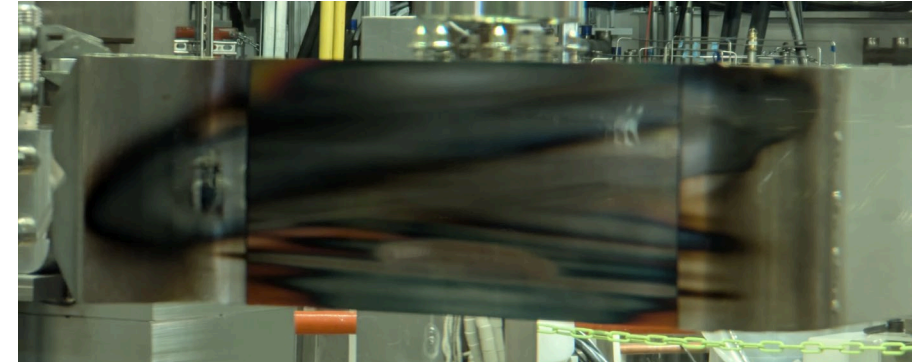
Presently used
solid beam dump:
Absorbs ~ 75%
beam power;
consideration of
activation in water
and surroundings



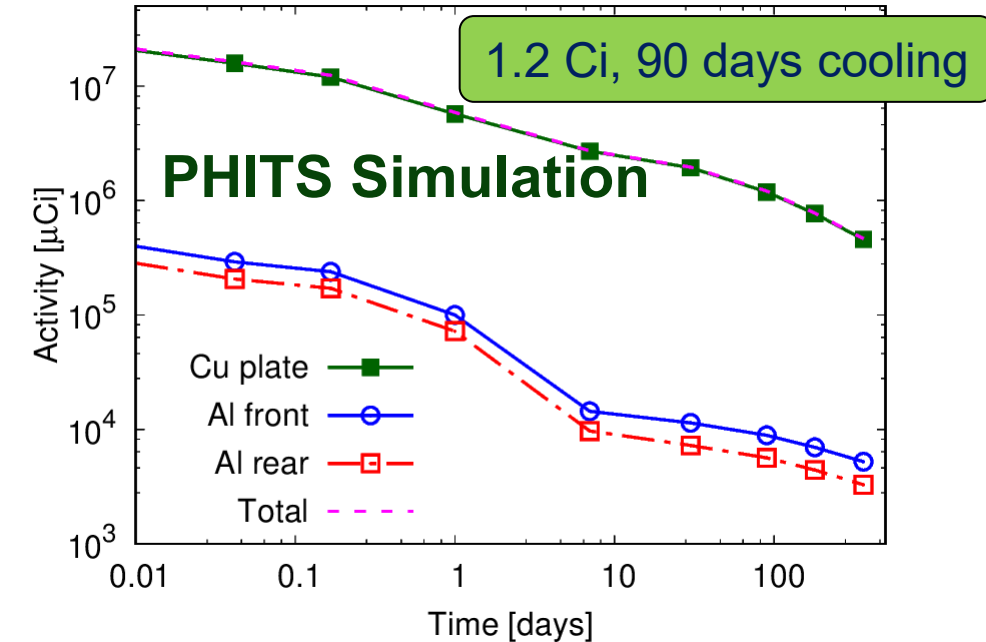
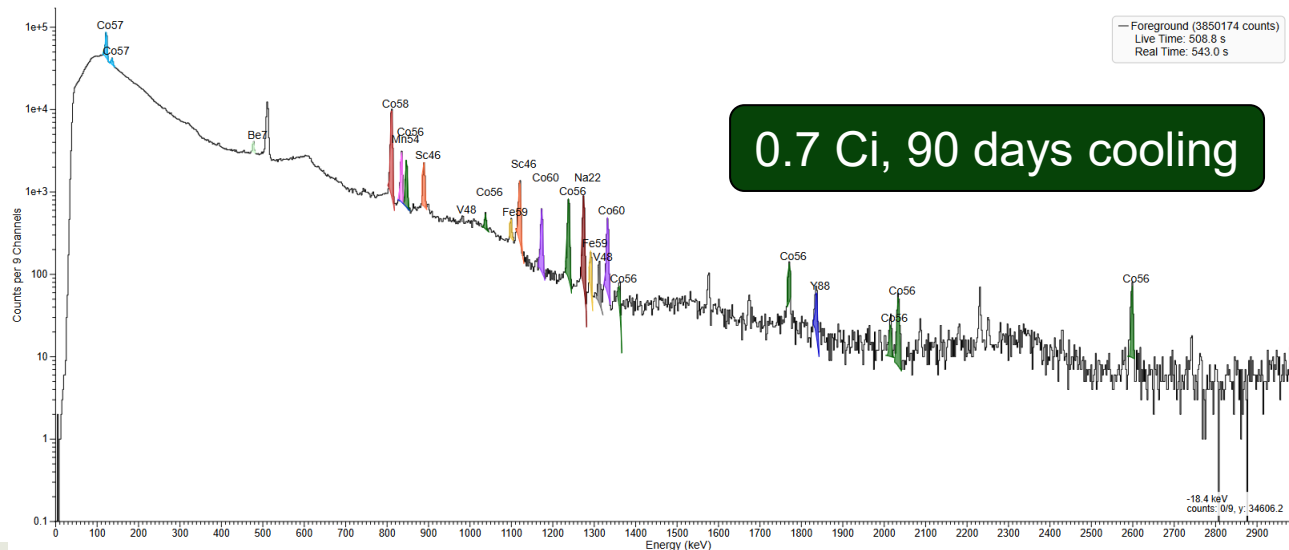
Beam Dump Residual Activity Determined

Simulation and Measurement Results Agree

- Activity after one year operation
- Dominated by the front copper plate
- Significant contribution of ^{22}Na , ^{58}Co , ^{54}Mn isotopes



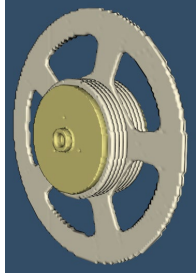
Measurement from Gamma Spectroscopy



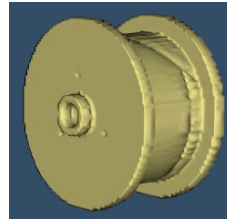
Target Disk Dose Rate Contributions Assessed

Hub Contributes Negligibly to Activity but Significantly to Dose Rate

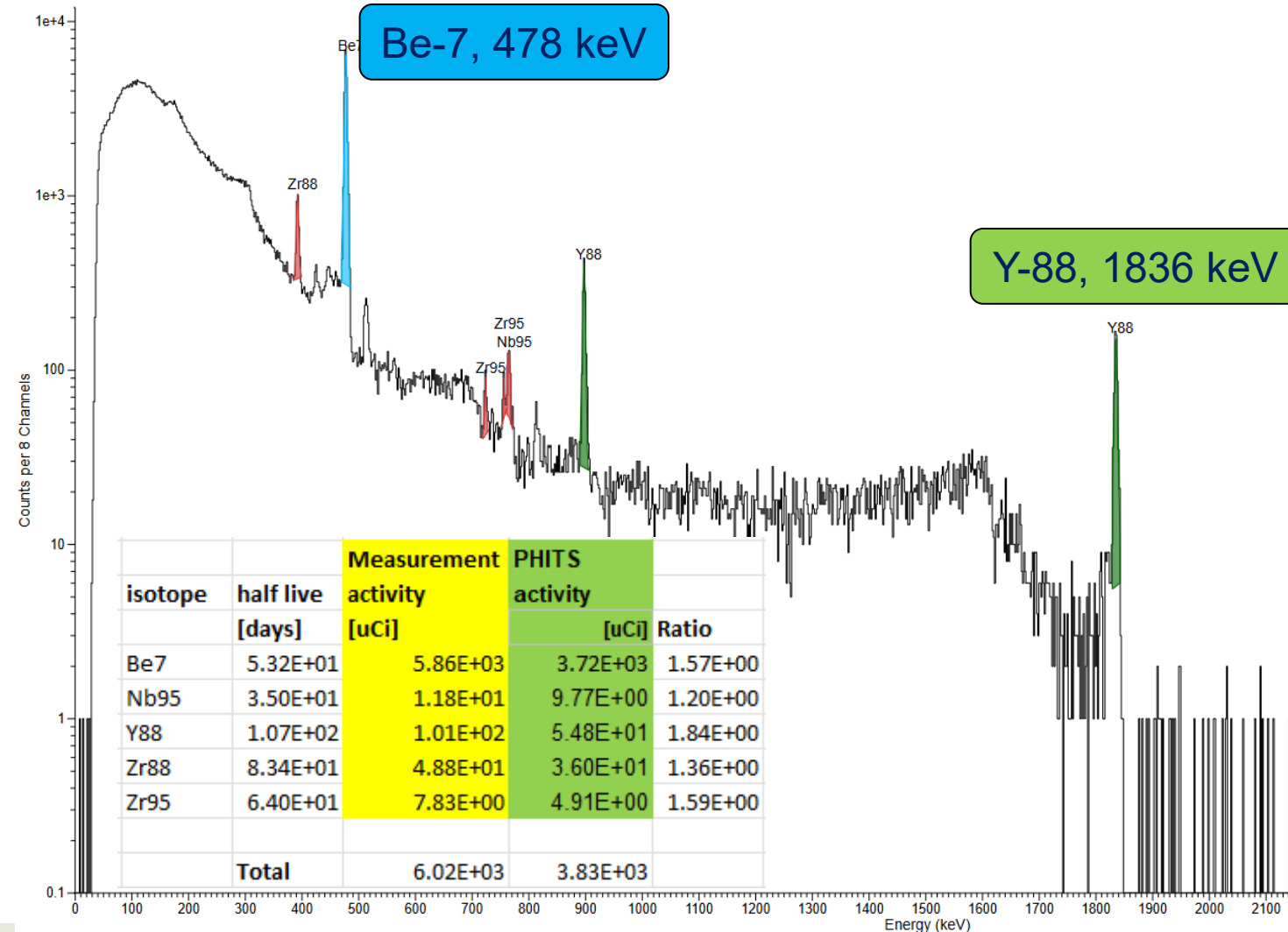
Graphite target
disk and hub



Hub only



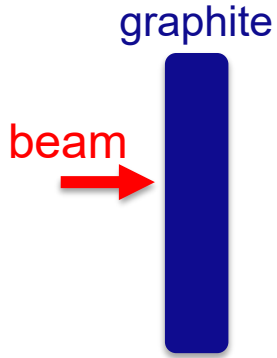
- Target is hit by beam which parts get highest activity and give highest dose rate?
- A recent gamma analysis shows a 1836 keV gamma line from Y-88
 - PHITS simulations confirm the production of Y-88 in the zirconia hub
- While contributing ~1% to activity for the case considered, Y-88 accounts for ~40% of the dose rate



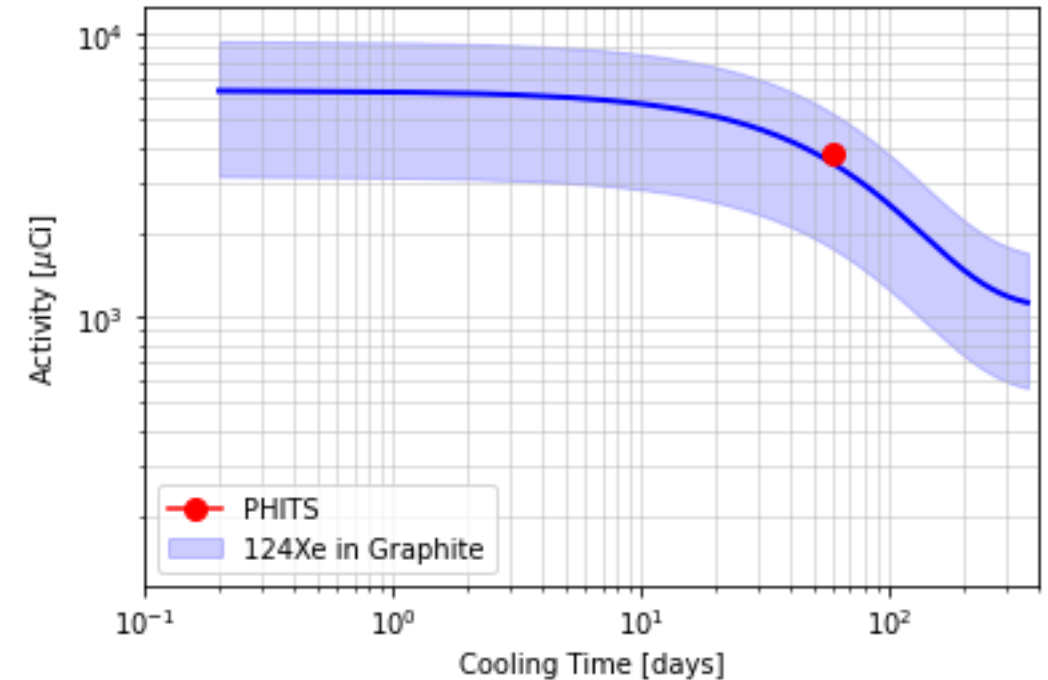
Surrogate Model for Fast Material Activation Analysis Developed [1]

Started with graphite activation

$$F(t, \rho, E, R, A, Z, T_I) \propto M(\rho) \cdot B(E, R, A, Z) \cdot \left[1 - \exp\left(-\frac{T_I}{T_R}\right) \right] \cdot \left[\exp\left(-\frac{t}{T_{C1}}\right) + \exp\left(-\frac{t}{T_{C2}}\right) \right]$$



- Built a surrogate model to estimate activation of beam intercepting materials
- Multiple input conditions: material, beam, irradiation and cooling times
- PHITS-DCHAIN informed model. Multivariate regression
- Fast estimate (~ ms)

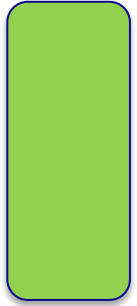


Surrogate Model for Fast Material Activation Analysis Developed [2]

Extended Model for Multiple Materials

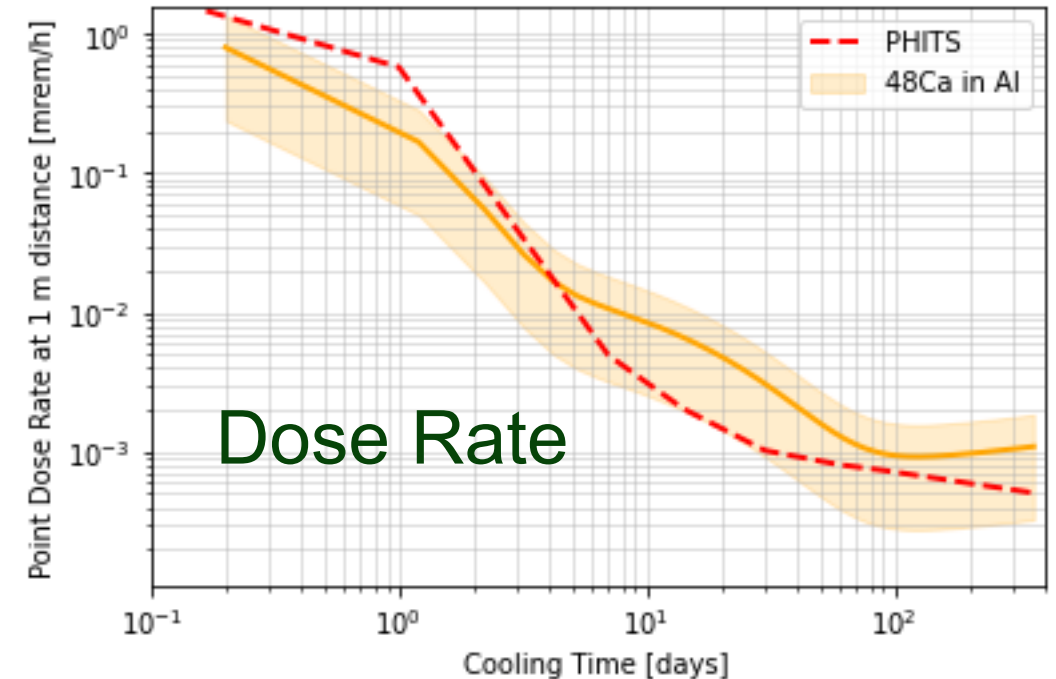
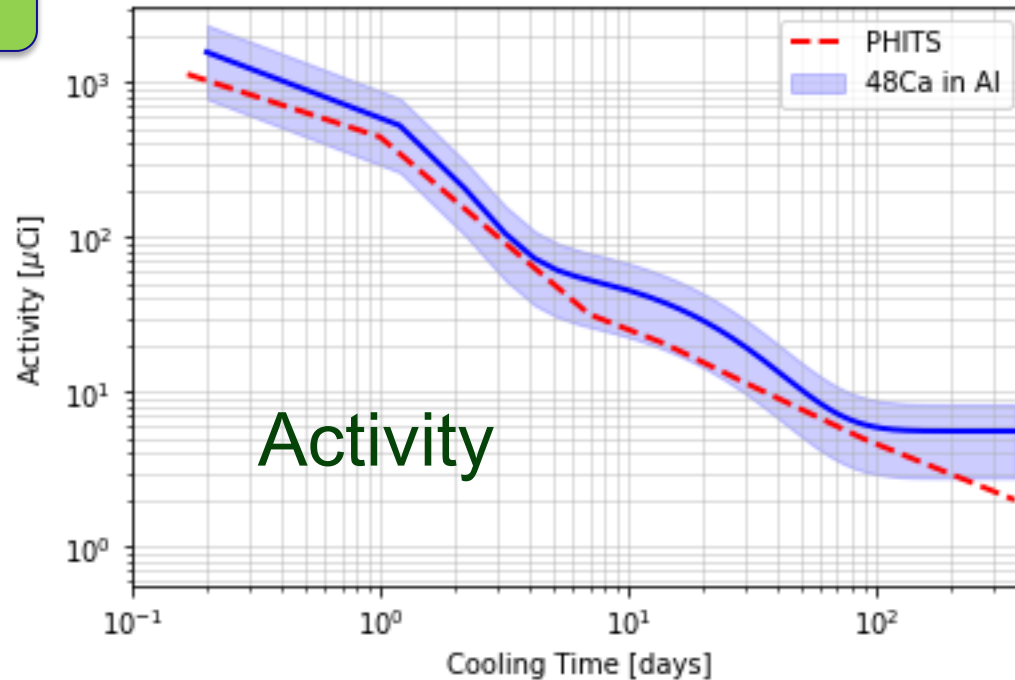
Stopping in Al

beam
→



Surrogate model provides a fast estimate for users without PHITS license. Important for keep the regulations limits of stored radioactive materials

^{48}Ca at 180 MeV/u, 1 W, 3 days irradiation 7E8 pps

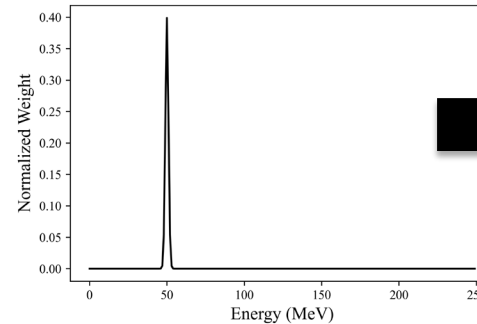


Shielding Optimization using Machine Learning [1]

Generated a Supervised ML Model using Radiation Transport Calculations

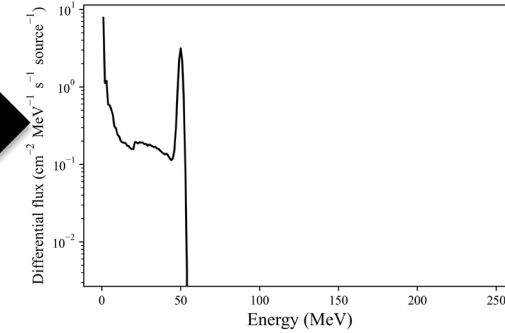
- Model trained with PHITS simulations
- A linear combination of monoenergetic neutron sources was assumed
- ML model predicts the neutron flux after shielding
- The model was applied to shields composed of multiple materials and thicknesses

Mono-energetic neutron field

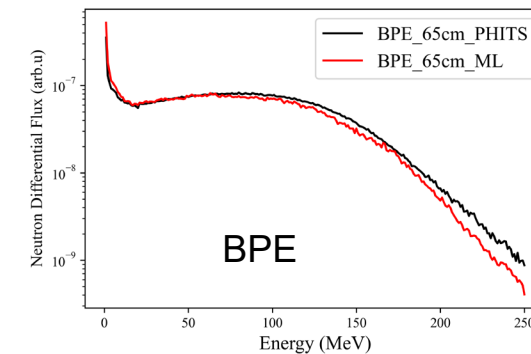
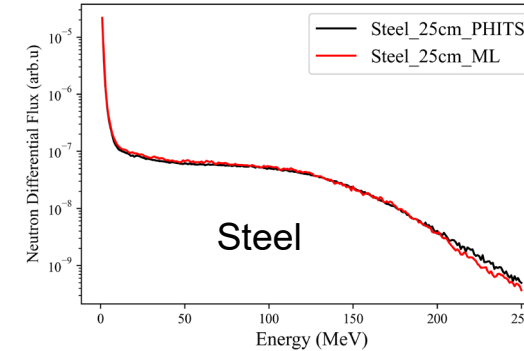
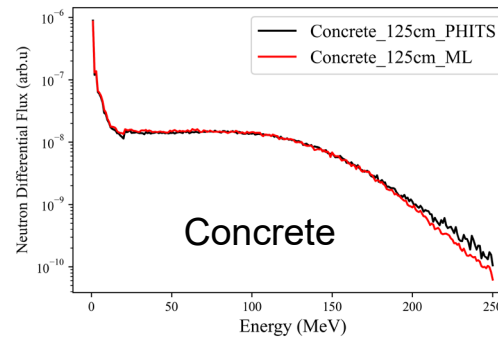


Variable
shielding
materials
and
thickness

neutron field after shield

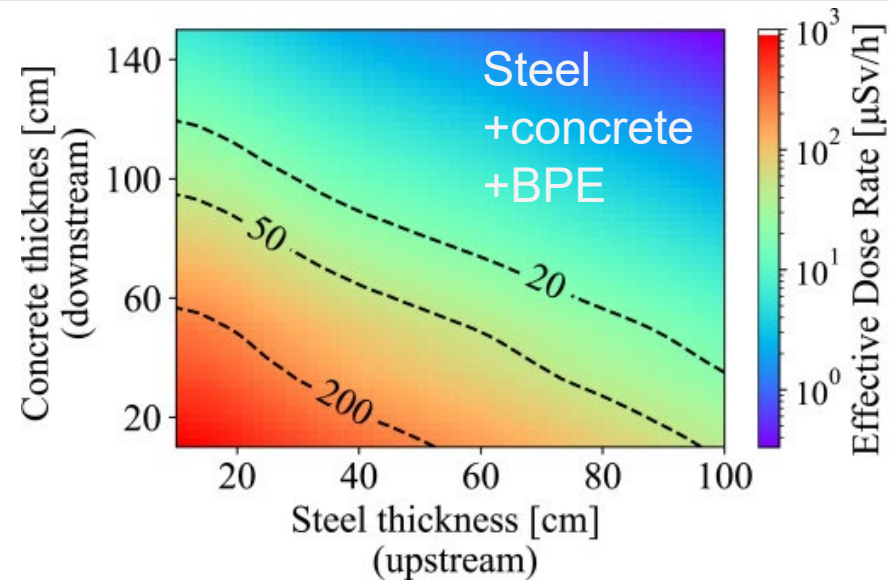
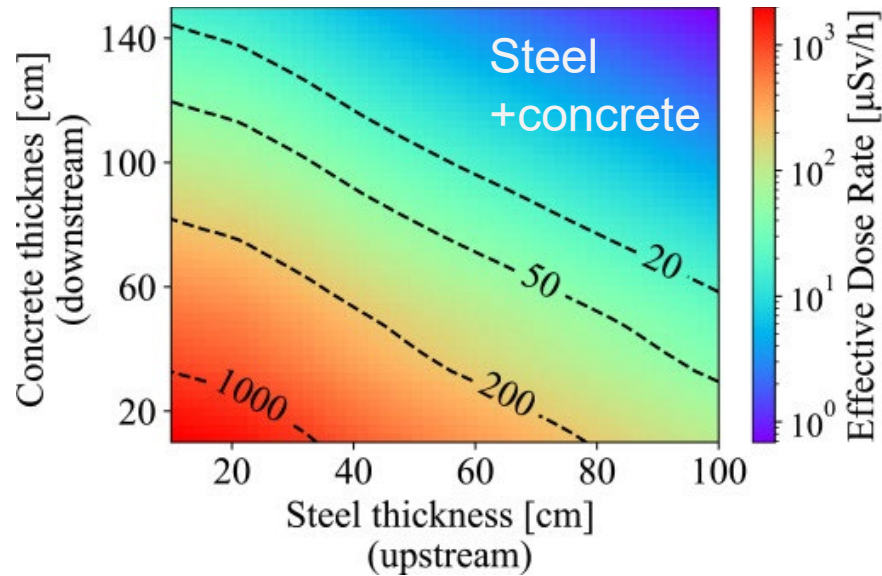


Pal Chowdhury et. al., NIMB, 570, 165909 (2026)

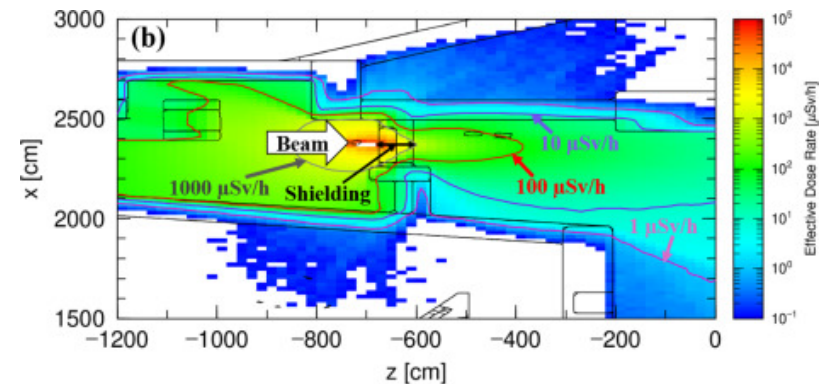


Shielding Optimization using Machine Learning [2]

Supervised ML Model Application to multiple layers demonstrated



- Good agreement with PHITS simulations
- Real application of optimization shielding materials and dimensions
- Significant reduction of computing time (minutes vs. days)

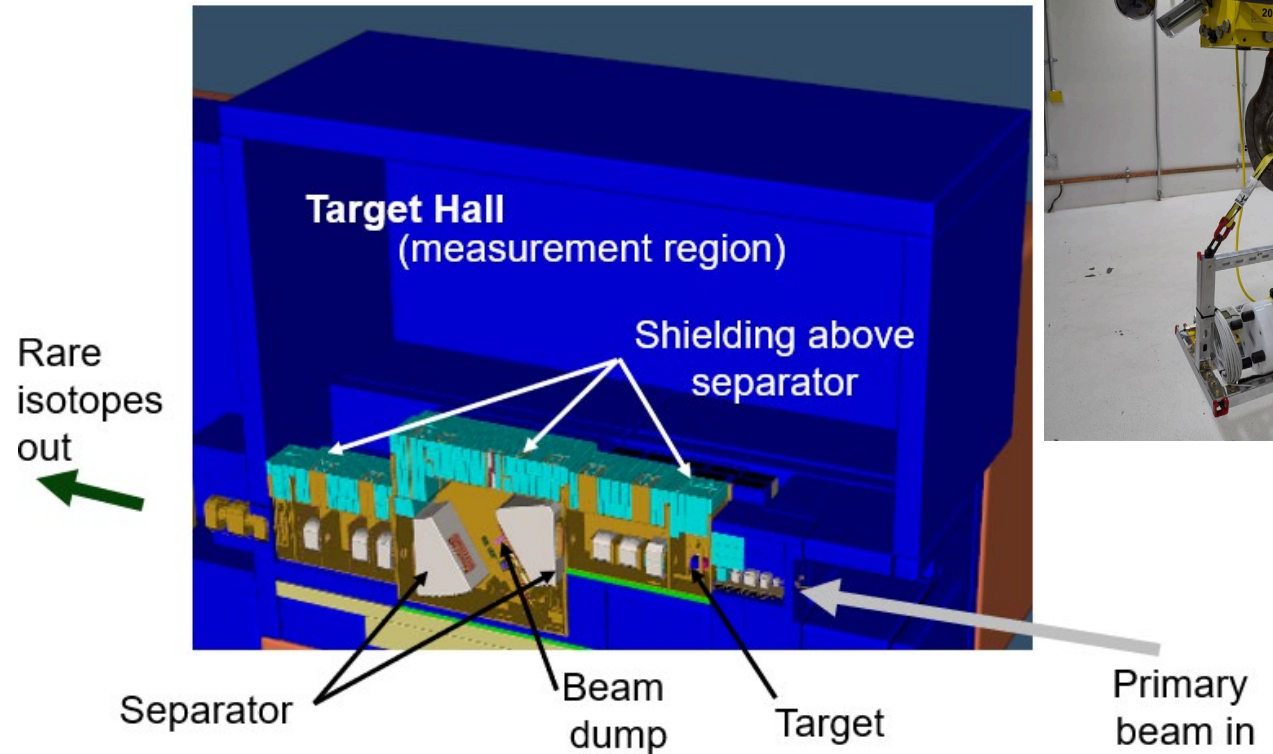


Pal Chowdhury et. al., NIMB, 570, 165909 (2026)

Dose Rates in the Target Hall Mapped to Validate Simulations

- Remote-handling crane used to position neutron monitor
 - WENDI-II
- >440 points in a 3D arrangement mapped
- Two mapping exercised performed for different primary beams
 - 10 kW ^{28}Si
 - 17 kW ^{238}U
- Measured dose rates range from 0.3 to 13 mSv/h

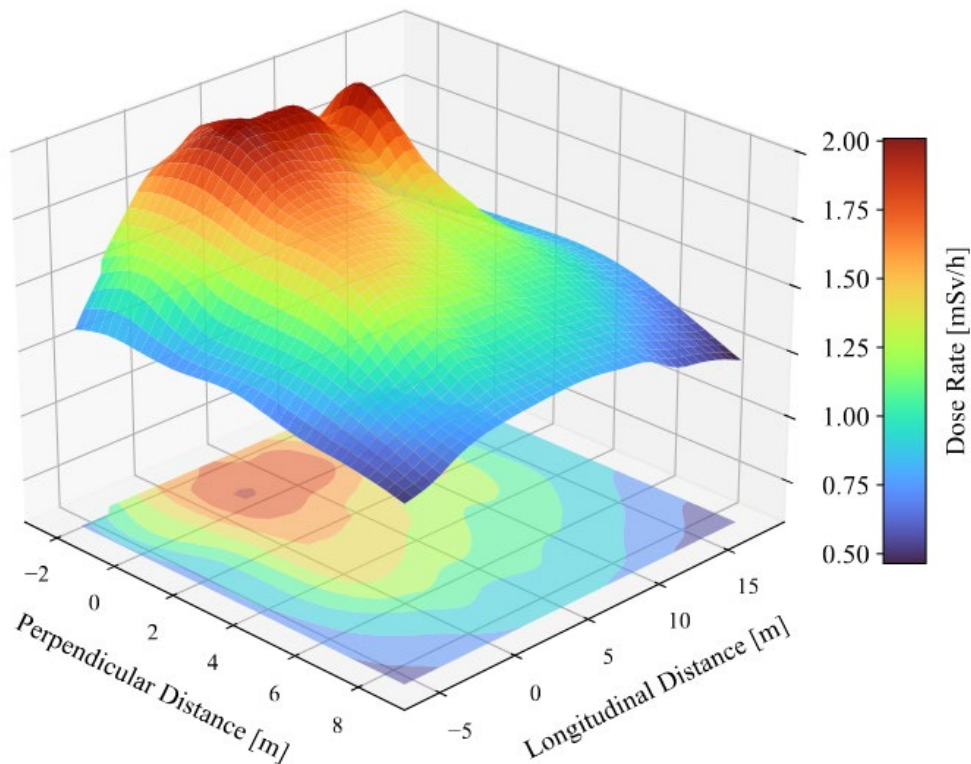
Zamora et. al., in preparation



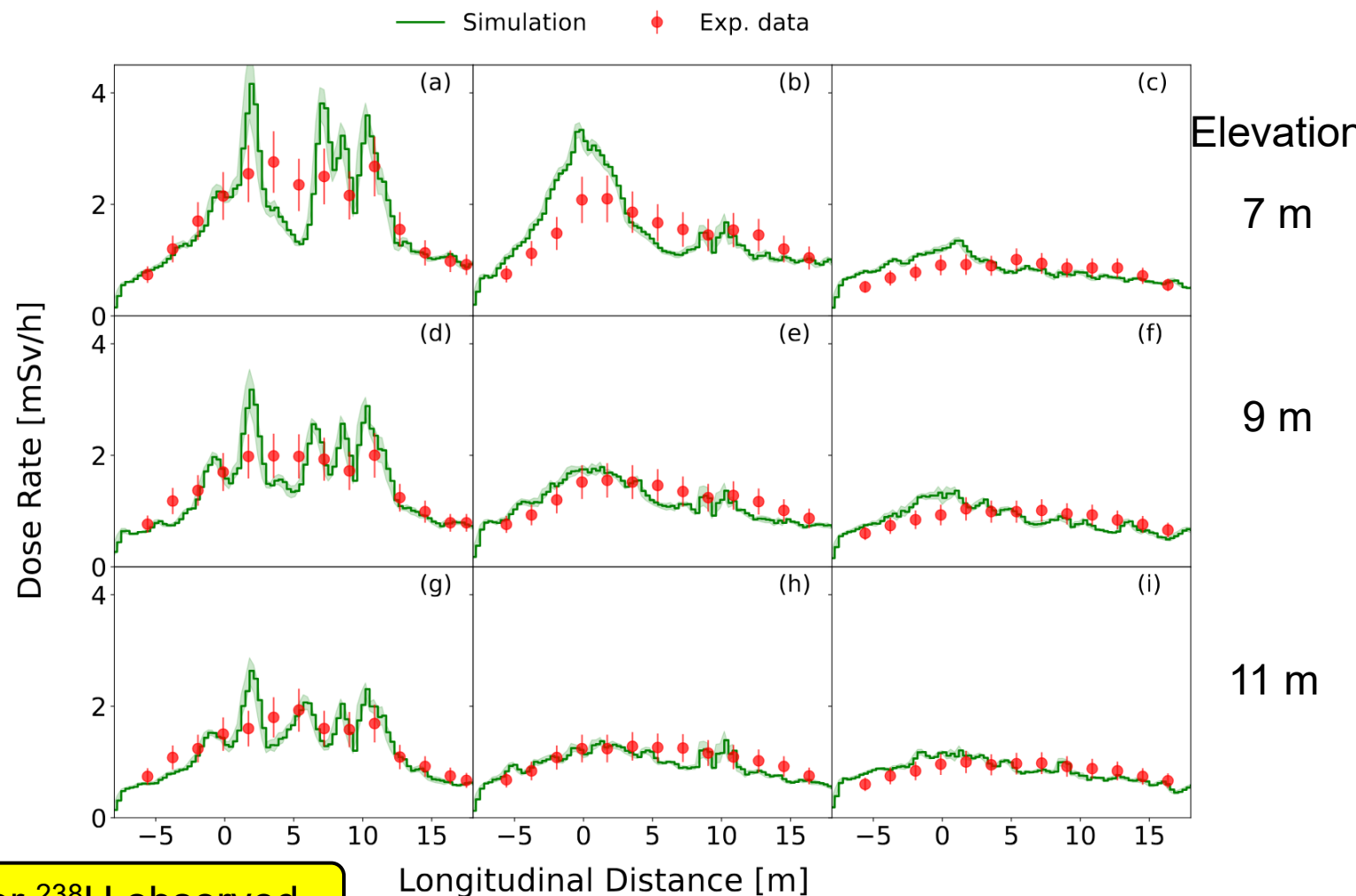
Measured Dose Rates Agree with PHITS Simulations

Example: 10 kW ^{28}Si at 175 MeV/u

Map for elevation of 9 m above target



Zamora et. al., in preparation



Similar agreement for ^{238}U observed

Summary

- FRIB has a large dynamic range of radiation source conditions
 - Isotope, energy, intensity, locations
 - Variable conditions of prompt and residual dose rates
- Surrogate models support FRIB power ramp-up
 - Fast estimates of material activation and shielding for variable conditions and increased power
 - Support design of new systems and shielding modifications that may be needed
- Radiation transport model results validated with experimental data
- Path forward
 - Will continue to develop and exploit ML for delivery of fast radiation transport results
 - Continue dose rate monitoring in the whole lab and compare to simulations
 - Conduct dedicated experiments for material activation and resulting radiation



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Thanks for your attention!

