# Survivability of proton beam degraders and beam stops: experience at Brookhaven Linac Isotope Producer

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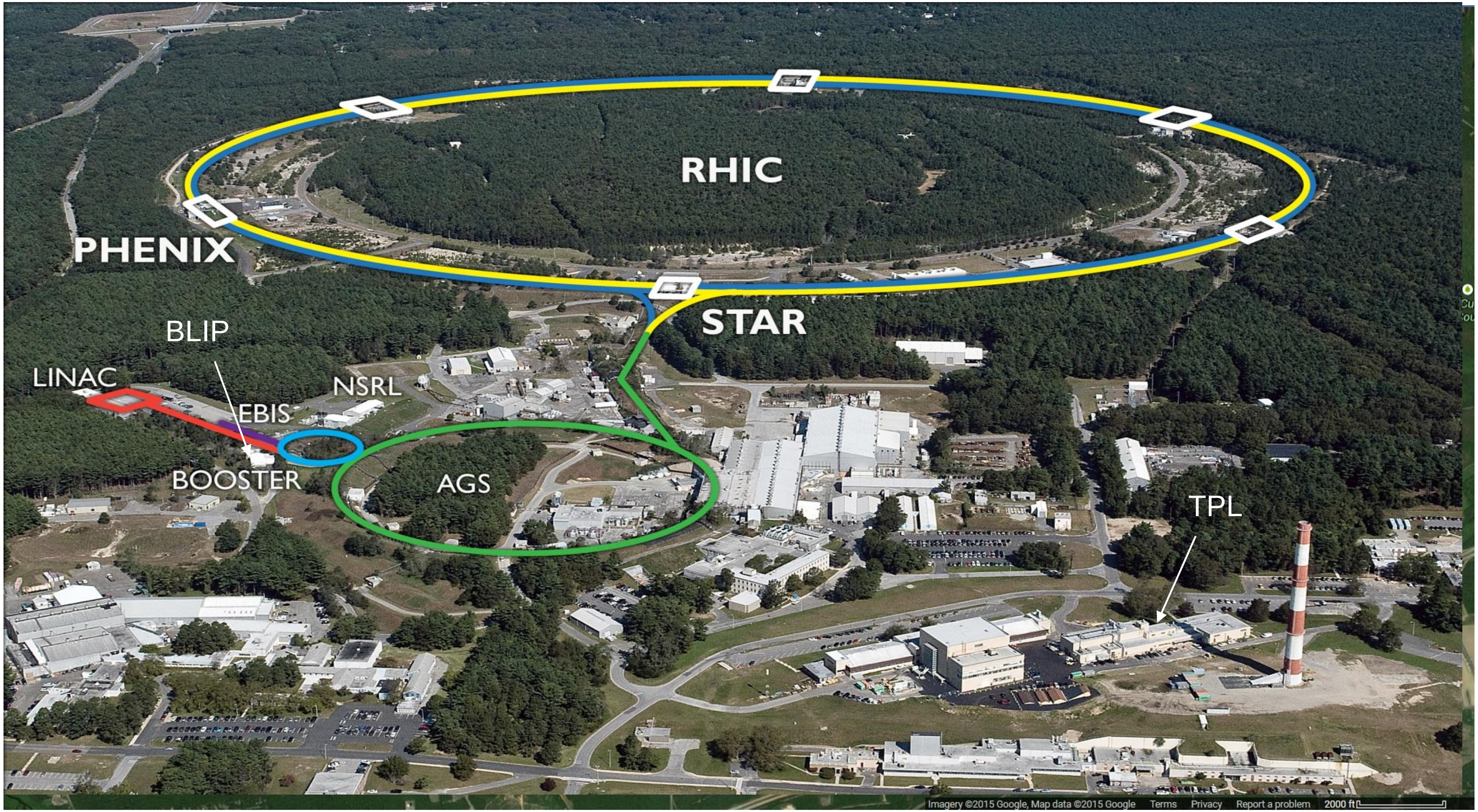
8th High Power Targetry Workshop, RIKEN Waco campus, Japan

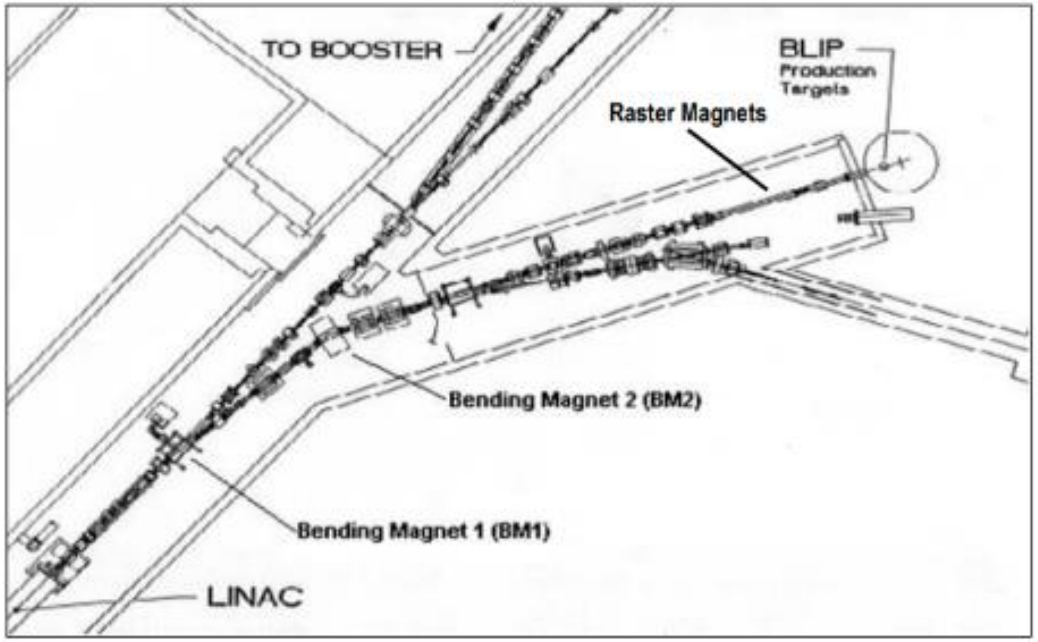
6-10 November, 2023

# Brookhaven Lab and its accelerator complex

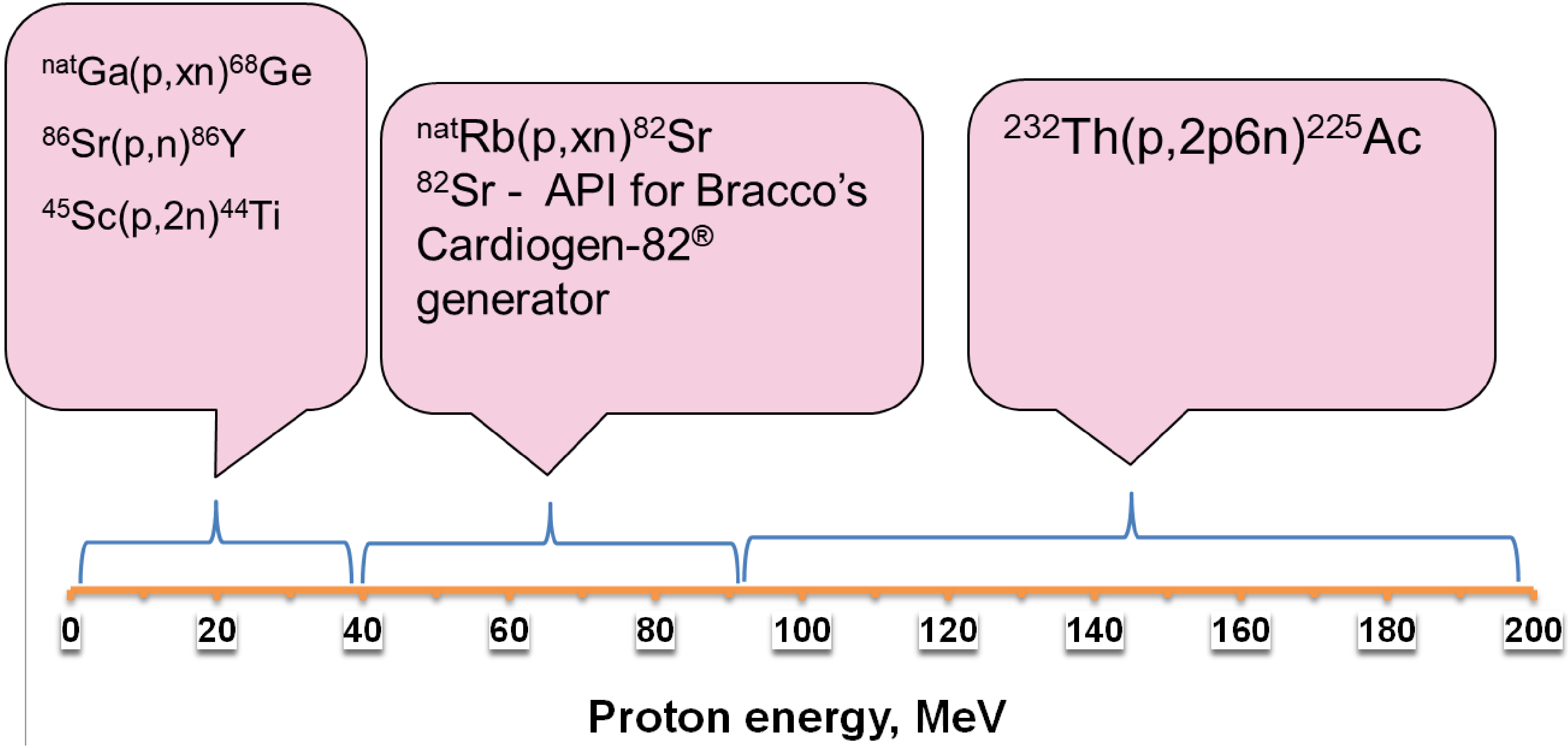


# 200 MeV Linac at BNL

- A 459-foot-long LINAC with 9 accelerator RFQ cavities
- Operates in a pulsed mode: >90% of the pulses are used for isotope production, the rest is used for HEP experiments
- The pulses for BLIP occur at frequency 6.67 Hz. Each pulse is 550 μsec long and can be up to 60 mA in intensity
- Energy is incrementally tunable from 10 to 200 MeV, with 66 MeV the lowest practical energy for isotope production
- Maximum average current of 165 μA is regularly achieved, 200 μA demonstrated
- Rastered and focused beam capability

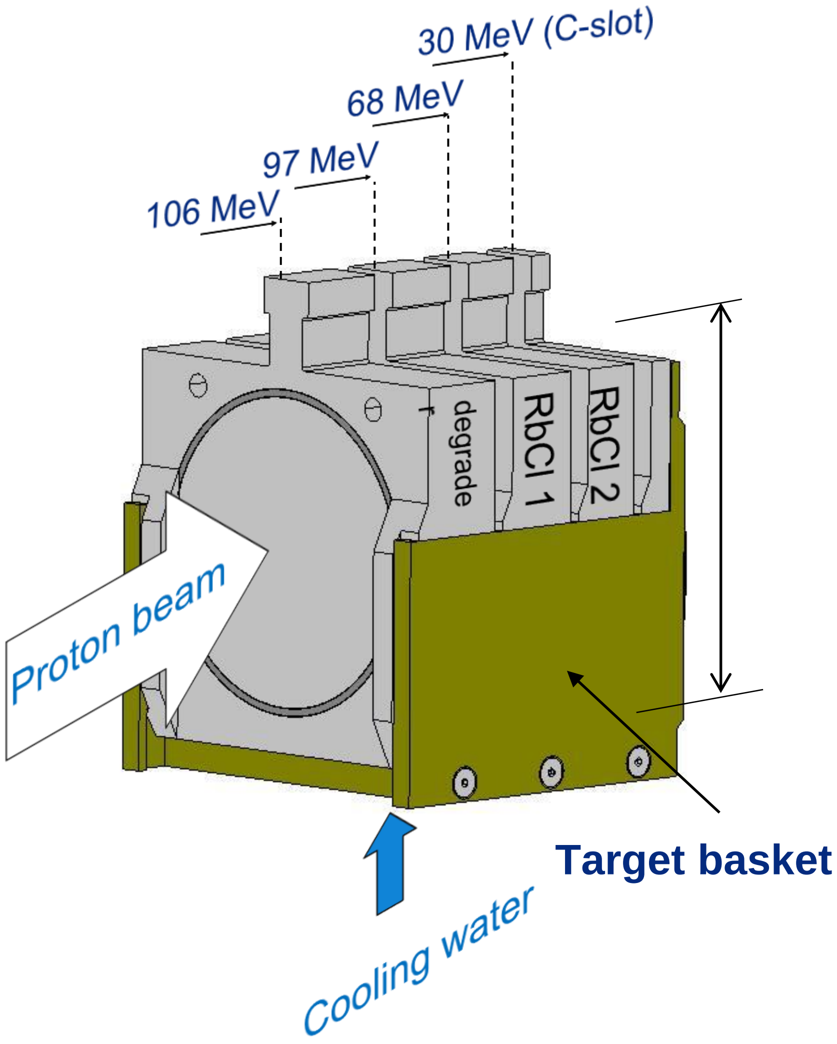


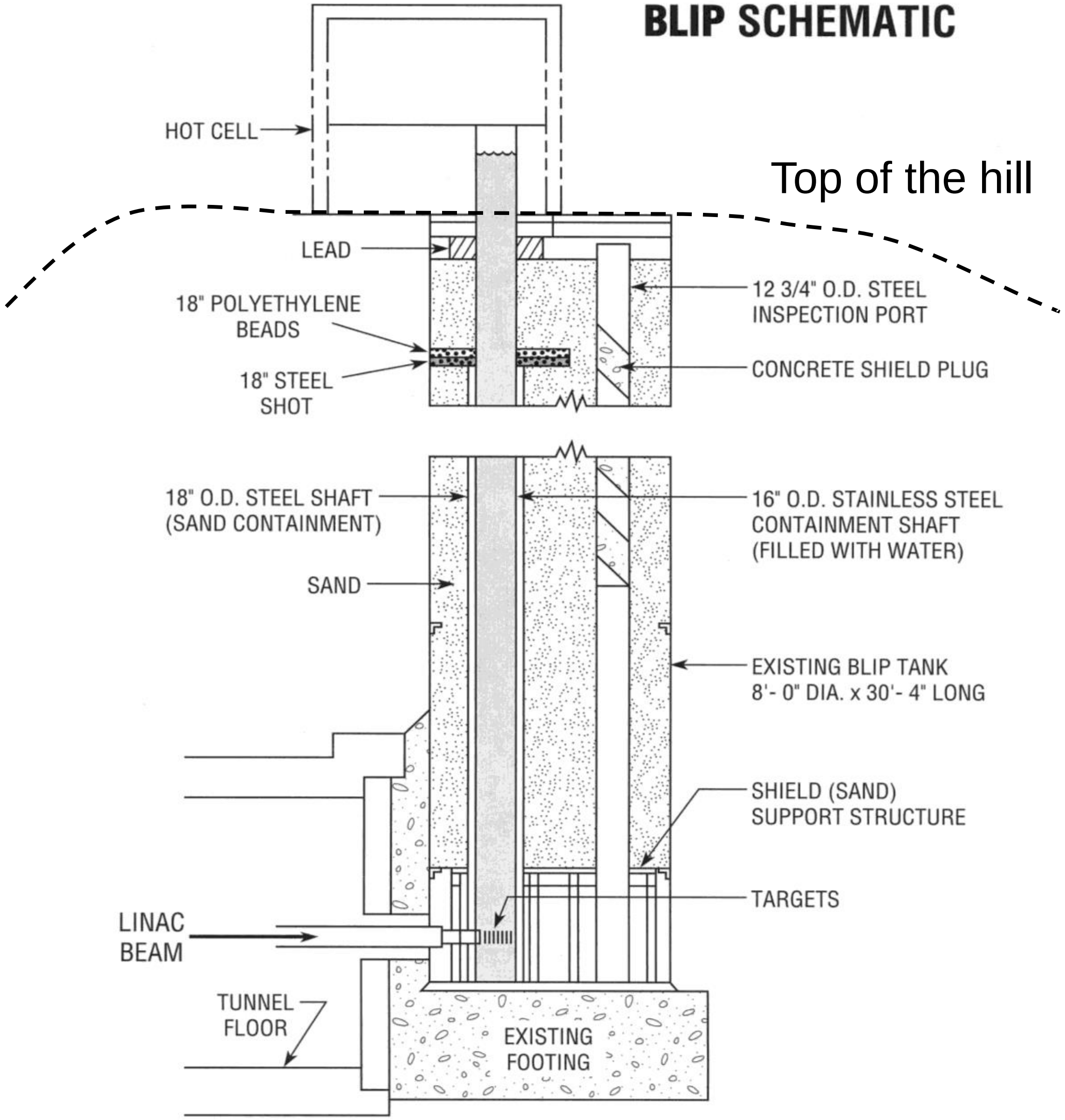
# Energy slots occupation by targets at BLIP*




**Both Ge-68 and Sr-82 are currently produced by commercial supplies*

# Brookhaven Linac Isotope Producer (BLIP) target station

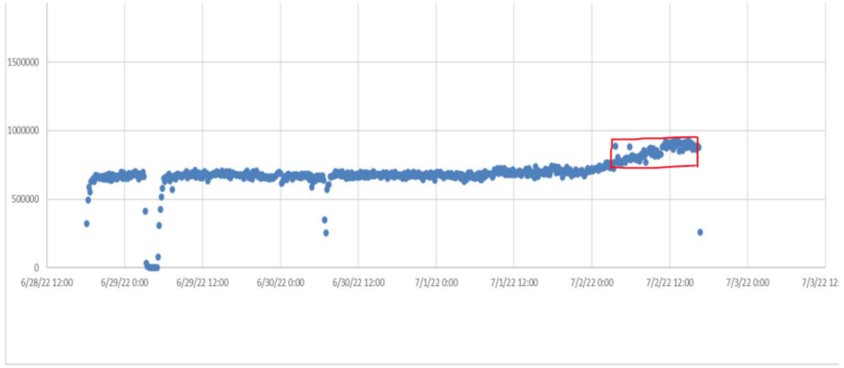


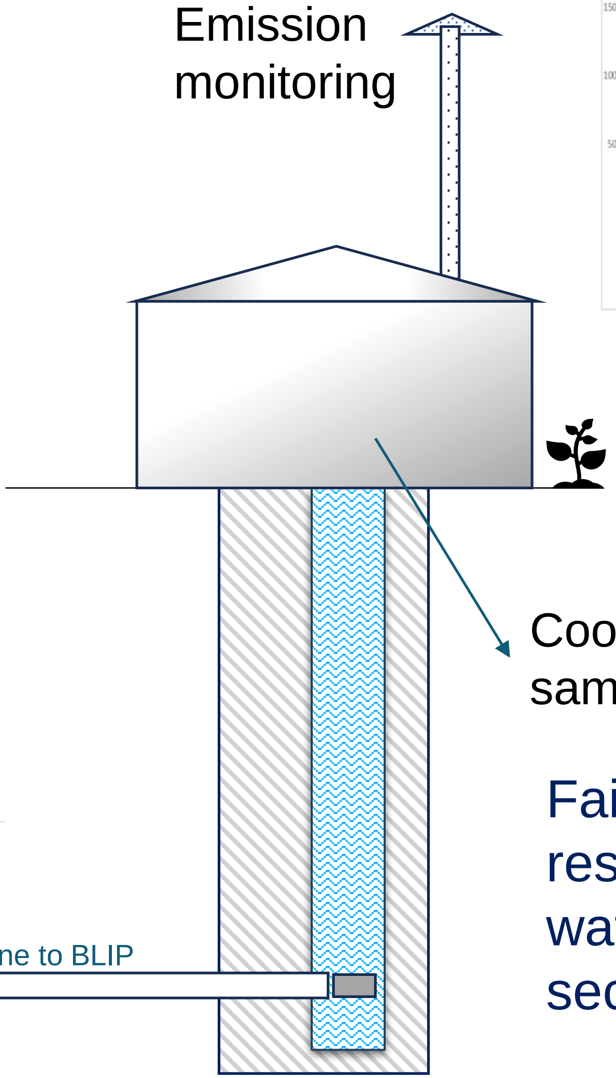





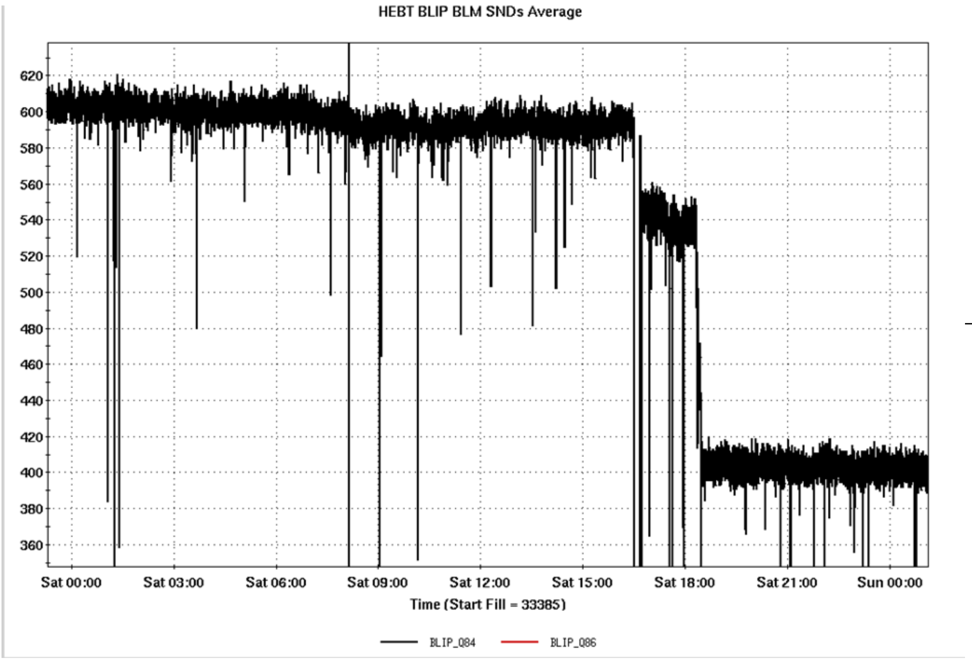

*D. Medvedev et al., 8th High Power Targetry Workshop (HPTW2023)*

# Realtime monitoring of targets' integrity






Cooling water
sampling




Neutron
monitoring

Failure of a target stack component results in emission increase due to water activation, and reduction of secondary neutrons flux

# High energy target irradiation at BLIP – 33 kW of beam power

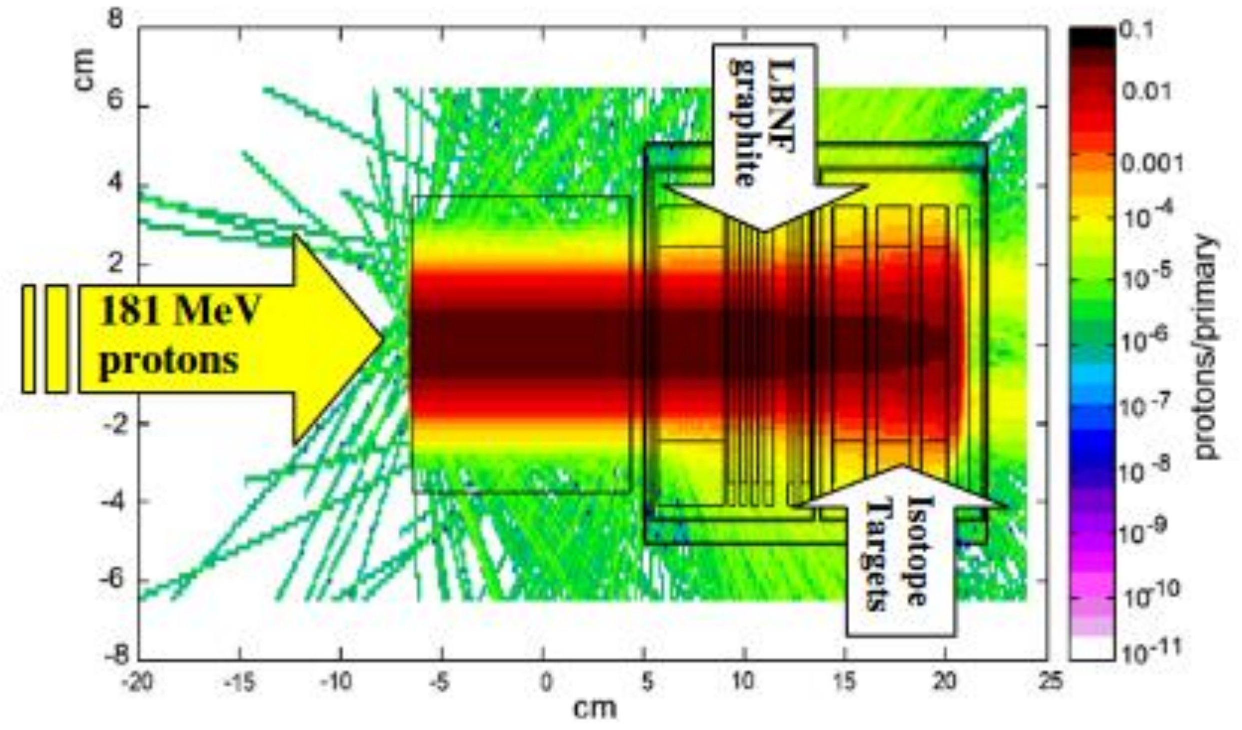



FIG. 4. Configuration of the 181 MeV proton irradiation experiment of graphite grades.

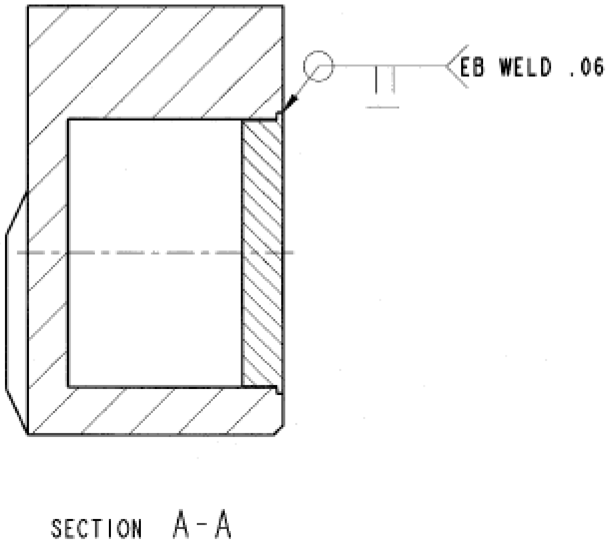
- About 200 MeV of proton energy is stopped by water, targets and degraders
- Water irradiation needs to be minimized
- Conventional isotope production with protons require energy below 100 MeV: some energy degradation is required as high as 60 MeV
- The choice of the materials is governed by:
  - Thermal conductivity and melting point
  - Activation profile
  - Density and stopping power
  - Resistant to water
  - Inexpensive and easy to machine
  - Do not present additional hazard upon disposal as radioactive material

*N. Simos et al. PHYSICAL REVIEW ACCELERATORS AND BEAMS 20, 071002 (2017)

# Materials used at BLIP for energy degradation

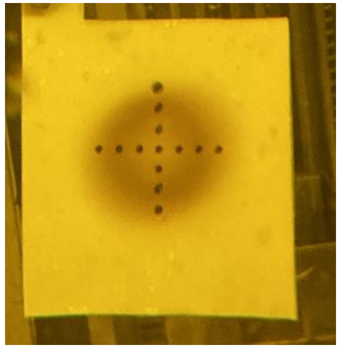
| Item | Aluminum | Copper |
|---|---|---|
| Thermal conductivity and melting point | ✓ | ✓ |
| Density | low | ✓ |
| Activation products: gamma emitters | Na-22: 1274 keV (99.9%)<br>Na-24: 2754 keV (99.9%) | Co-60: 1173.23 (99.9%)<br>1332 (99.9%) |
| Cost | ✓ | ✓ |
| Machining | ✓ | ✓ |
| Water resistance | ✓ | ✓ |

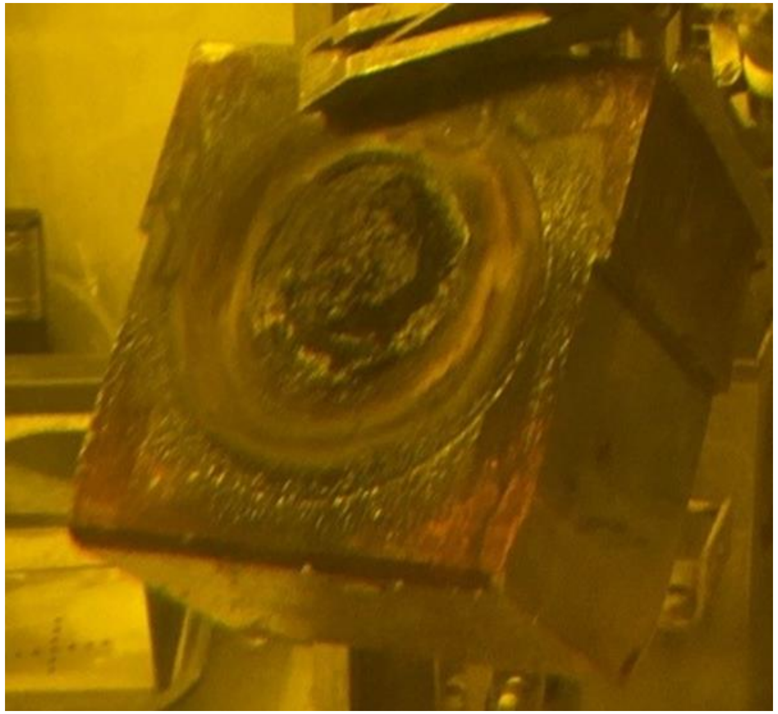
# Copper vacuum degraders to reduce emissions: 10 kW

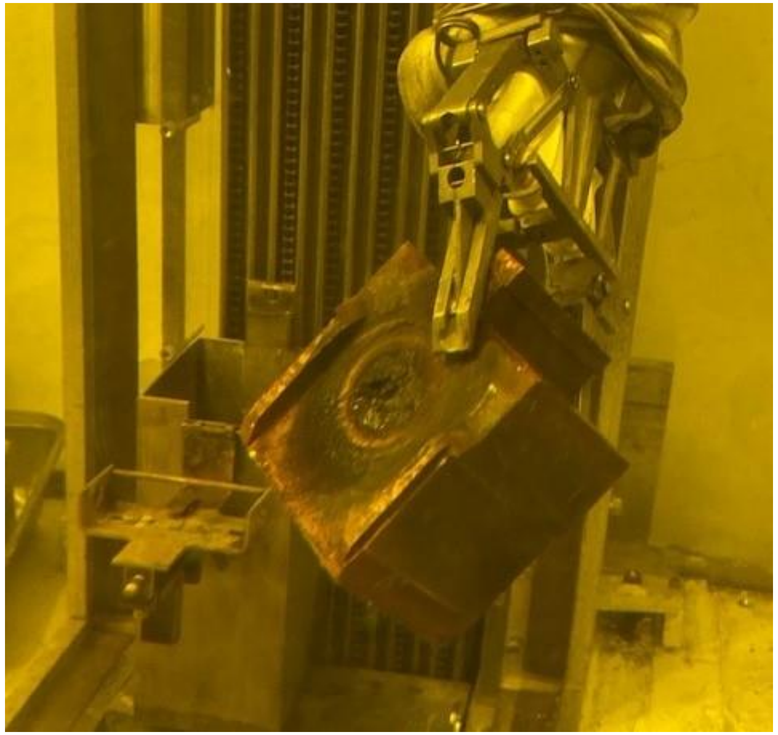



| Material in Beam | density | thickness | | Energy deposited (MeV) | watts at |
|---|---|---|---|---|---|
| | (g/cm^3) | inches | (mm) | | 165 µA |
| Copper degrader window | 8.96 | 0.377 | 9.5758 | 29.14 | 4808.1 |
| Vacuum | 0.00 | 1.636 | 41.554 | 0.00 | 0.0 |
| Copper degrader window | 8.96 | 0.376 | 9.550 | 33.20 | 5478.0 |

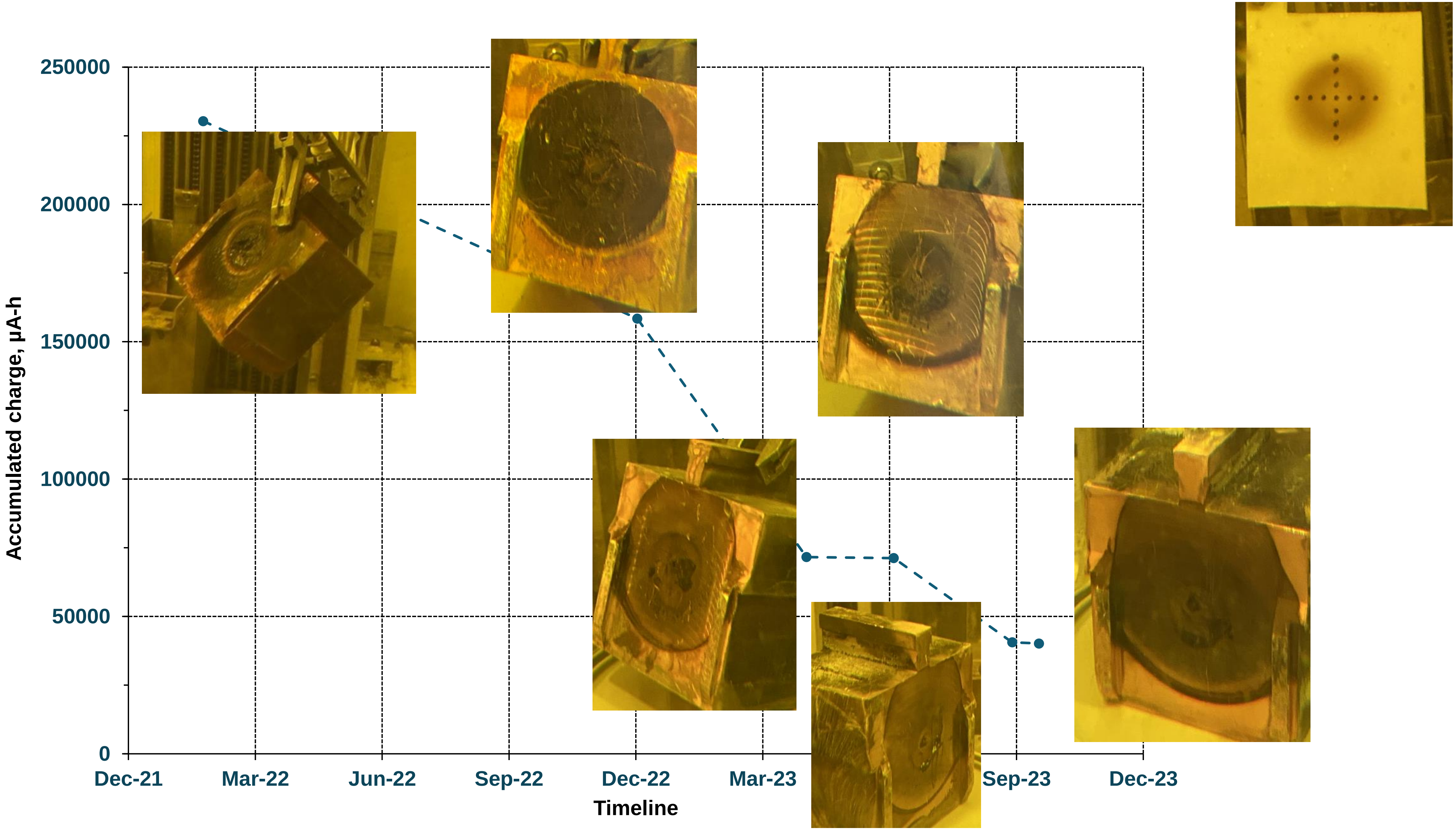
# What happens in beam after ~230000 µA-h







| | |
|---|---|
| Total received beam | 230326uAh |
| Total beam-on-target time | 1516.95hours |
| Total beam days | 63.21days |
| Avg. current | 151.84uA |



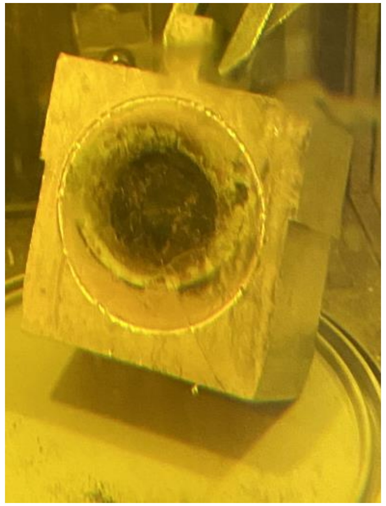

*D. Medvedev et al., 8th High Power Targetry Workshop (HPTW2023)*

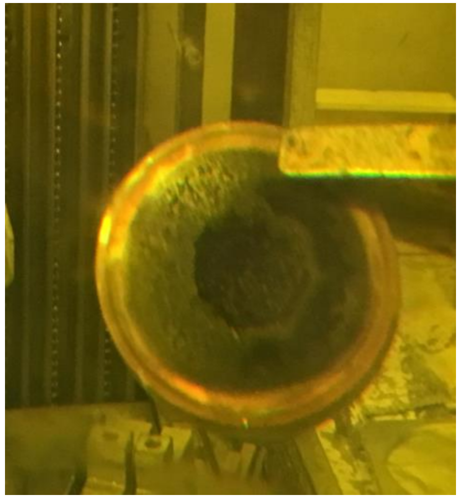
# Tested approaches

- Ni coating of copper surface – did not really help (163,000 μA-h picture to the right)
- Isolation in Inconel capsule under He worked for solid pucks

Potential solutions

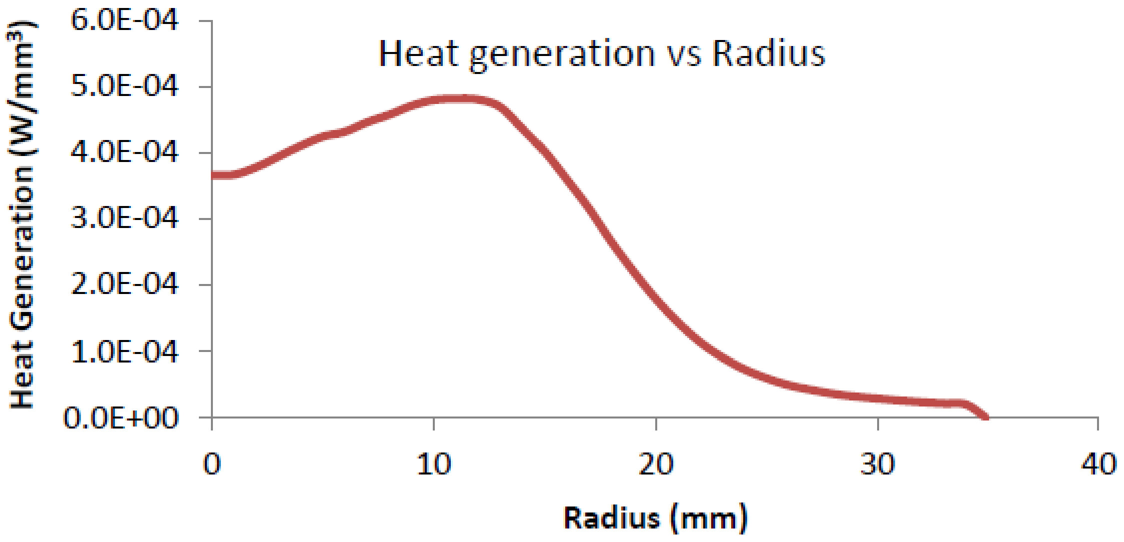
- Use Helium, not vacuum, to fill the empty space inside the degrader to improve cooling
- Use multiple solid puck Inconel encapsulated degraders. Minuses: increased emissions, more items to keep track of, easy to confuse with isotope targets
- Improve cooling system – major upgrade
- Other materials?





# Benchmarking of theoretical calculations for beam stop

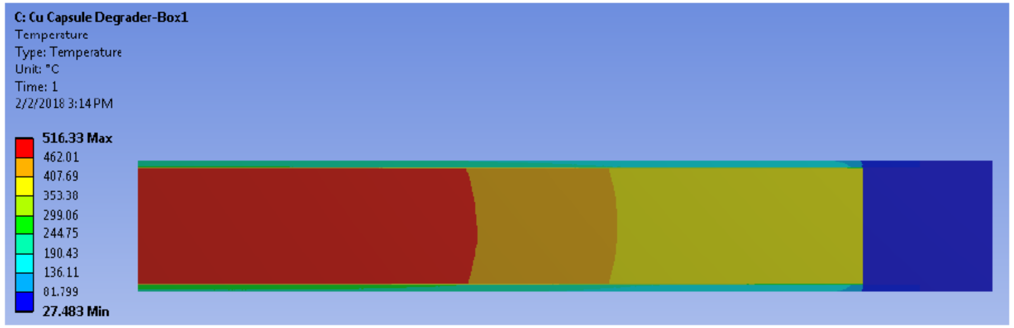
- Beam Current = 165µA
- Heat Load on Cu = 5612.54 watt, front window = 297.53 watt, back window = 0.00 watt
- Cu degrader is welded under He.

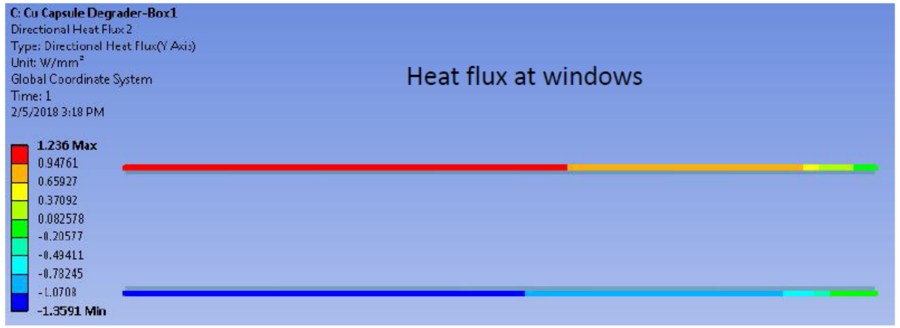



**Heat generation profile for raster beam**

Raster 12.5mm/5.5mm (4:1)

Beam FWHM 10.5mm



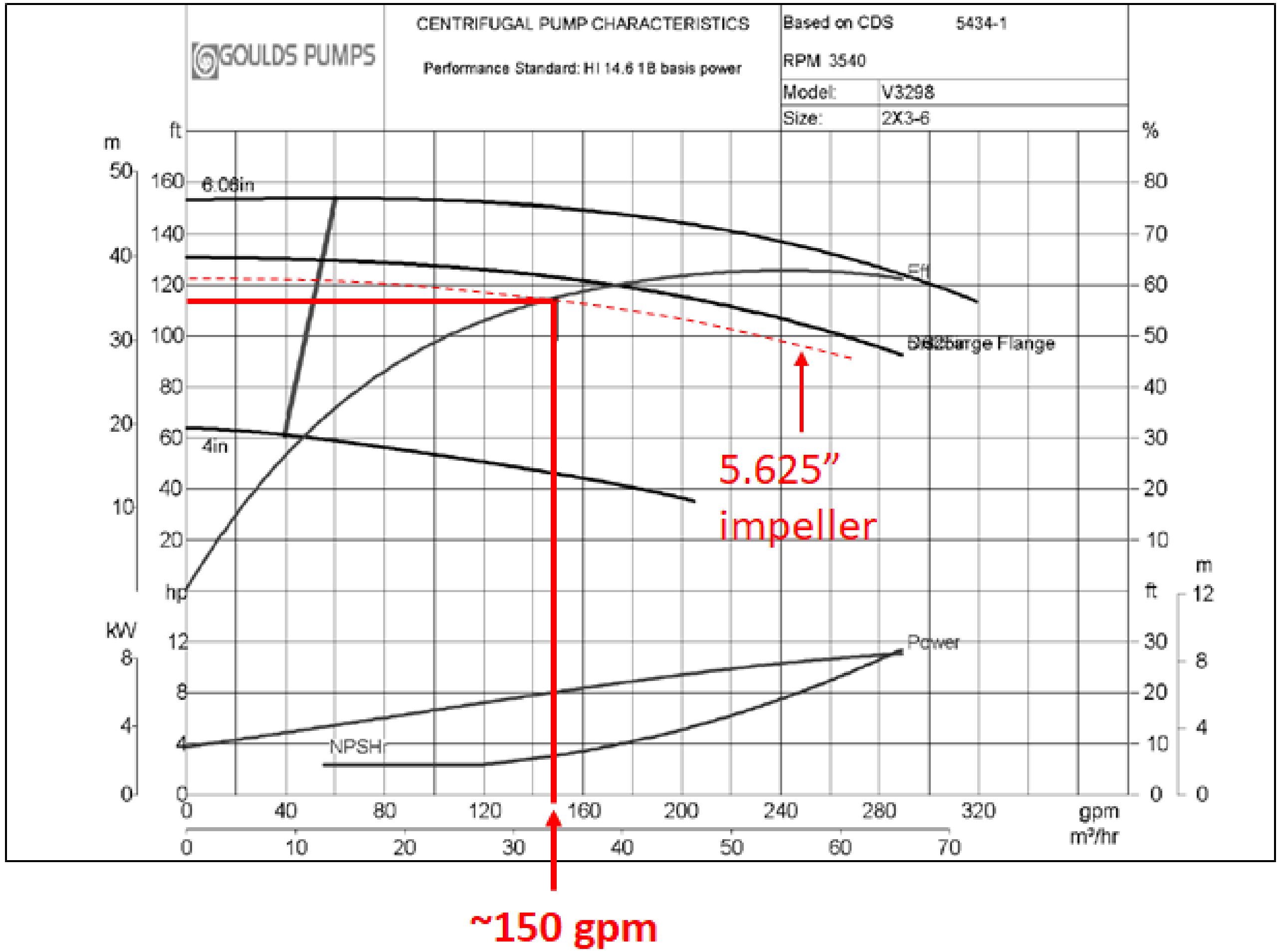



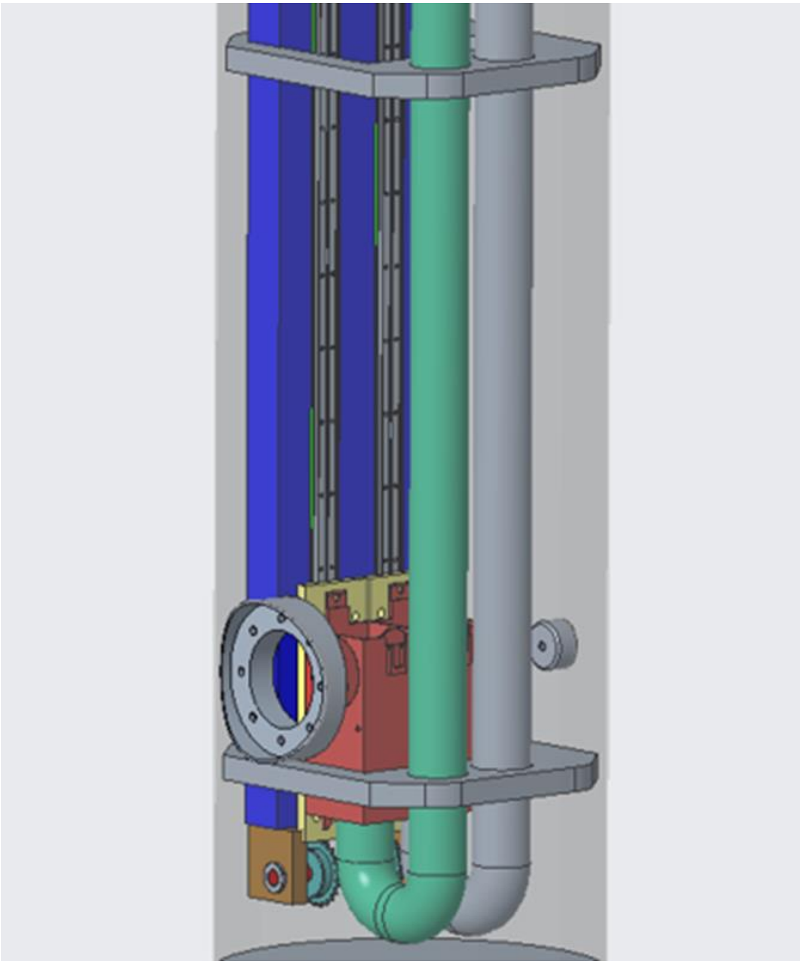

Melting point of Cu = 1083 $^0$C
Melting point of Inconel = 1290 - 1350$^0$C
Critical Heat Flux = 2.17 W/mm$^2$

**courtesy of Sumanta Nayak*

# Cooling upgrade: new target drive and water system*

- Larger pumps and an increase in the size of supply pipes from 6 x 0.75-inch to 2 x 2-inch resulting in 3 fold increase in flow



*courtesy of Steve Bellavia

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# Acknowledgement


- The MIRP program is funded by the US DOE Isotope program
- BLIP operators:
  - Henryk Chelminski
  - Lisa Muench
  - David O'Rourke