



Plans for the RaDIATE high-energy proton materials irradiation at BLIP

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Motivation

- Radiation damage study of various materials used in critical accelerator components
 - Beam windows, secondary particle production targets, beam dumps

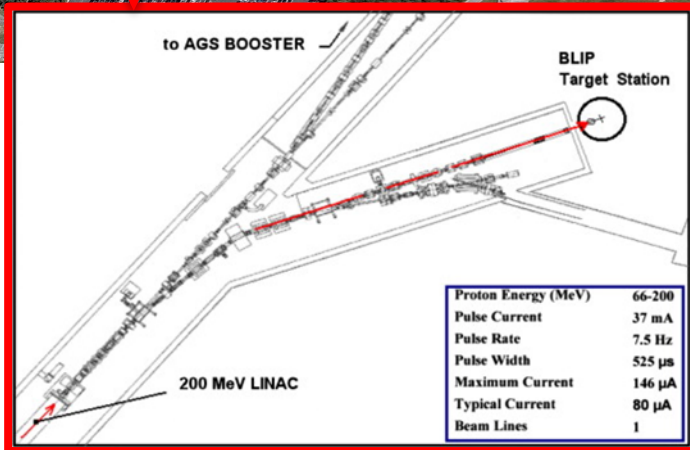
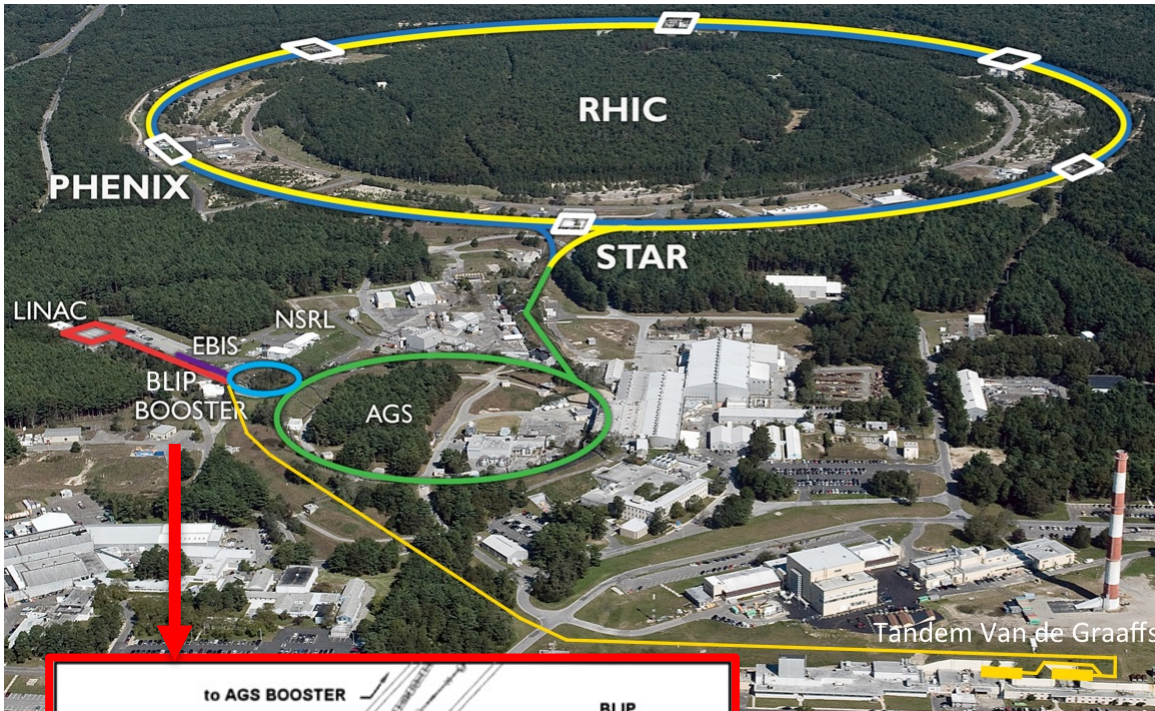
Objectives

- Irradiate several materials of interest with high energy protons
- Coordinate PIE activities: measurement of strength (tensile, bend, fatigue), thermal properties (CTE, conductivity), annealing effects, microstructural analysis (SEM, TEM, EBSD, etc.)
- Characterize property changes due to proton-irradiation damage



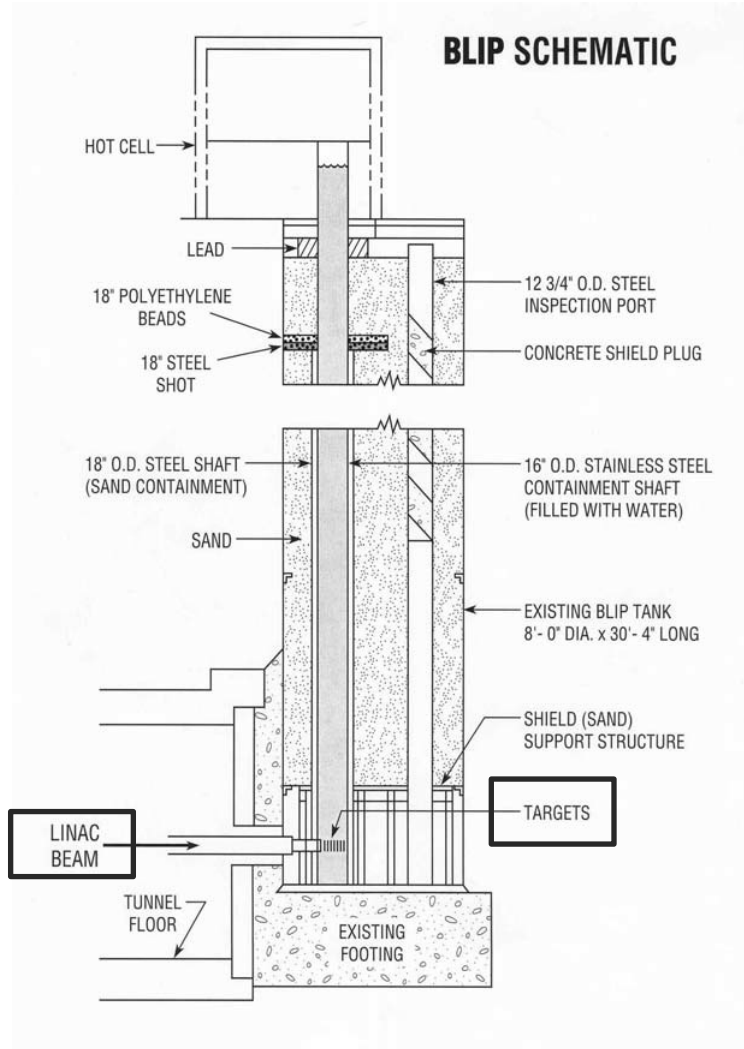
BLIP Irradiation Facility at BNL

Brookhaven Linac Isotope Producer (BLIP)



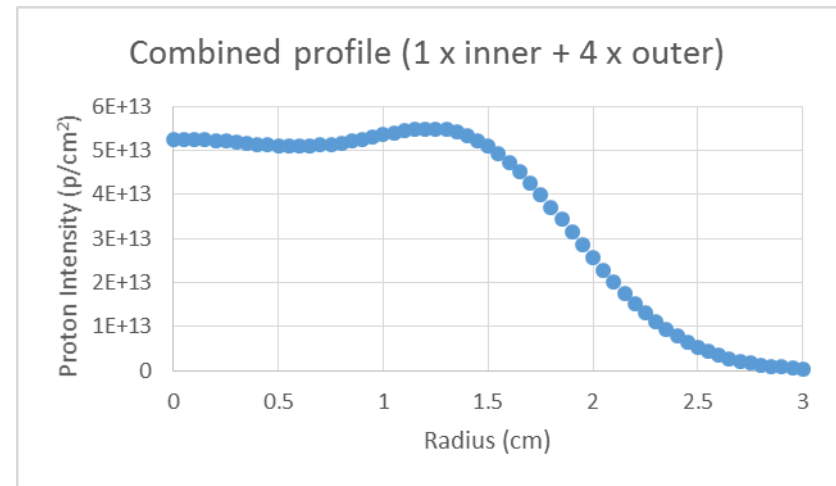
- **Primary mission of BLIP is for medical isotope production**
- **High energy protons**
 - Energy: $66 < E < 200$ MeV
 - Peak current: $165 \mu\text{A}$
- **Material irradiation**
 - Runs in tandem upstream of isotope target
 - Optimized target array needed to deliver precise beam energy and flux for isotope production
 - Energy at isotope target location $93.5 - 94.0$ MeV

BLIP Facility



Beam parameters

- Rastered beam sigma: 0.51 cm
 - 1 x inner sweep: 0.55 cm radius
 - 4 x outer sweep: 1.5 cm radius
- Pulse frequency: 6.67 Hz
- Peak current: 165 μA
- Peak fluence: $7\text{e}13 \text{ p/cm}^2/\text{s}$

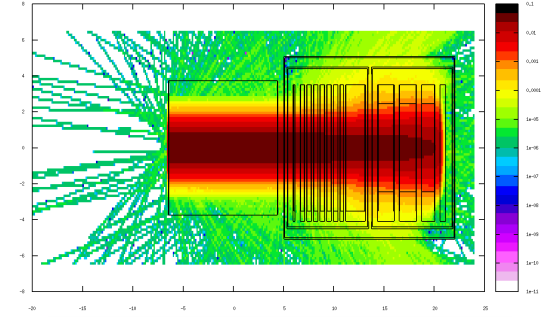


Irradiation Run in 2010

- Several grades of graphite
 - IG-430, ZXF-5Q, C2020, R7650, 3D C/C composite
- 181 MeV beam energy
- σ_x : 10 mm, σ_y : 7 mm
- Peak DPA: **0.1**
- Peak irradiation temperature ~ 160 °C
- 9-week irradiation time



Graphite layers in capsule



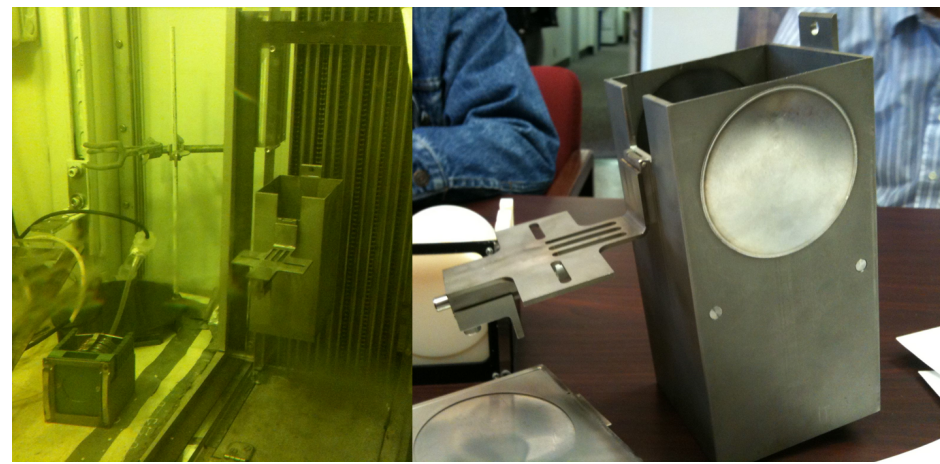
Graphite & isotope targets analysis



Target basket



Capsule holders

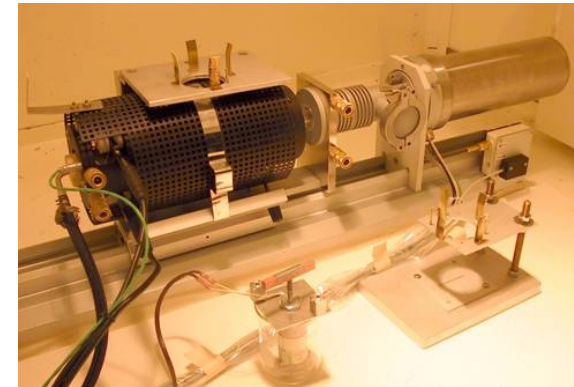
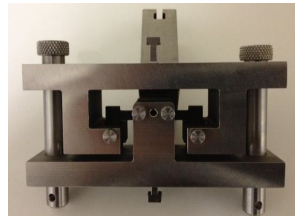
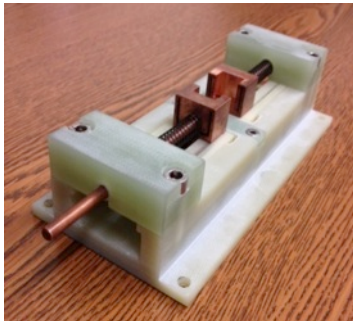
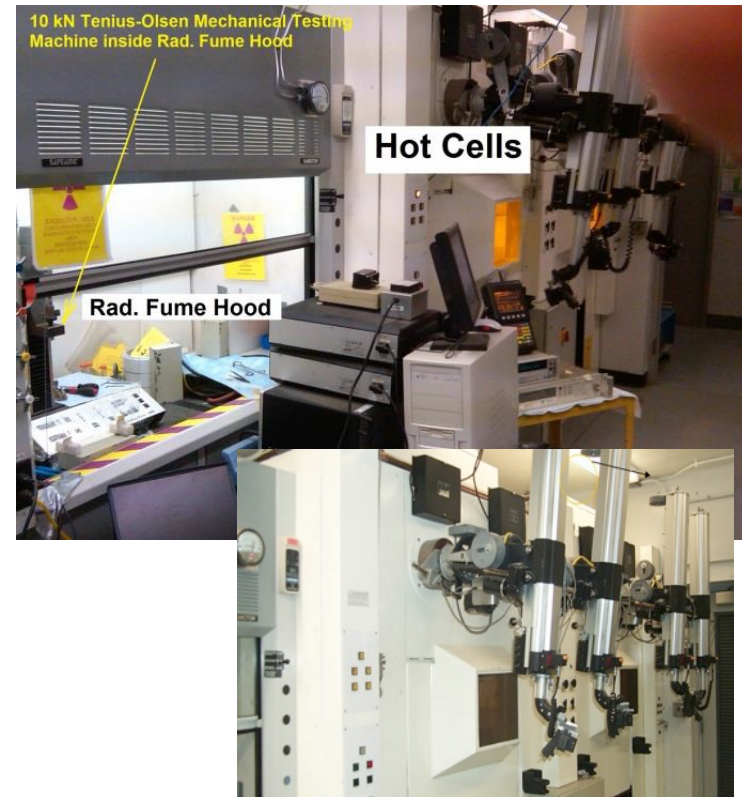


BLIP hot cell

Target drive box

PIE Capabilities at BNL

- 2 hot cells and HEPA-filtered fume hood
- PIE equipment:
 - Stress-strain (tension, 3-point and 4-point bending)
 - Ultrasonic measurements
 - Thermal expansion and annealing (dilatometer)
 - Thermal conductivity (electrical resistivity)
 - X-ray diffraction at NSLS II
 - Laser induced annealing, tension, 4-pt bending
- ALSO
 - Photon spectra and isotopic analysis
 - Activity measurements
 - Weight loss or gain

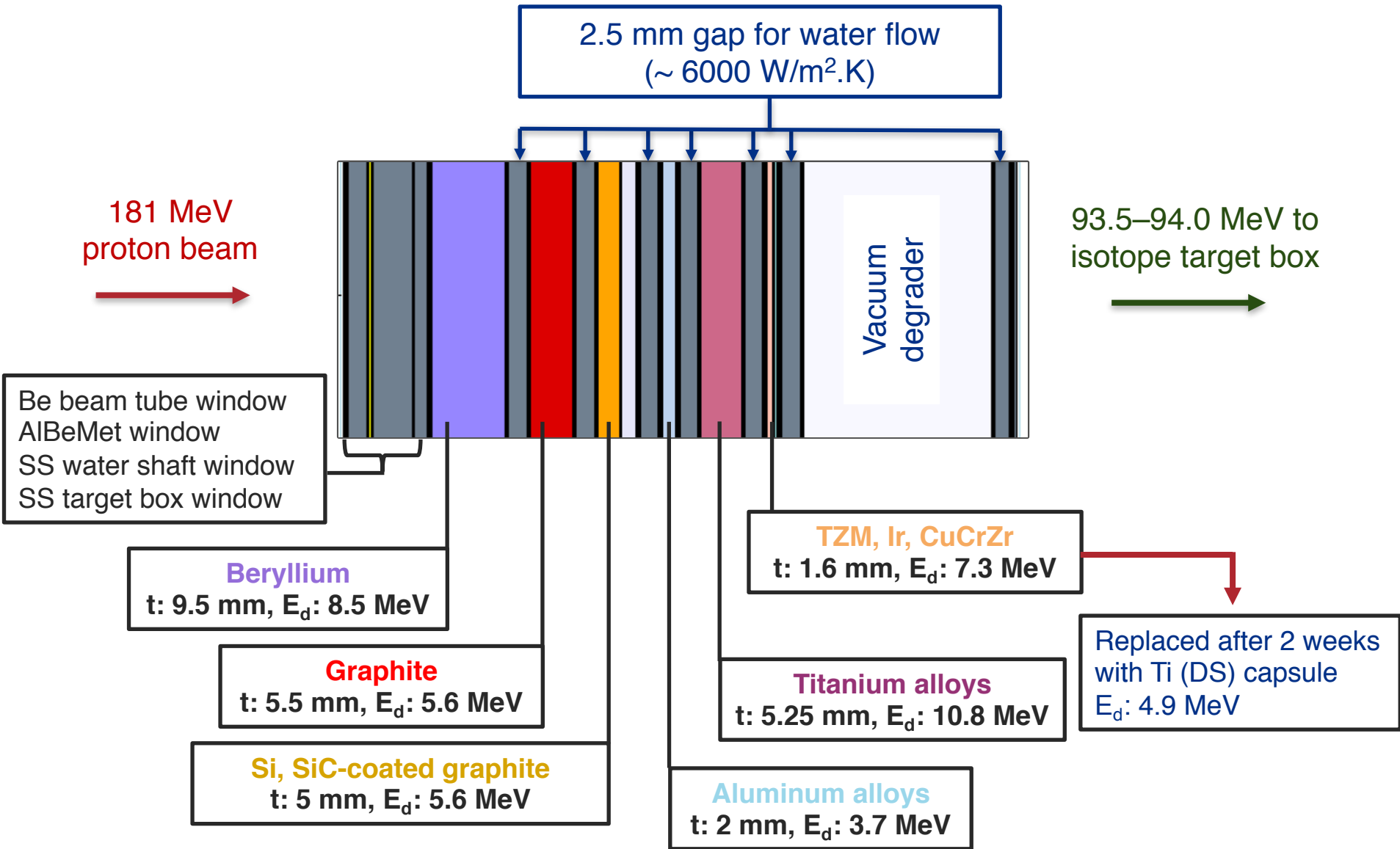


RaDIATE Irradiation Run 2017

- Multiple capsules containing different materials
 - **Capsule 1:** Beryllium (FNAL)
 - **Capsule 2:** Graphite (FNAL)
 - **Capsule 3:** Silicon, SiC-coated graphite, Expanded graphite (CERN, KEK)
 - **Capsule 4:** Aluminum alloys (ESS)
 - **Capsule 5:** Titanium alloys (FRIB, KEK, Oxford, STFC, FNAL)
 - **Capsule 6:** TZM, Iridium, CuCrZr, Flexible graphite (CERN)
 - **Capsule 7 (replacement):** Titanium alloys (KEK, Oxford, STFC, FNAL)
- Planning for total of **8-week** irradiation
 - Capsules 1 – 5: **8 weeks**
 - Capsule 6: **2 weeks**
 - Capsule 7: **6 weeks**



Target Box Composition

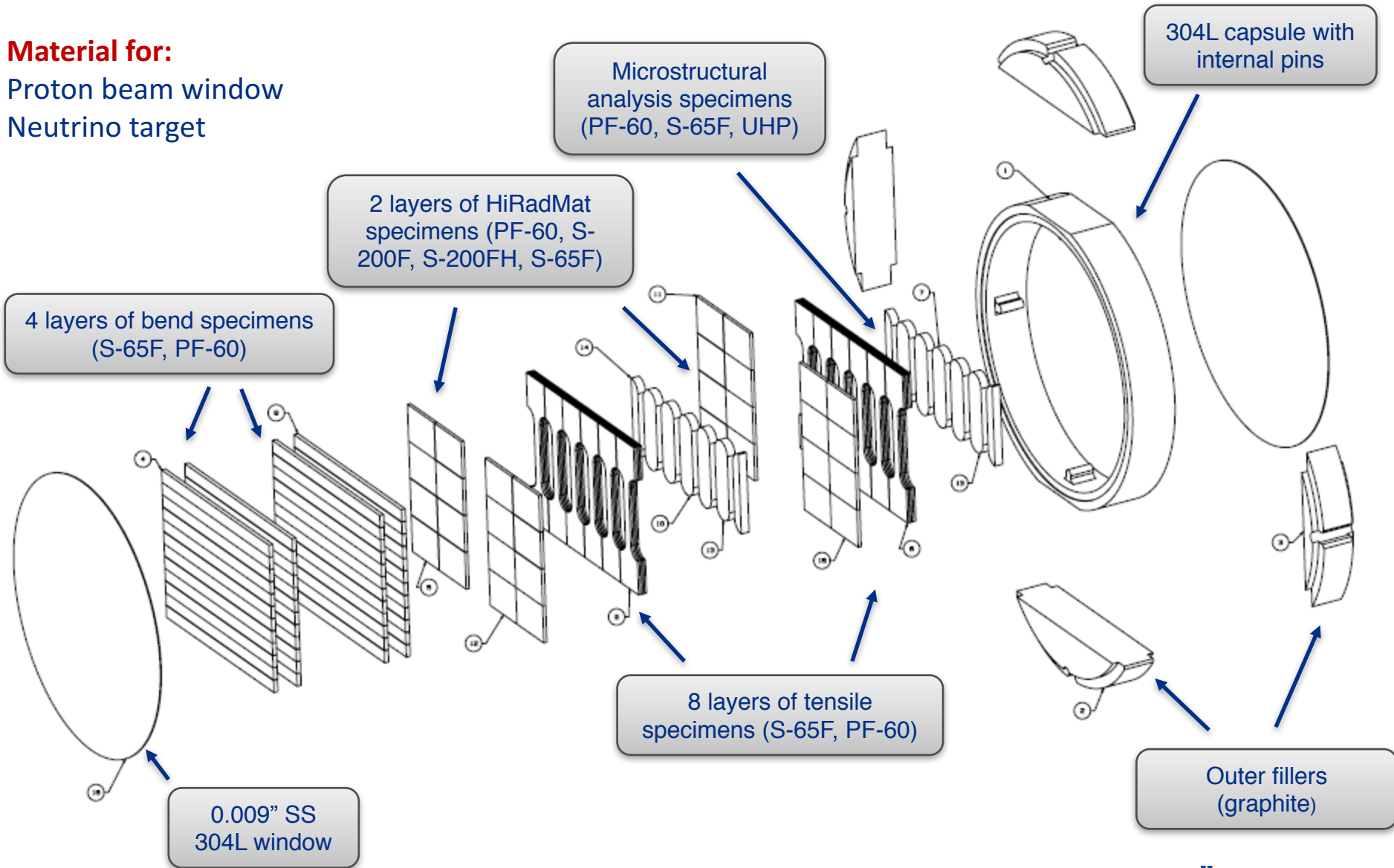


Beryllium Capsule (FNAL)

Material for:

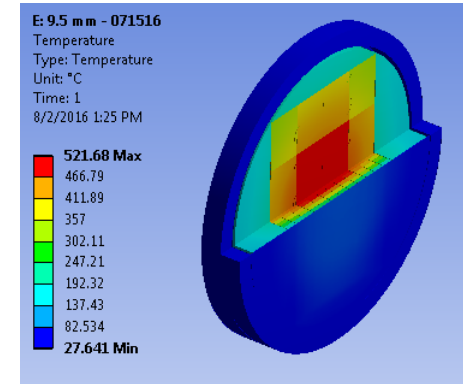
Proton beam window

Neutrino target

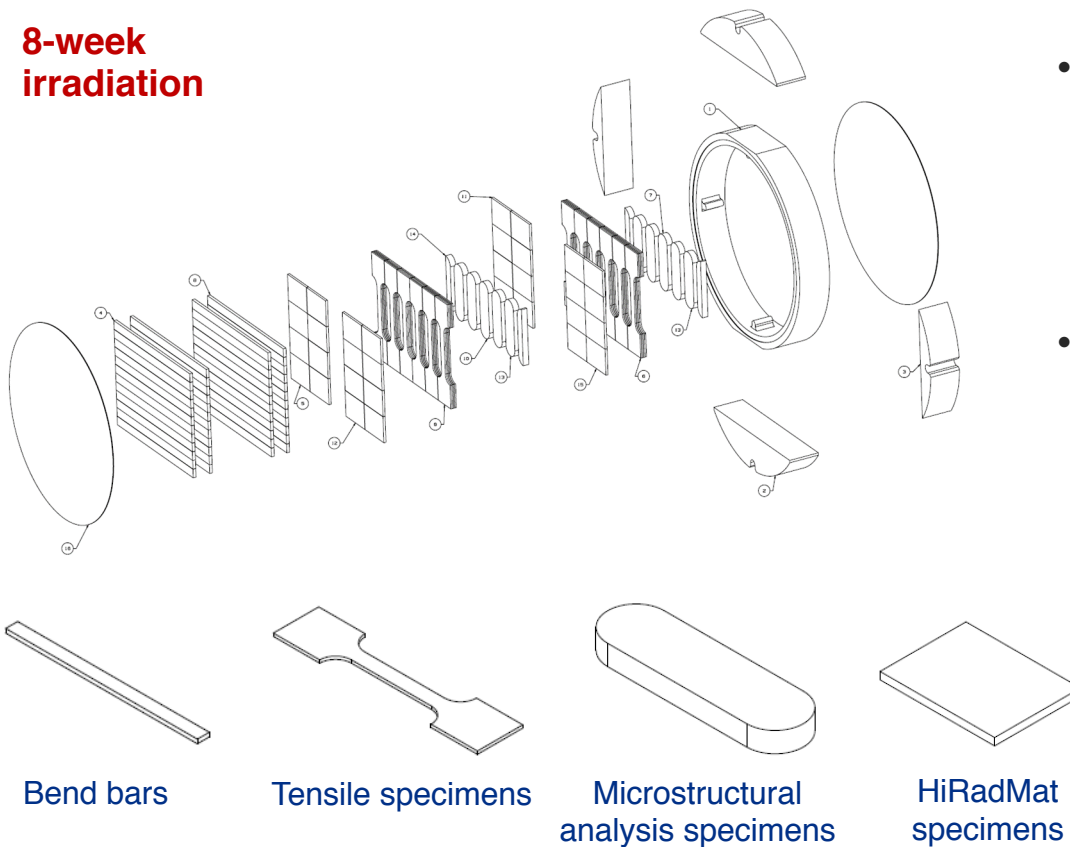


Beryllium Capsule (FNAL)

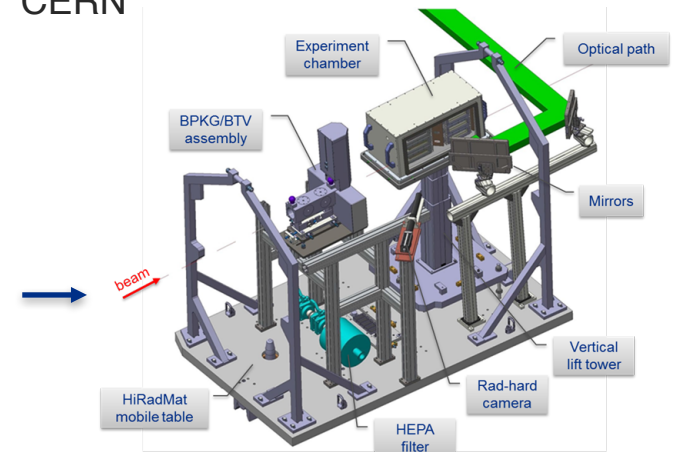
- Capsule atmosphere: **Argon**
- Total specimen thickness: **9.5 mm**
- Energy degradation: **8.48 MeV** (1400 W)
- Estimated peak irradiation temperature: **~ 520 °C**



8-week irradiation

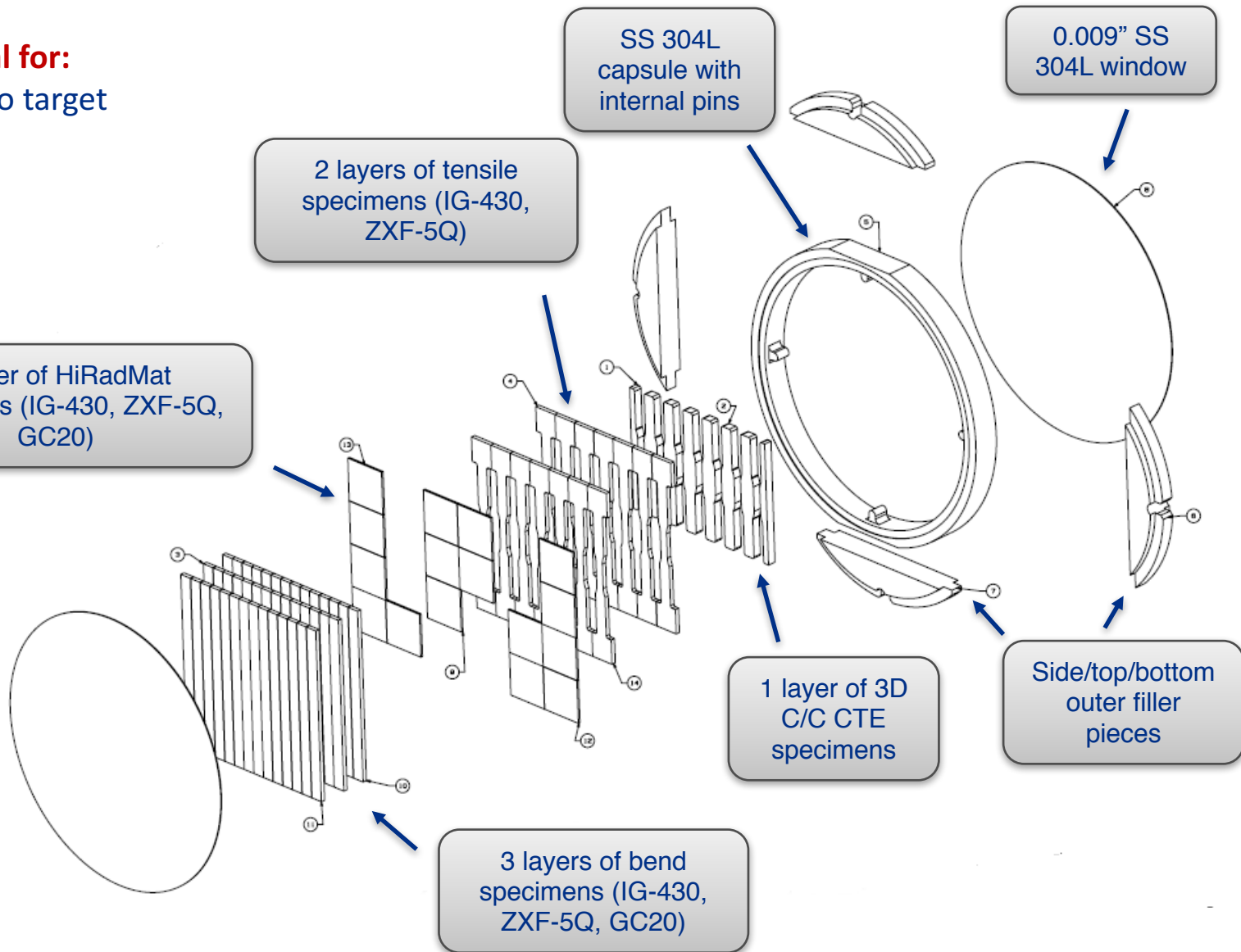


- Beryllium grades
 - PF-60
 - S-65F
 - S-200F
 - S-200FH
 - UHP
- PIE at PNNL, Oxford/CCFE & CERN



Graphite Capsule (FNAL)

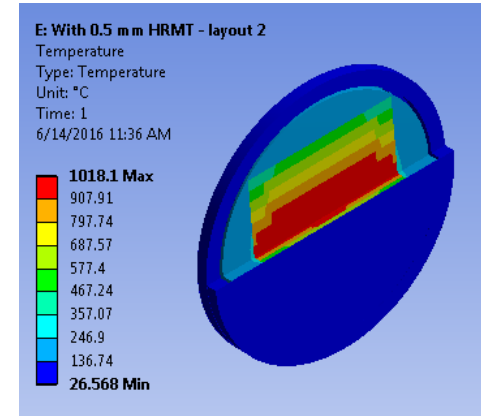
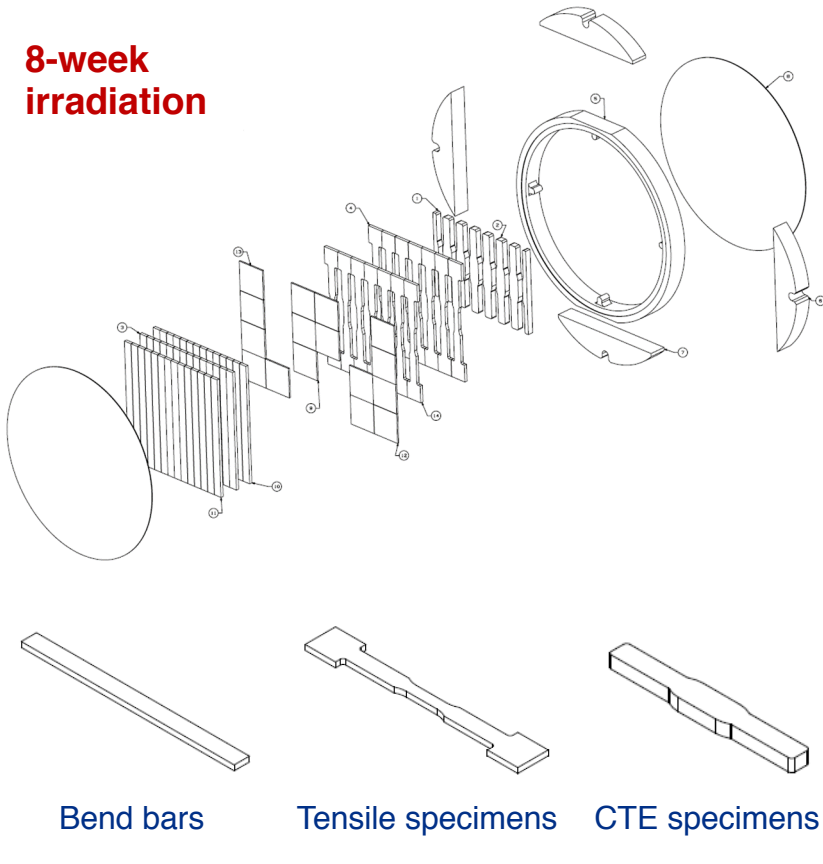
Material for:
Neutrino target



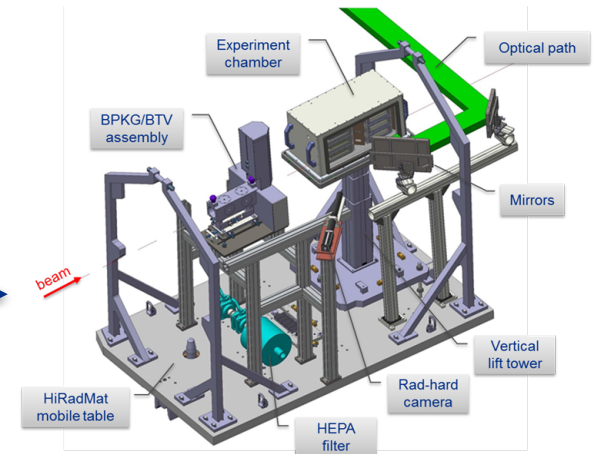
Graphite Capsule (FNAL)

- Capsule atmosphere: **Vacuum**
- Test specimen layer thickness: **5.5 mm**
- Energy degradation: **5.56 MeV** (927 W)
- Estimated peak irradiation temperature **~ 1020 °C**

8-week irradiation



- Graphite grades
 - IG-430
 - ZXF-5Q
 - GC20
 - 3D C/C composite
- PIE work at PNNL, BNL & CERN



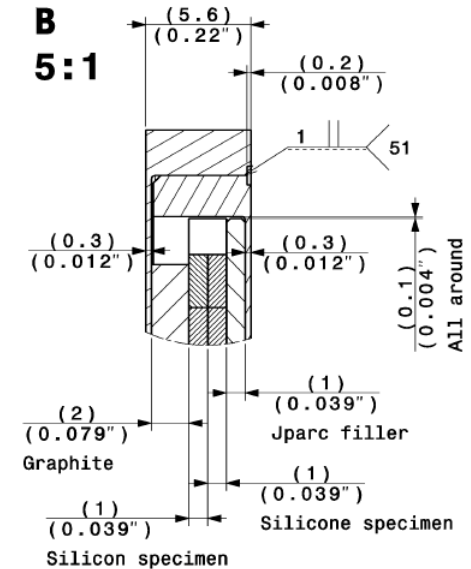
Silicon Capsule (CERN, KEK)

Candidate material for:

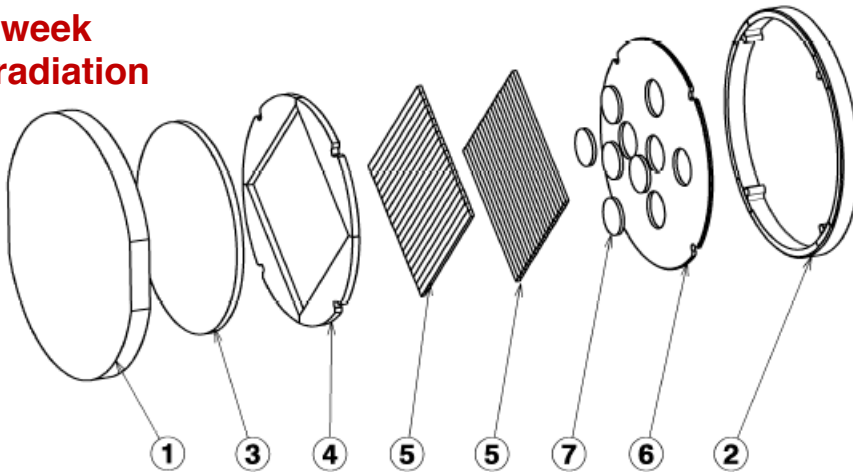
CERN SPS internal dump (Si)

KEK muon production target (SiC-coated graphite)

- Capsule atmosphere: **Vacuum**
- 3 layers of materials in capsule (5 mm total)
 - 1 mm thick **SiC-coated graphite** specimens ⑦
 - 2 mm thick **Si** bend specimens ⑤
 - 2 mm thick expanded graphite disk ③
- Energy degradation: **5.62 MeV** (927 W)



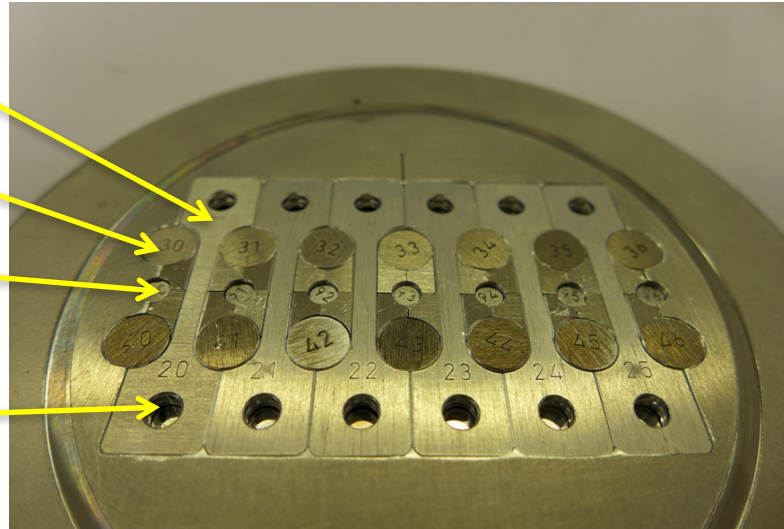
8-week irradiation



- PIE work at PNNL
- Capsule will be assembled and welded at CERN

Aluminium Capsule (ESS)

Component	Material	Quantity
Tensile Specimen	Al6061-T6	6
	Al5754-O	6
LFA Specimen	Al6061-T6	7
	Al5754-O	7
TEM/SP Specimen	Al6061-T6	14
	Al5754-O	14
Luminescent Coating Specimen	Al ₂ O ₃ -Cr1%	18
	Y ₂ O ₃	6
	Activation foils	-
Filler	Al6061-T6	1
Substrate	Al6061-T6	-
Frame	SS 304	-
Window	SS 304	-



8-week irradiation

Y. Bessler and F. Hanusch (FZJ)

Candidate material for:
 Proton beam window
 Luminescent coating on PBW

- Capsule atmosphere: **Helium**
- Test specimen layer thickness: **2 mm**
- Energy degradation: **3.72 MeV** (614 W)
- Estimated peak irradiation temperature **~ 73 °C**
- PIE work at PNNL & LANL
- Capsule assembled and welded by ESS

- Several grades of Al alloys
- Specimen types:
 - Tensile
 - LFA
 - TEM
 - Luminescent coating disks

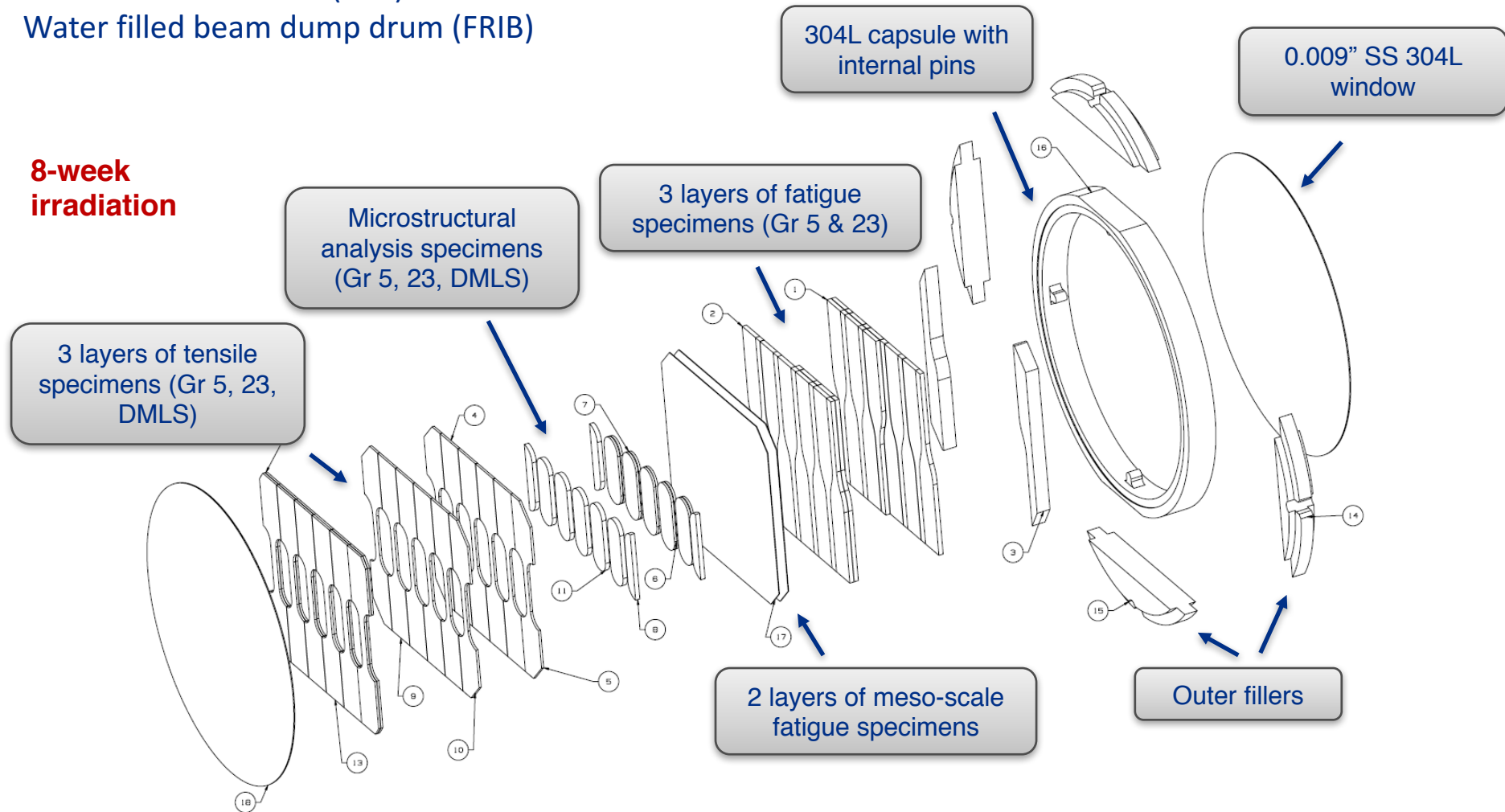
US Titanium Capsule (FRIB, KEK, Oxford, STFC, FNAL)

Candidate material for:

Proton beam window (KEK)

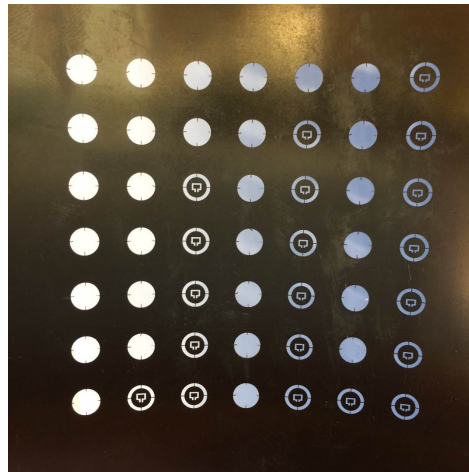
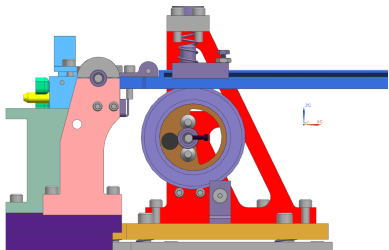
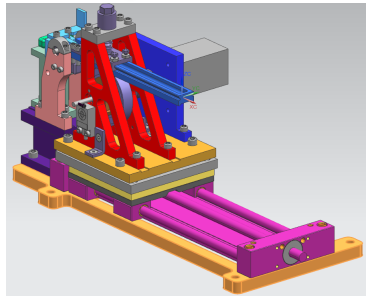
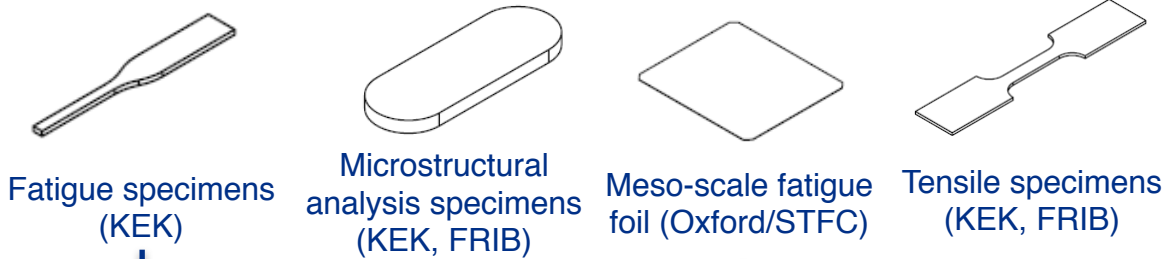
Water filled beam dump drum (FRIB)

8-week irradiation

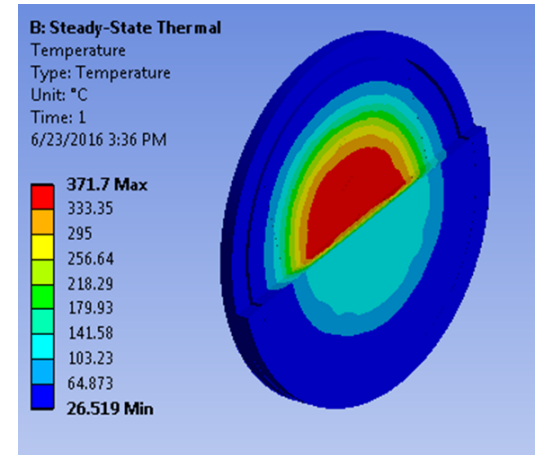


US Titanium Capsule (FRIB, KEK, Oxford, STFC, FNAL)

- Capsule atmosphere: **Helium**
- Total specimen thickness: **5.25 mm**
- Energy degradation: **10.8 MeV** (1780 W)
- Estimated peak irradiation temperature: **371 °C**



meso-cantilevers



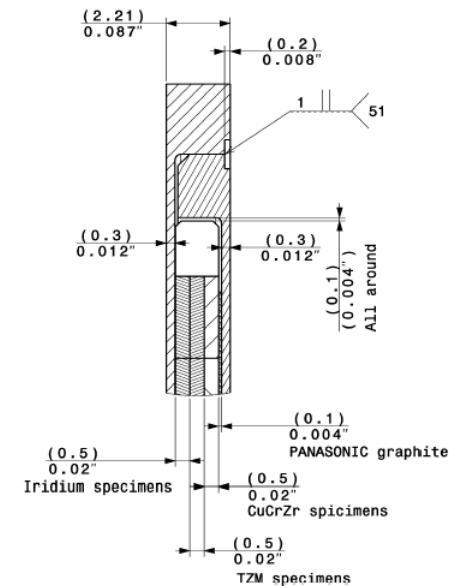
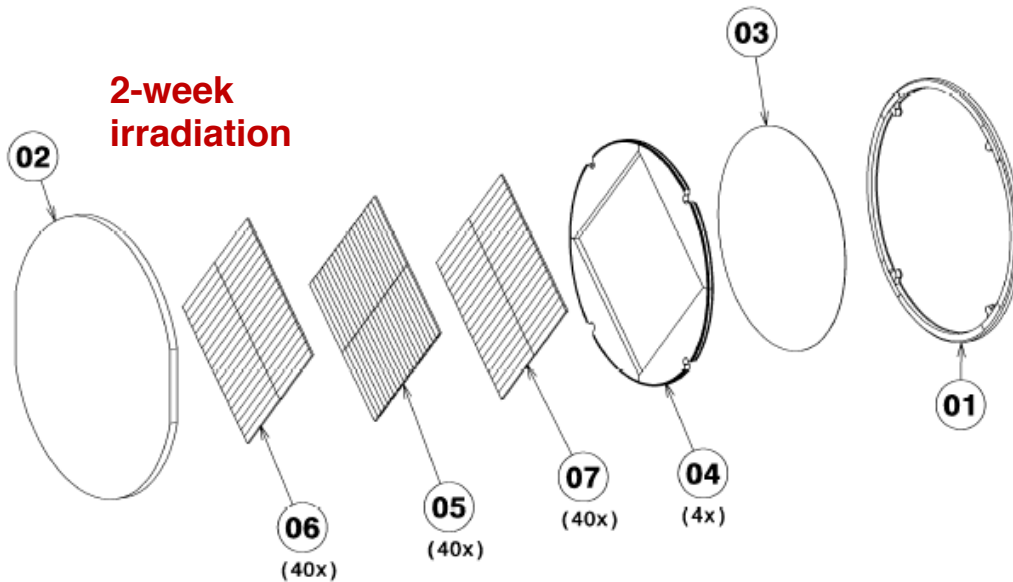
- Titanium alloys
 - Ti6Al4V (Grade 5 & 23)
 - DMLS (Gr 5)
 - HIP and as-received
 - PM rolled (Gr 5)
 - Commercially pure Ti
- PIE work at PNNL, BNL, Oxford/CCFE

High-Z Capsule (CERN)

- Capsule atmosphere: **Vacuum**
- 4 layers of materials in capsule (**1.6 mm total**)
 - 0.5 mm thick **Iridium** bend specimens ⑥
 - 0.5 mm thick **TZM** bend specimens ⑤
 - 0.5 mm thick **CuCrZr** bend specimens ⑦
 - 0.1 mm thick PANASONIC graphite foil ③
- Energy degradation: **7.29 MeV** (1200 W)

Candidate materials for:
 SPS internal dump (CuCrZr)
 AD & SHiP target (Ir, TZM)

- PIE work at PNNL
- Capsule will be assembled and welded at CERN



- Capsule will be replaced after 2 weeks of irradiation

Titanium Capsule (DS) - replacement

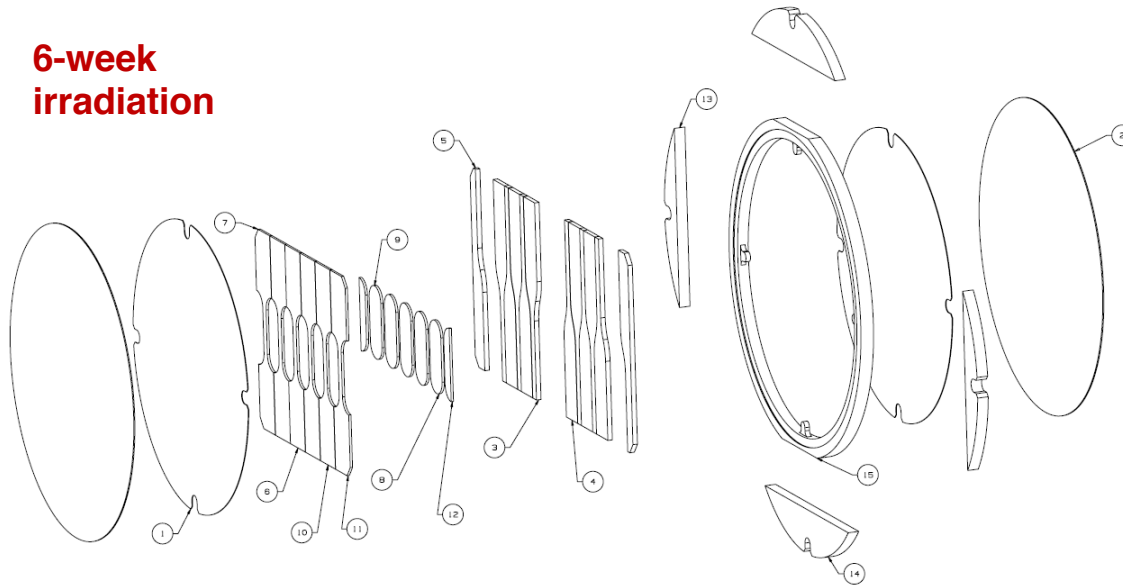
- Capsule atmosphere: **Helium**
- Test specimen layer thickness: **1.75 mm**
 - 1 mm layer of **fatigue** specimens
 - 0.5 mm layer of **tensile** specimens
 - 0.25 mm layer of **meso-scale** fatigue specimens
- Energy degradation: **4.87 MeV** (800 W)
- Lower peak irradiation temperature than US Ti capsule
- **Replaces high-Z capsule after 2 weeks**

Material for:

Proton beam window (KEK)

- Titanium alloys
 - **Ti6Al4V (Grade 5 & 23)**
- PIE work at PNNL, BNL, Oxford/CCFE

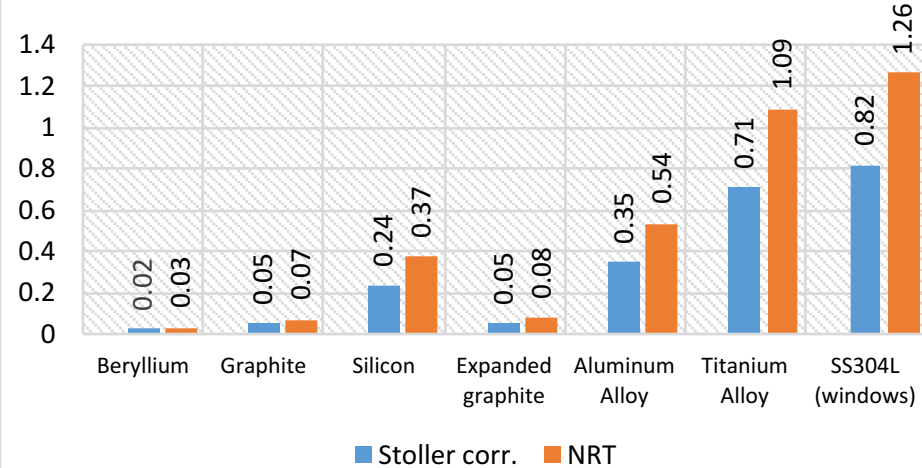
**6-week
irradiation**



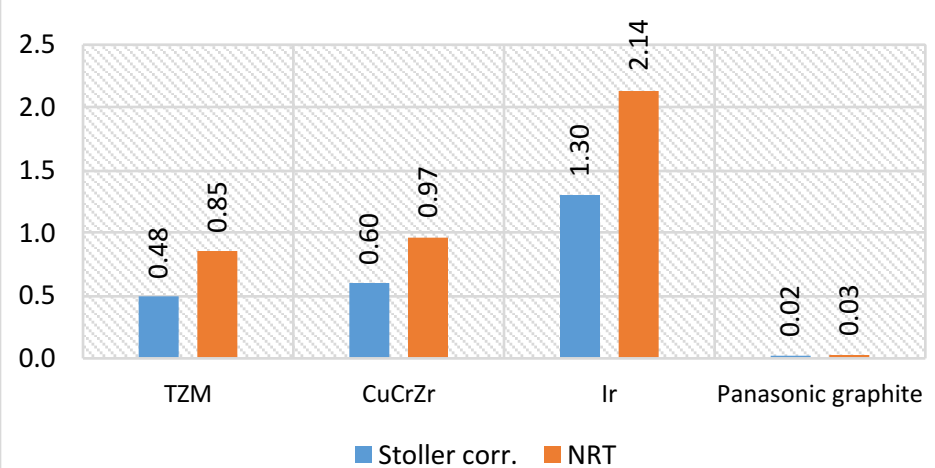
Peak DPA Values

- Medium stats MARS simulation
- Beam energy: 181 MeV
- Beam current: 165 μA (rastered beam)
- Peak proton fluence: 7×10^{13} p/cm²/s

Peak DPA, 8-week irradiation

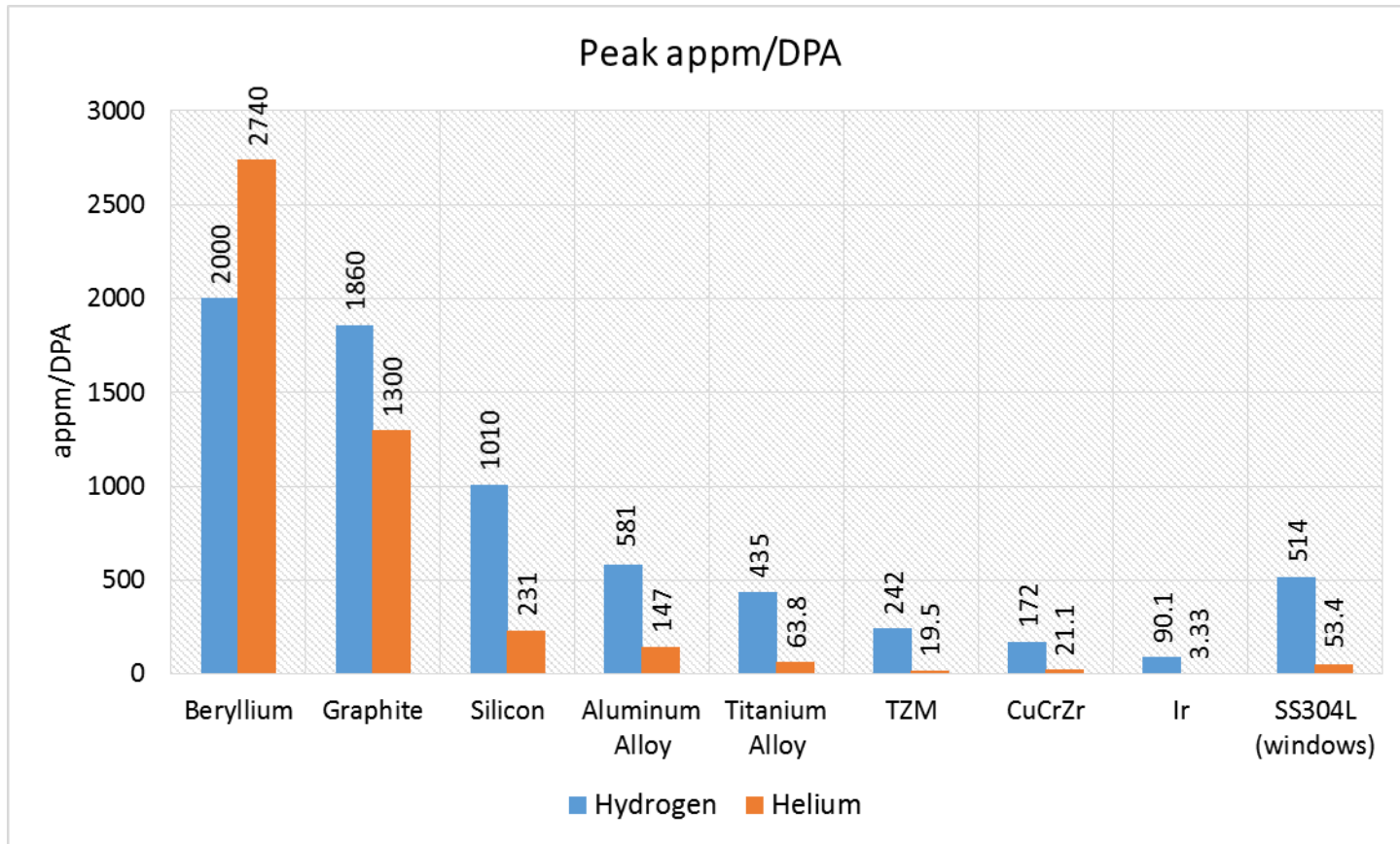


Peak DPA, 2-week irradiation



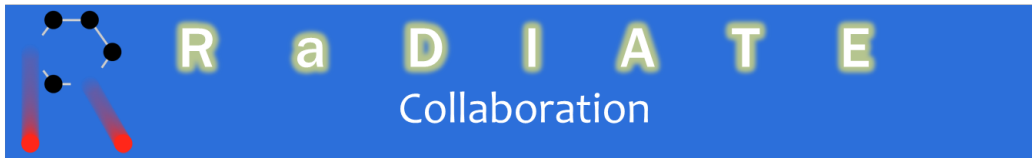
Peak Gas Production Values

- Medium stats MARS simulation
- H¹ and He⁴ stopped in target
- appm/DPA values based on Stoller corr. DPA values



Current Status & Next Steps

- All capsules finalized, specimens/parts procured and are being fabricated
 - Leak checking of capsule after assembly and welding
 - Shipment to BNL for target box assembly
 - By end of Dec. 2016
- Detailed FLUKA analysis (N. Simos at BNL)
 - Optimize target box and vacuum degrader to ensure uniform energy degradation and final desired energy for isotope target
 - Evaluate impact of proton flux degradation on isotope yield during irradiation run
 - 2 vacuum degraders for target box containing:
 - Heavy capsule
 - Ti replacement capsule
 - Estimate activity/dose rate of specimens and target box
 - Operator dose outside isotope extraction hot cell
 - Determine cool-down time before shipment of capsules/specimens
- Safety review with BNL health physics and safety committee
- PIE work plan
 - Arrange for capsule shipment to various PIE laboratories
 - Identify and ensure certification of Type A container
- Experiment start date scheduled for February 2017



Radiation Damage In Accelerator Target Environments

Thank you for your attention