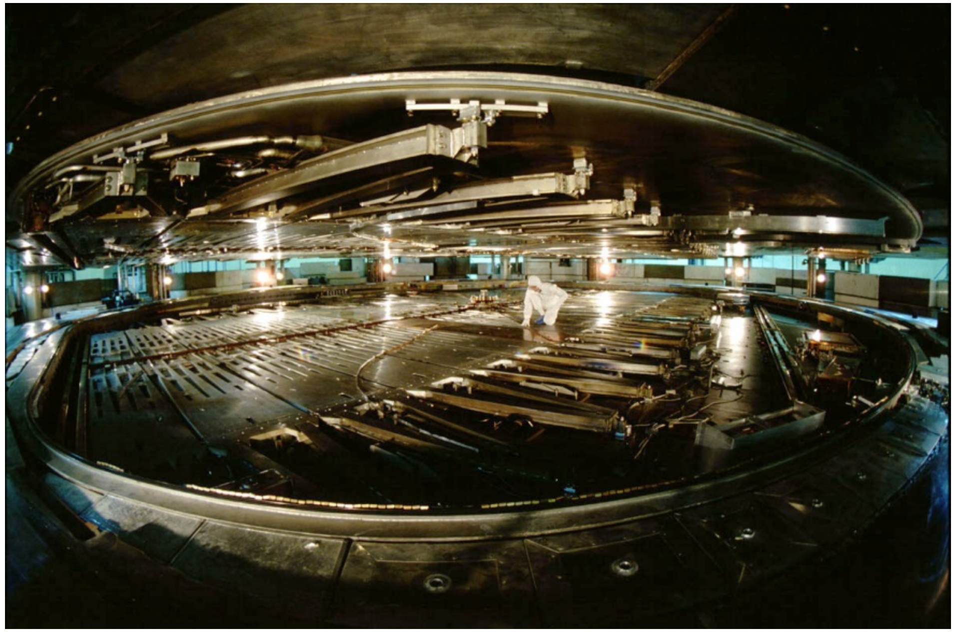
TRIUMF High Intensity Proton Beams Operating Experience with Radiation Effects

Ewart Blackmore TRIUMF

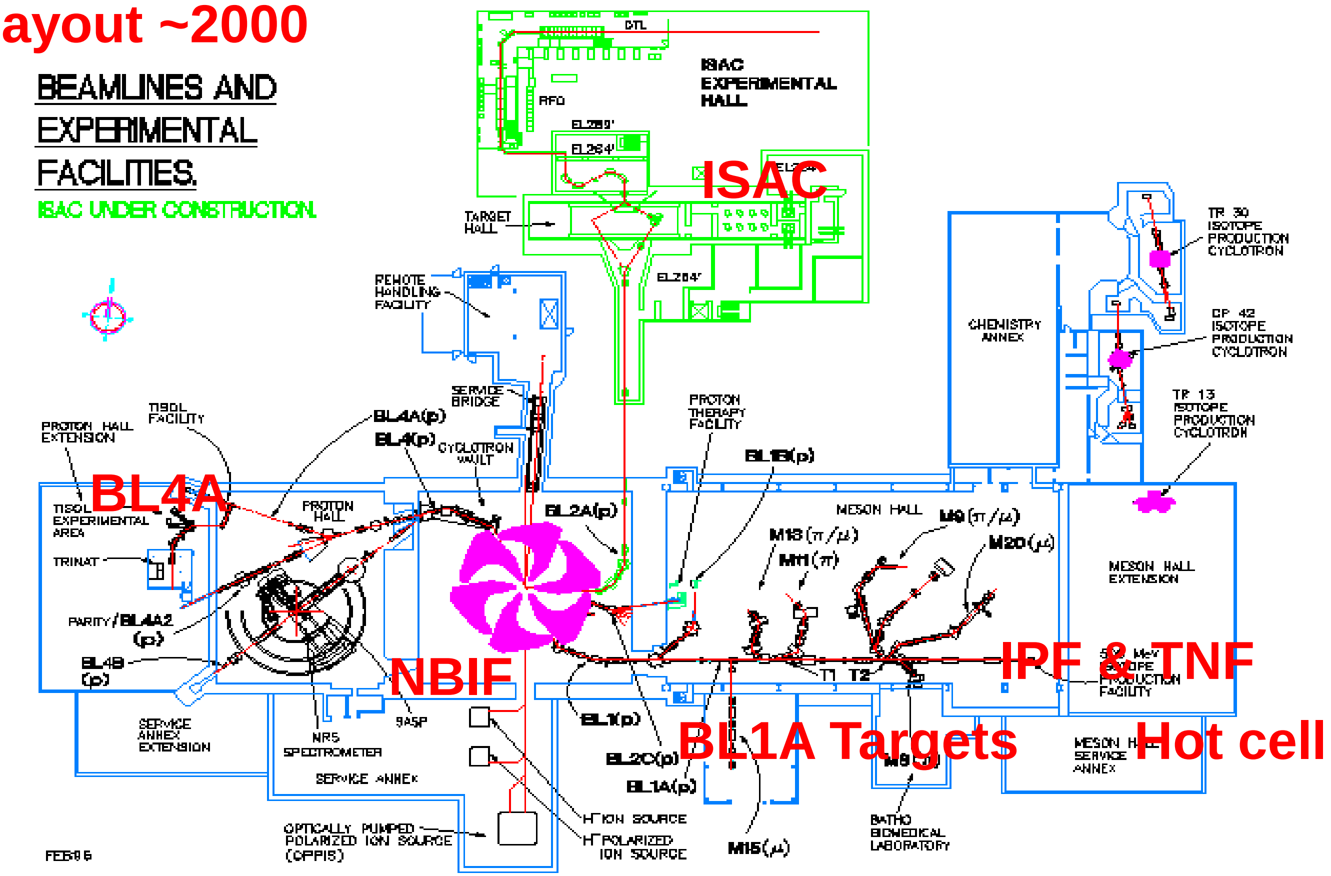


500 MeV H^- Cyclotron
Extraction by Stripping
3-4 Proton Beam Lines
Different Energy & Intensity
DC beam with microstructure
Operating since 1974
ISAC RIB Facility since 1998
Muon Physics CMMS
Isotope Production
PIF&NIF Facilities

Outline of Talk

- ☐ High Intensity Proton Beams ~ 100 µA
  - BL1A for meson production & IPF for isotopes
  - BL2A for ISAC radioactive ion beams
  - BL2C for medical isotopes at ~ 100 MeV
- ☐ Experience with meson targets to 10^{23} p/cm^2/yr
- ☐ Radiation damage samarium-cobalt magnets -1985
- ☐ PIF&NIF beams for electronics TID, DD and SEE
  - BL2C, BL1B 480 MeV to 5 MeV at < 10^{13} p/cm^2
  - NBIF facility 450-480 MeV protons parasitic beam

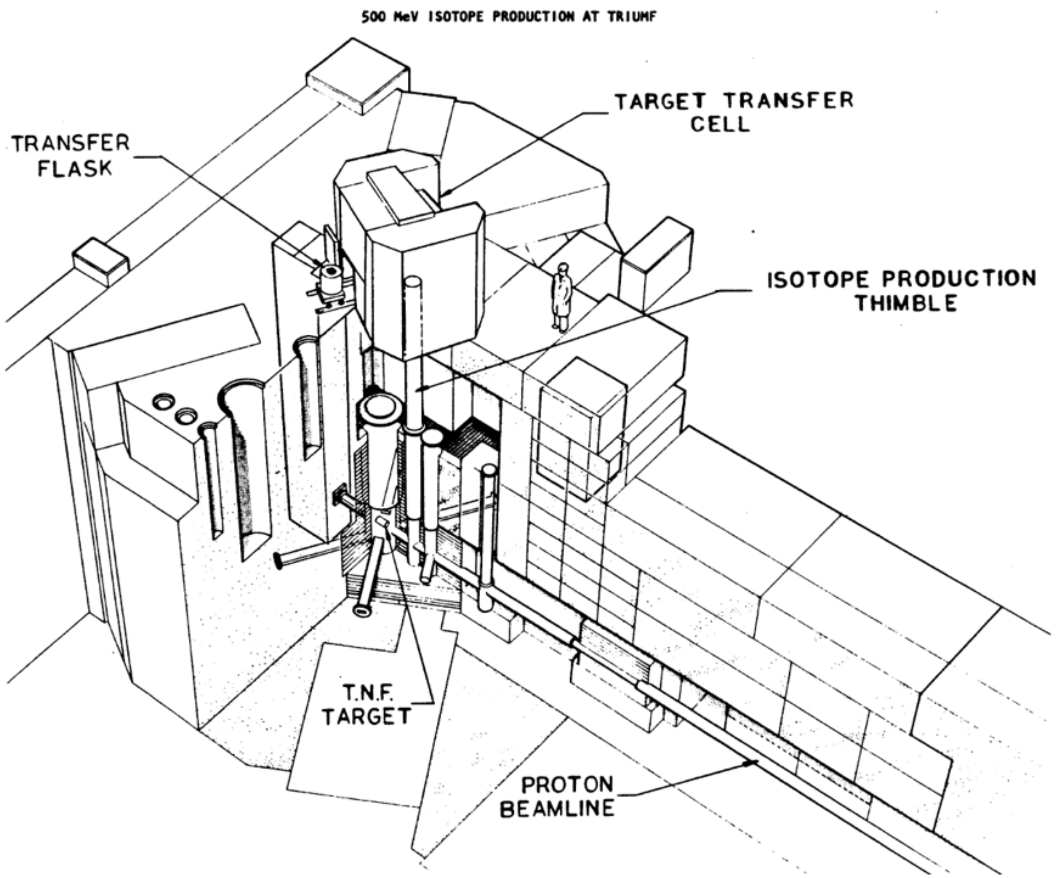
Layout of Beams

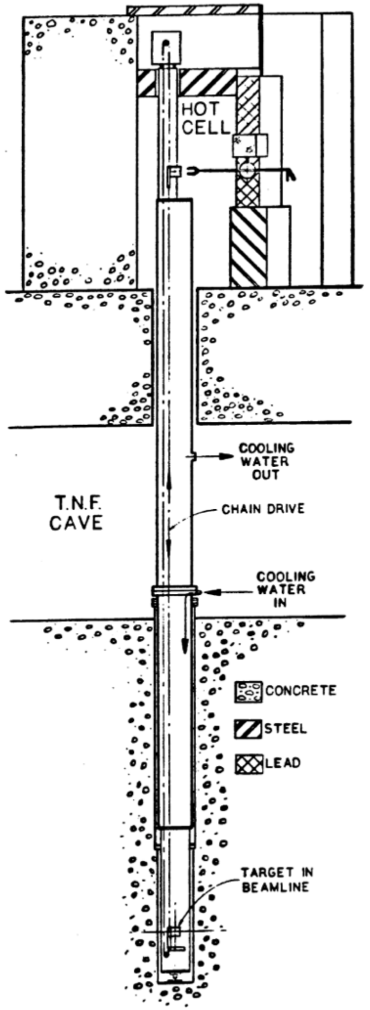


High Radiation Area Expertise

- shielding and activation of components and air
- remote handling & thermal design of targets, beam dumps and collimators
- beam diagnostic and spill monitors for target/dump, magnet, vacuum protection
- rad-hard/remote handleable vacuum connections (all metal) eg. indium seals
- rad-hard magnets (ceramic insulation eg Pyrotenax).
- water cooling systems – closed loop, resin exchange, high resistivity, tritium and Be^7 if near proton beam.
- cabling, flow, temperature transducers etc radiation hard or well-shielded.
- remote handling/maintenance strategy – vertical access, transfer to hot cells

Isotope Production Facility



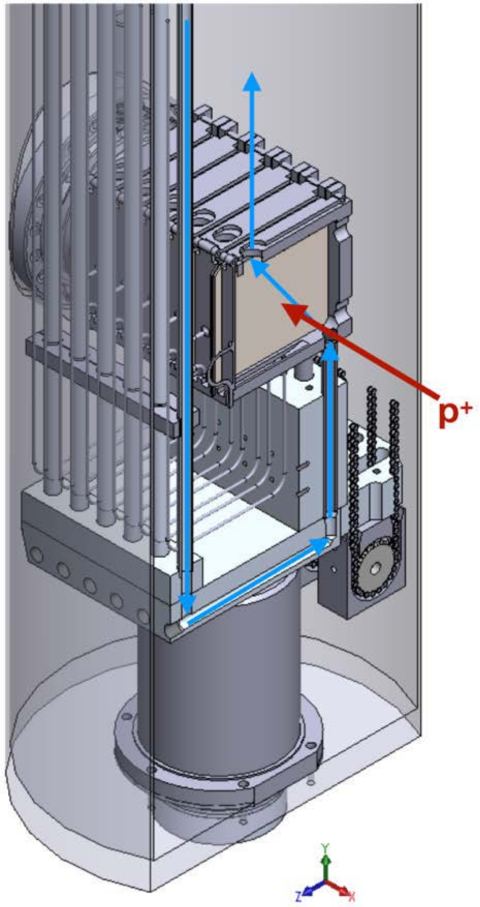


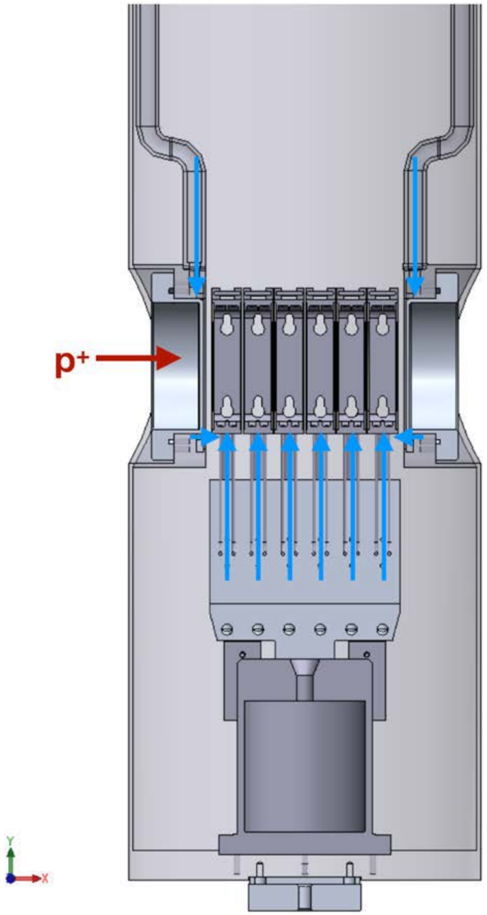
Beams and targets in shielded canyon of steel, concrete or water ~ 2m of steel and 6-8 m of concrete.

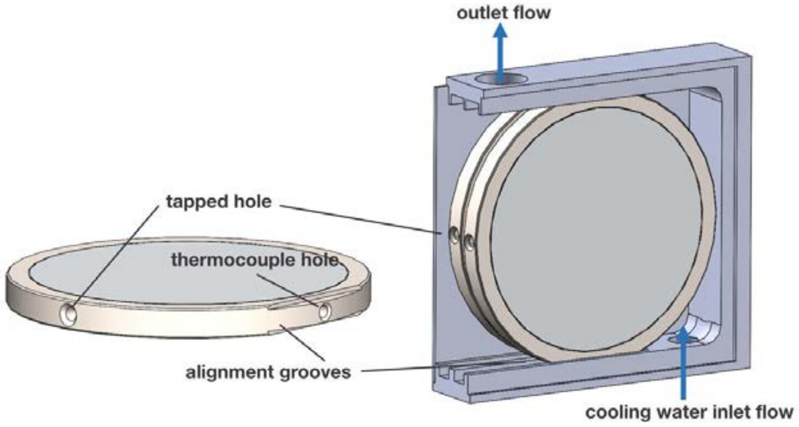
Access for personnel for services (beam off) at midpoint pos’n - internal shielding.

Removal for servicing using shielded flask or intermediate hot cell

IPF Target Cassettes





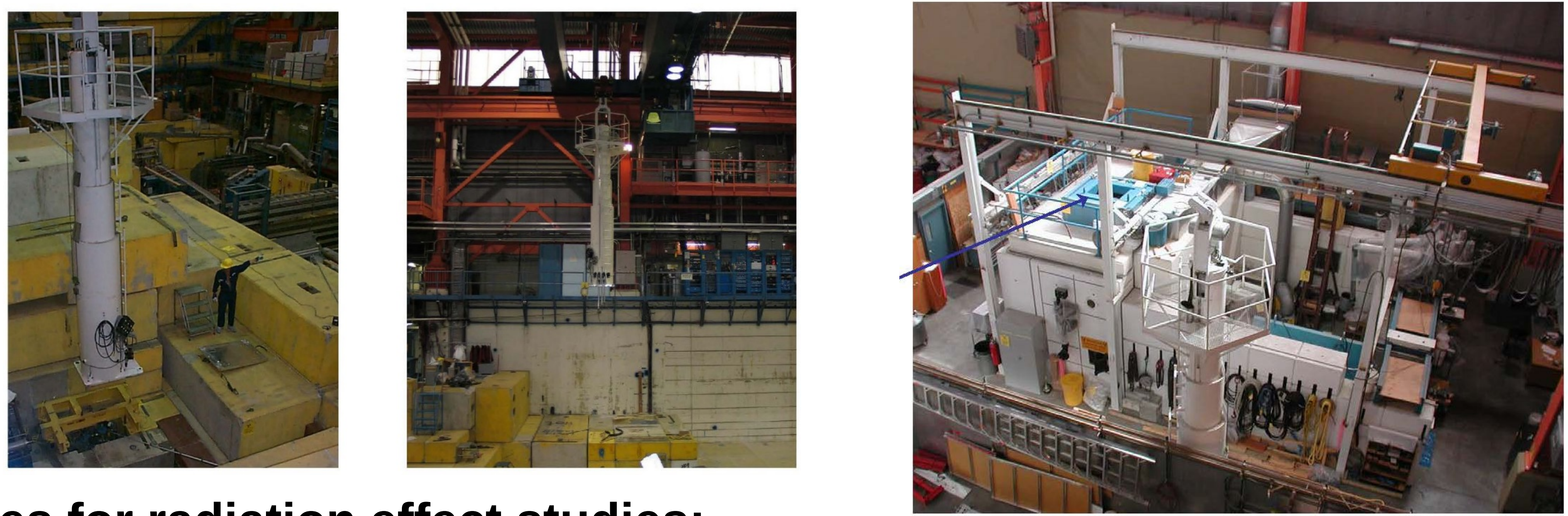


Operates 4000 hrs per year with 430-450 MeV protons at 70 µA and 3 cm diam. spot.

Cassettes filled with powder eg Mo for ^{82}Sr^{82}Rb prod’n or KCl for ^{32}Si prod’n.

Now used for actinides on thorium foil target.

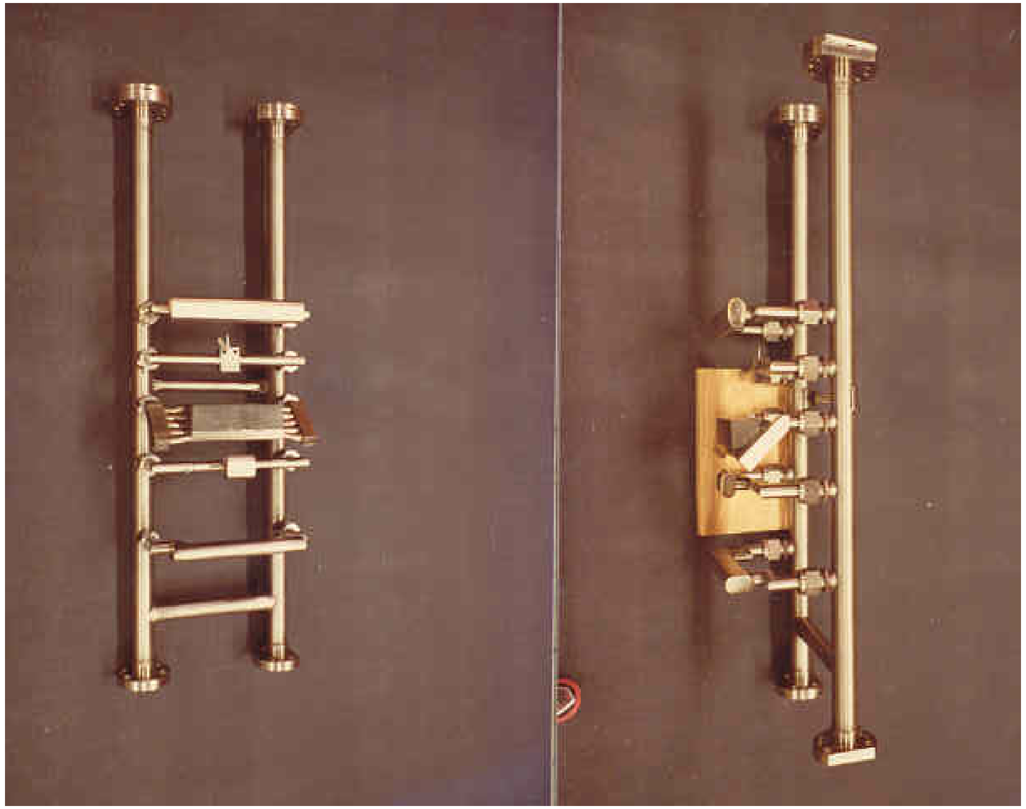
Target transport to hot cell



Strategies for radiation effect studies:

- Move irradiated components to diagnostic hot cell using shielded flasks (eg targets) for studies. (> 10^{20} p/cm^2)
- Devise method for testing in-situ - $SmCo_5$ magnets (10^{17-} 10^{19} p/cm^2)
- Keep radiation levels low enough that local handling is possible, after short decay and using long tools (10^{13} -10^{16} p/cm^2) PIF-NIF & NBIF facility)

Meson Production Targets



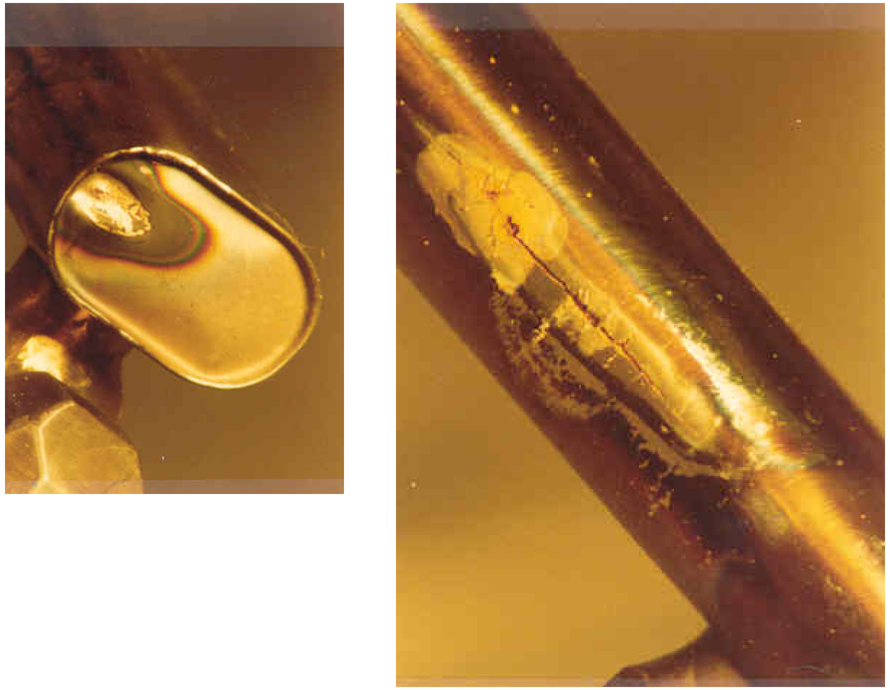
6 positions for targets Be, C, Cu, V on ladder with vertical drive. Now mostly Be used.

Photo of beam on entrance window of Be tgt

Figure 1: Target designs used at TRIUMF.

Target protection by 4 segment halo monitor.
Beam size 2 mm x 5 mm for Be

Target Damage Learning Experience



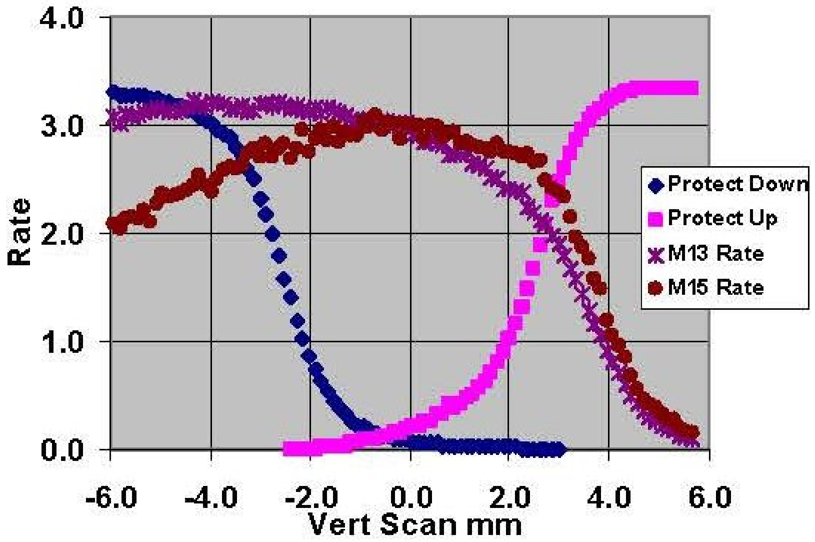


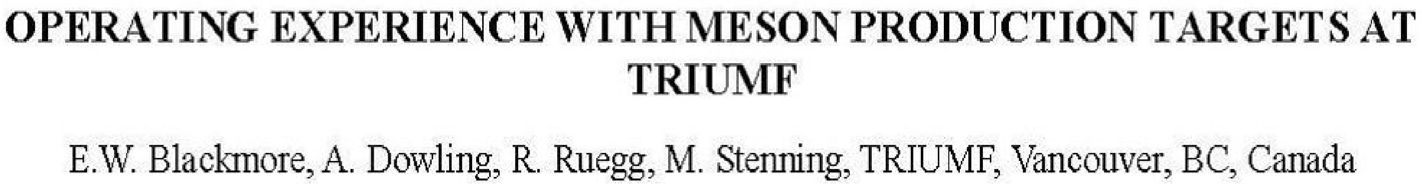
Figure 2: Target scan to check alignment of protect monitor to target.

Thermal damage - misaligned target and protect monitor

After any target changes a target scan is taken at low current to centre beam

Radiation Damage Issues

Proc. 2005 PAC



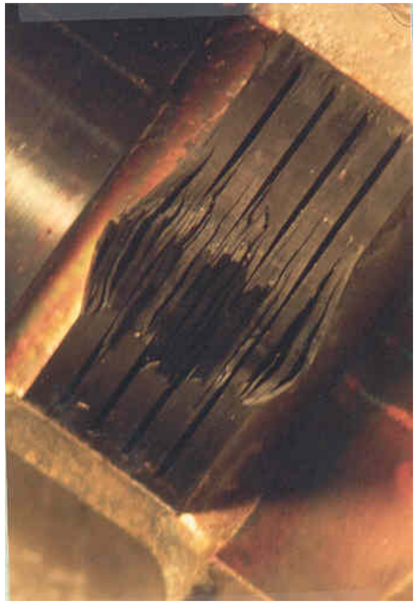
OPERATING EXPERIENCE WITH MESON PRODUCTION TARGETS AT TRIUMF

E.W. Blackmore, A. Dowling, R. Ruegg, M. Stenning, TRIUMF, Vancouver, BC, Canada

Radiation-cooled thin graphite targets 2 mm at 100 µA lasted for many weeks but eroded at 120 µA and small beam size – thermal effect.

Failure of 1 cm water-cooled graphite target after 1-2 weeks at 120 µA – thermal + radiation damage?.

Beryllium targets lasted for > 10^{23} p/cm^2 600 mA-hrs with possibly 1-2 failures of Be metal itself over 40 years. Now use mainly Be tgts.



Calculated peak temp ~ 300-350 °C for 1 mm diam beam

Advantages for surface muon prod’n

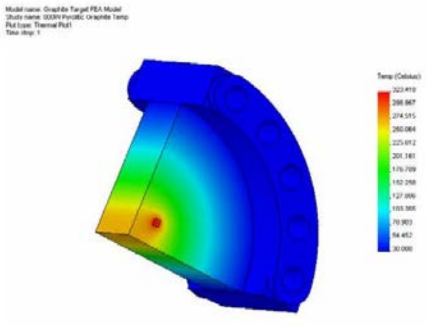


Figure 4: Temperature profile in the edge-cooled pyrolytic graphite target.

Pyrolytic graphite vacuum brazed to TiCuSil foil and soldered to copper saddle

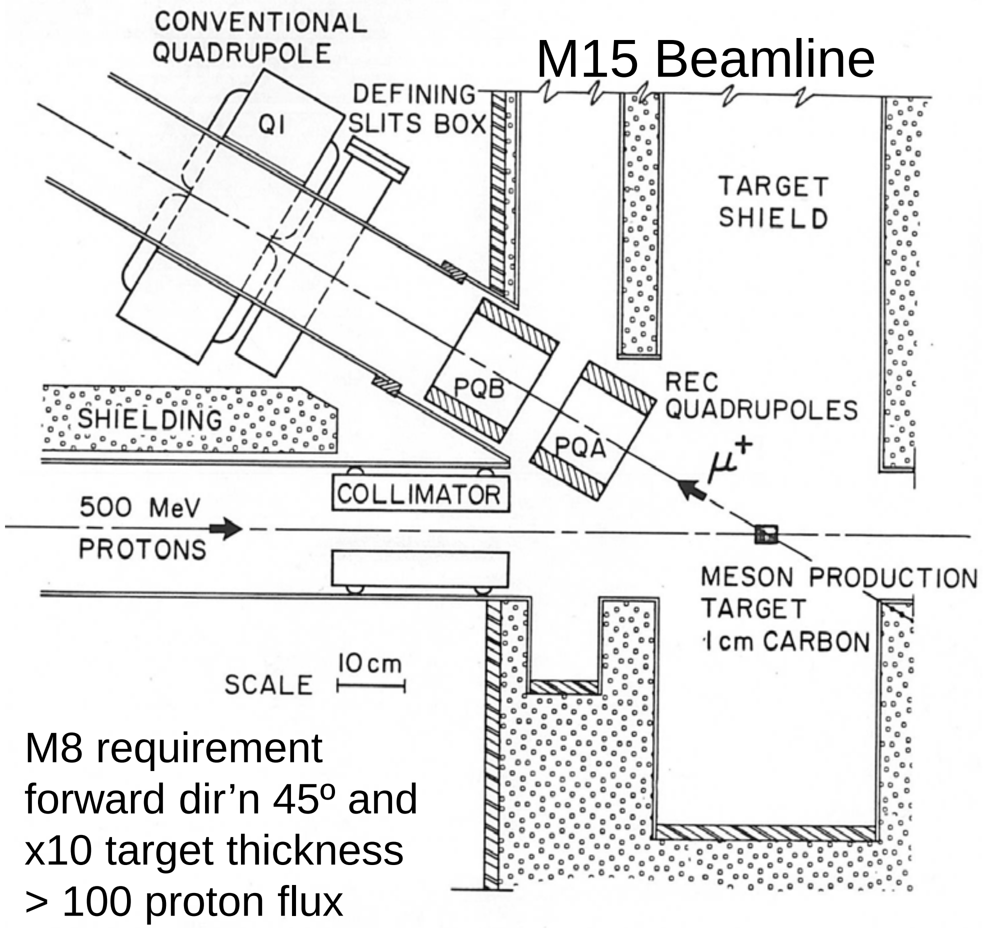
Radiation Damage Studies

- Move irradiated components to diagnostic hot cell using shielded flasks (eg targets, beam dumps, monitors) for studies or repairs (> 10^{20} p/cm^2)

- Devise method for testing in-situ - $SmCo_5$ magnet tests (10^{16} -10^{19}) p/cm2 for M8 pion therapy or M15 surface muon line 1980’s.

- Keep radiation levels low enough that local long tool handling is possible, after sufficient decay (10^{13} -10^{16} p/cm^2). PIF-NIF and NBIF.

M15 Beamline



M8 requirement forward dir’n 45º and x10 target thickness > 100 proton flux

FIG. 3 THE FRONT END OF THE M15 CHANNEL SHOWING LOCATION OF REC QUADRUPOLES.

Rare Earth Magnet Studies

Proc. 1985 PAC

RADIATION EFFECTS OF PROTONS ON SAMARIUM-COBALT PERMANENT MAGNETS

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Irradiation at 0.25 µa at 500 MeV, limited by REC sample temperature with magnetic field measured by integrating current in rotating coil over magnet sample.
Result showed advantage of 2:17 samarium-cobalt.
Degradation OK for M15 application but not M8.
M15 has operated for 30 years with ~10% reduction in magnetic field.

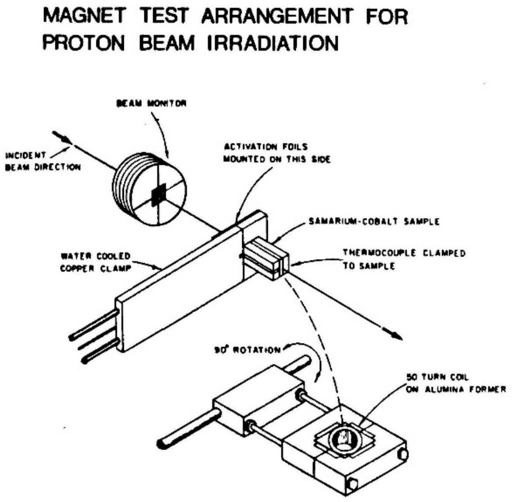


Fig. 2. Experimental arrangement.

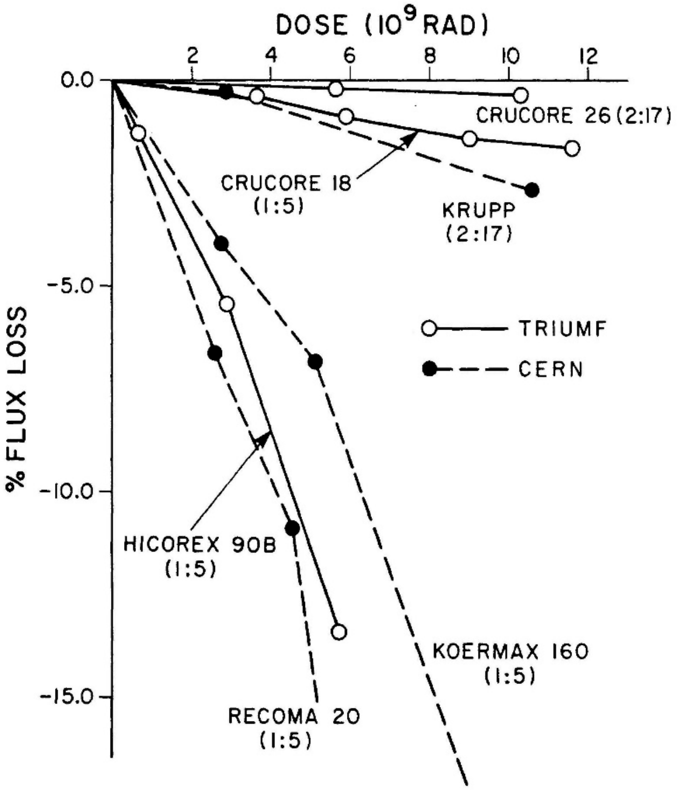
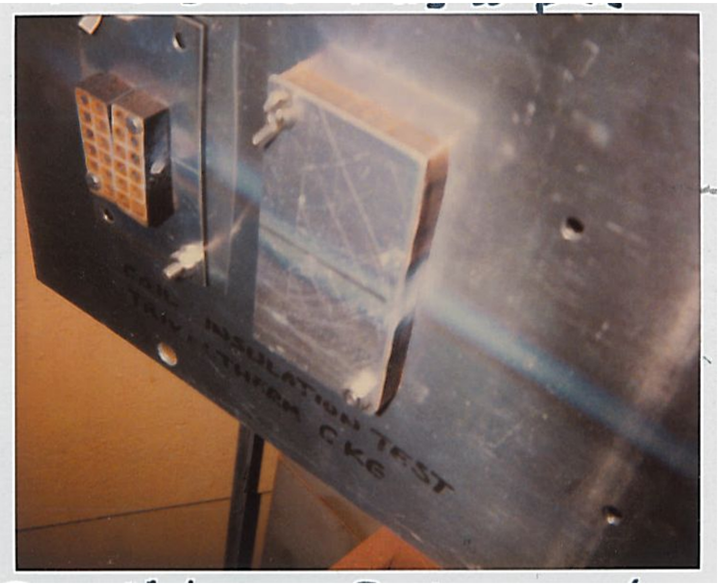


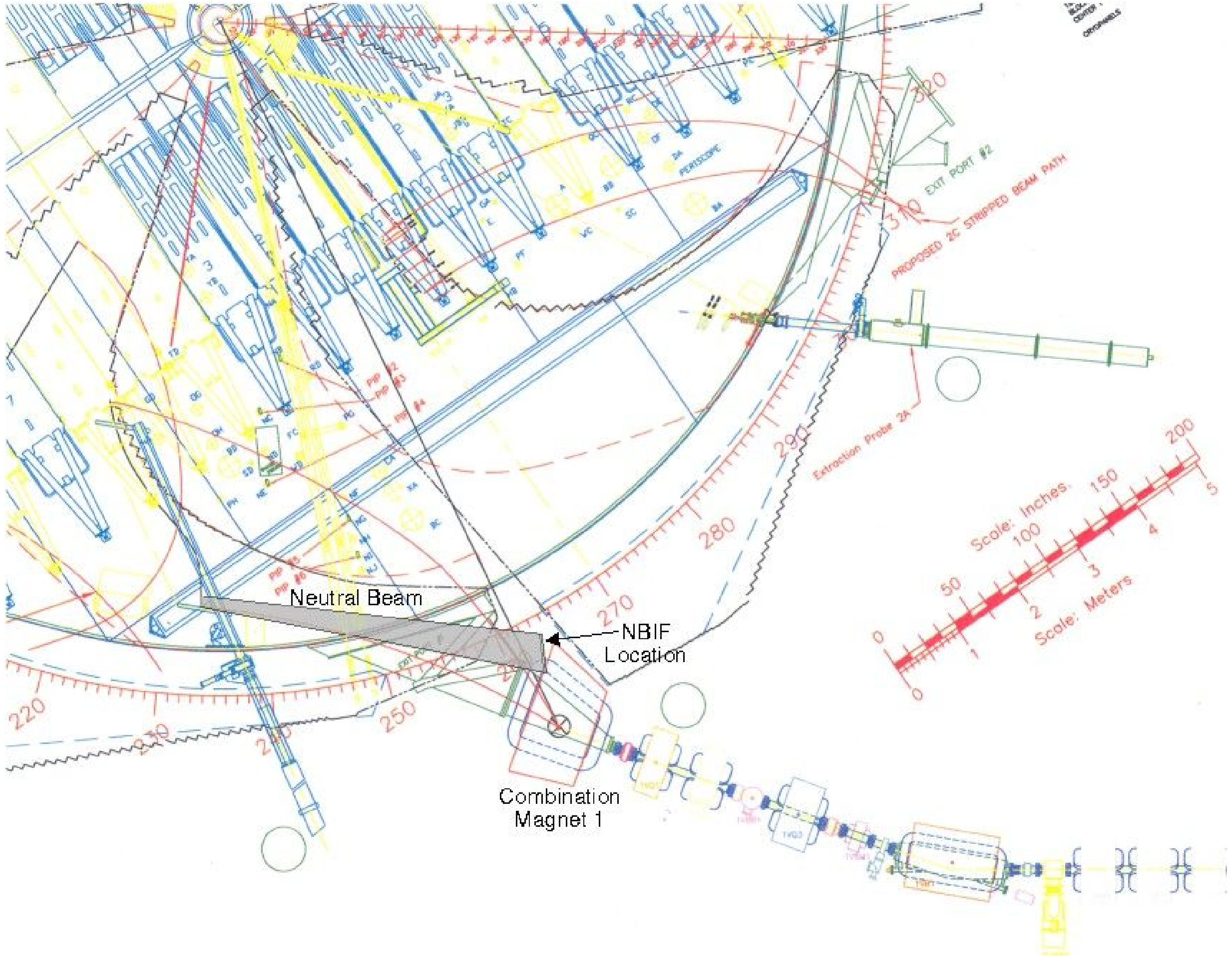
Fig. 5. Comparison of TRIUMF and CERN data.

Neutral Beam Irradiation Facility NBIF

H^- beam at 450-500 MeV EM (vxB) stripped in highest magnetic field and emerges as a fan of H^o beam ~ 2 cm high by 100 cm wide and ~ 1 nA/cm^2



Coil samples to 500 MGy

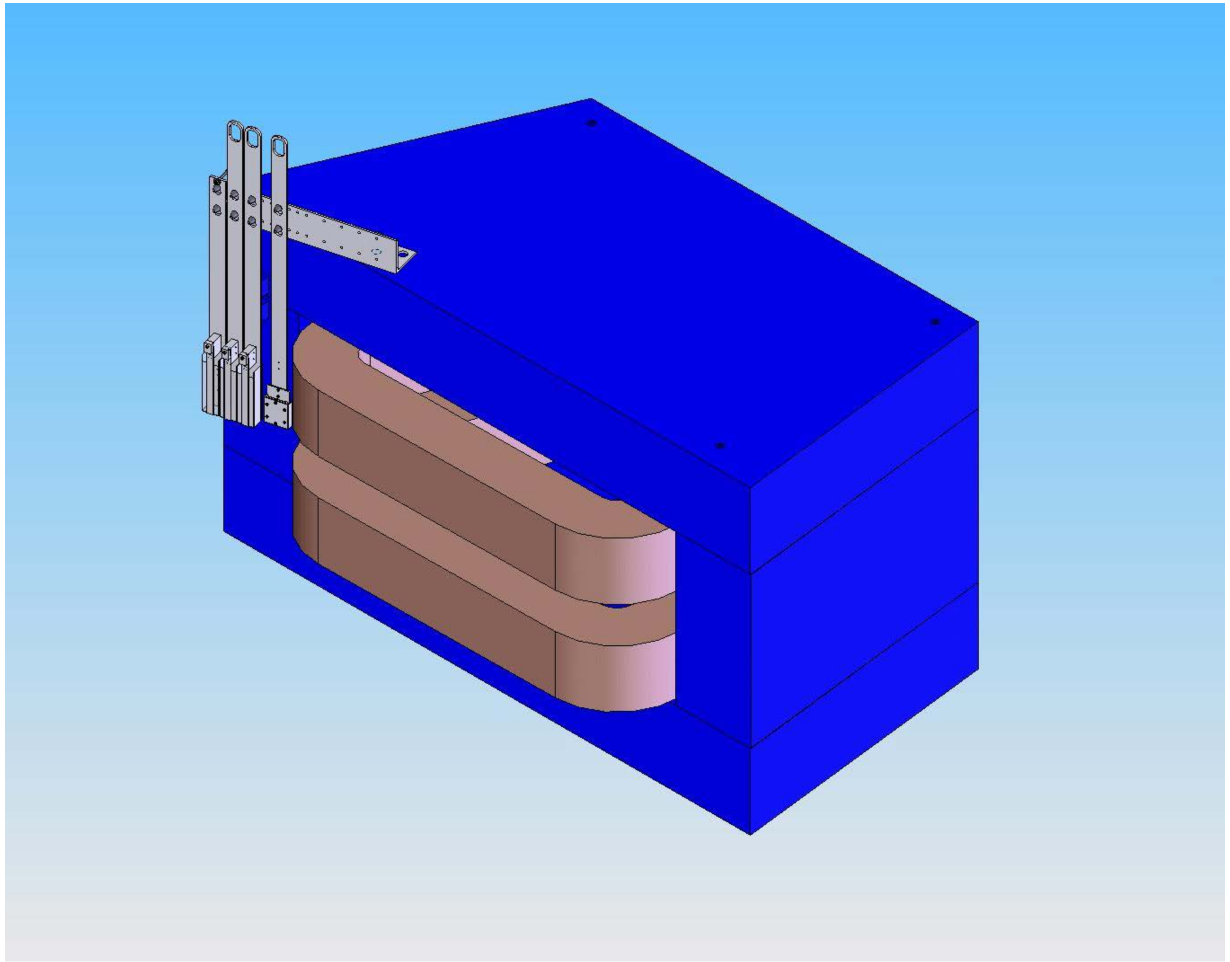


NBIF arrangement for radiation damage studies

Fluence to 10^{17} p/cm^2 per year ~ 4 x10^9 Gy
Access for installation/removal of test parts limited to shutdowns – no cooling required as rate ~ 1 nA/cm^2

Beam fluence using Al foil activation

Used for coil samples, cable insulation studies, carbon composites, diamond detectors for LHC etc.
Long activation cooldown required before testing, especially off-site.



PIF-NIF Radiation Effects to Electronics

Single Event Effects (SEU, SEL, SET, SEB, SEGR)

- protons (trapped or solar events)
- heavy ions (GCR or solar events)
- neutrons (aircraft or ground)

Important for SRAM, DRAM, FPGA, MOSFET

Soft or Permanent Errors

Bit flip, latchup, burnout, gate rupture

Total Ionizing Dose (TID)

- trapped protons & electrons
- solar proton events

Important for bipolar transistors, CMOS etc.

Threshold voltage shifts

Increased switching times

Logic state failure

Displacement Damage (NIEL)

- low energy protons, neutrons (1/E effect)

Important for LEDs, CCDs, solar cells etc.

Gain degradation

LED reduced output

Dark current

Transient Effects

- high dose/fluence rate effect

Important for diodes, imagers, CCDs etc

Star tracker error

Sensor error

Proton/Neutron Beam Test Area

Energies 500 MeV – 5 MeV

Cable lengths – 65 ft, 20 m

Fairly low radiation levels in area so PCs, testing units etc can stay in area.

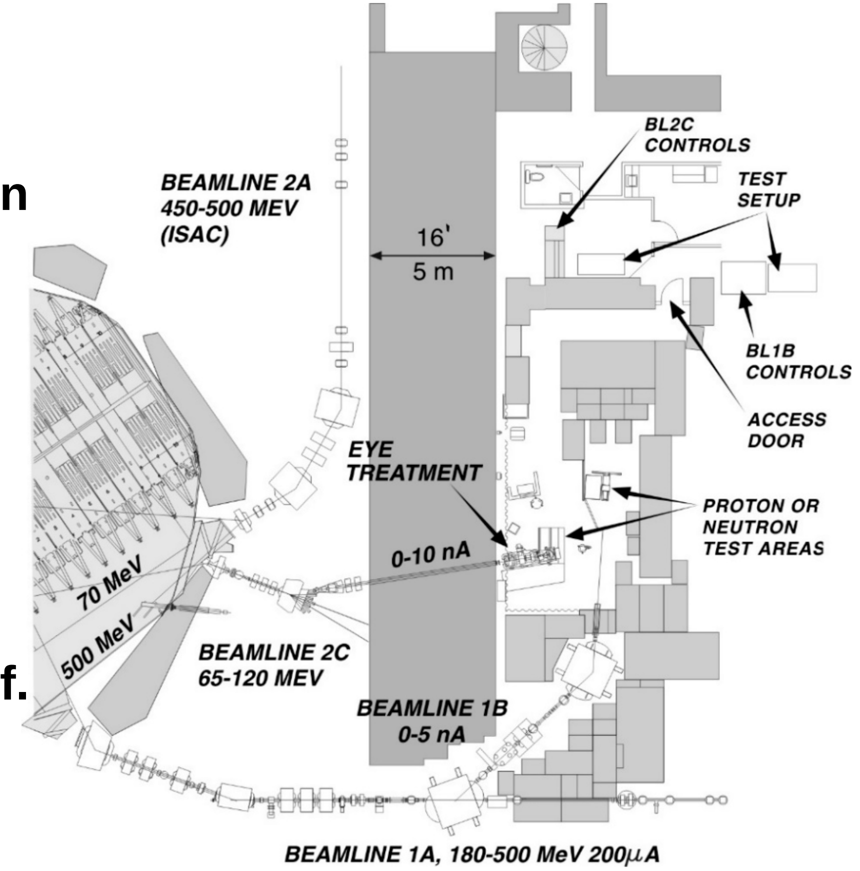
Access to area in < 1 min.

TV monitoring and remote X-Y table for device positioning.

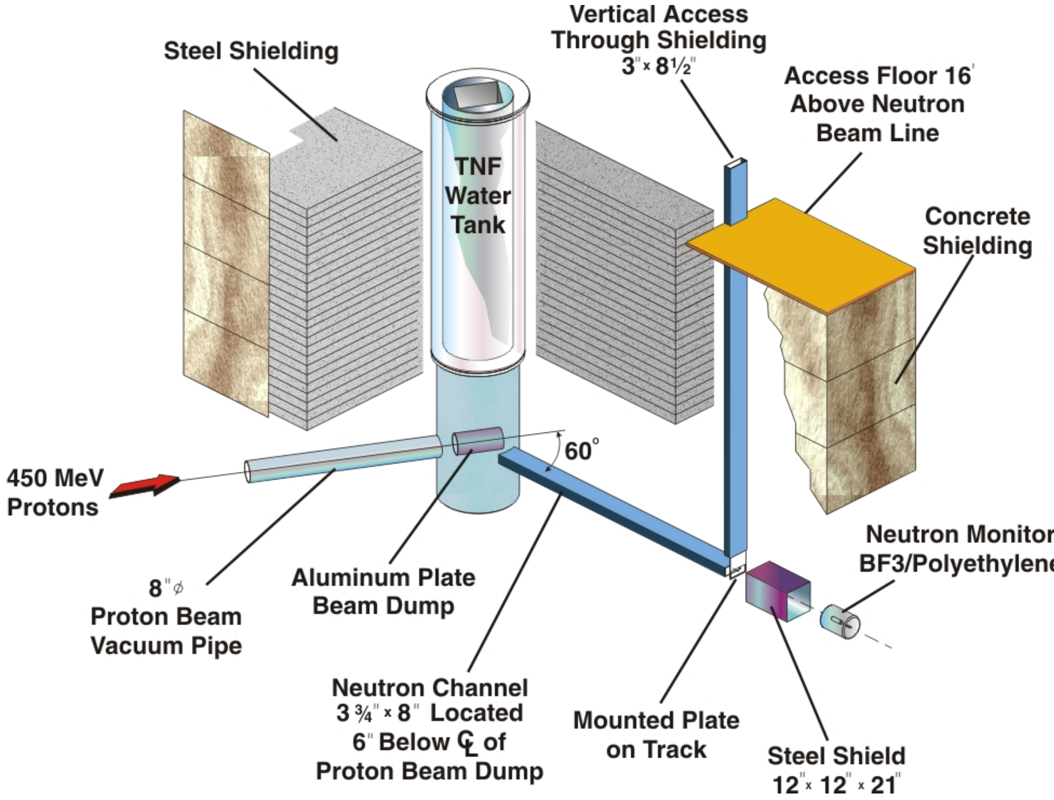
User control of beam on/off.

Intensity changes in seconds.

Energy changes by degrader in seconds, by extraction 15-30 minutes.



BL2C/1B Proton Beams



TNF Neutron Beam

Proton Beam Specifications

Item	BL1B	BL2C
Energy – MeV	**180-500**	65-120
	Typically 350, 480 MeV	5-65 by degrader
Initial beam intensity	0.1-5 nA	0.1-10 nA
Back Test Location		
Intensity – protons/cm²/s	max 4x10^7	max 1x10^8
	min 10^4	min 10^4
Dose rate – Rad/sec	1.0-2.0	5-10
Field size cmxcm (larger beams possible with special setup)	max 7.5x7.5 min 2x2	max 5x5 min 5 mm dia
Dose uniformity	~10%	~5%
Front Test Location		
Intensity – protons/cm²/s	max 1x10^9	max 2x10^9
Dose rate – Rad/sec	25-50	50-100
Field size cm dia.	1.0-2.0	1.0-2.0

Takeaway

Deliver 10 year mission dose for ISS in 10 minutes

Beam sizes from 5 mm to 75 mm

Energies
5-500 MeV

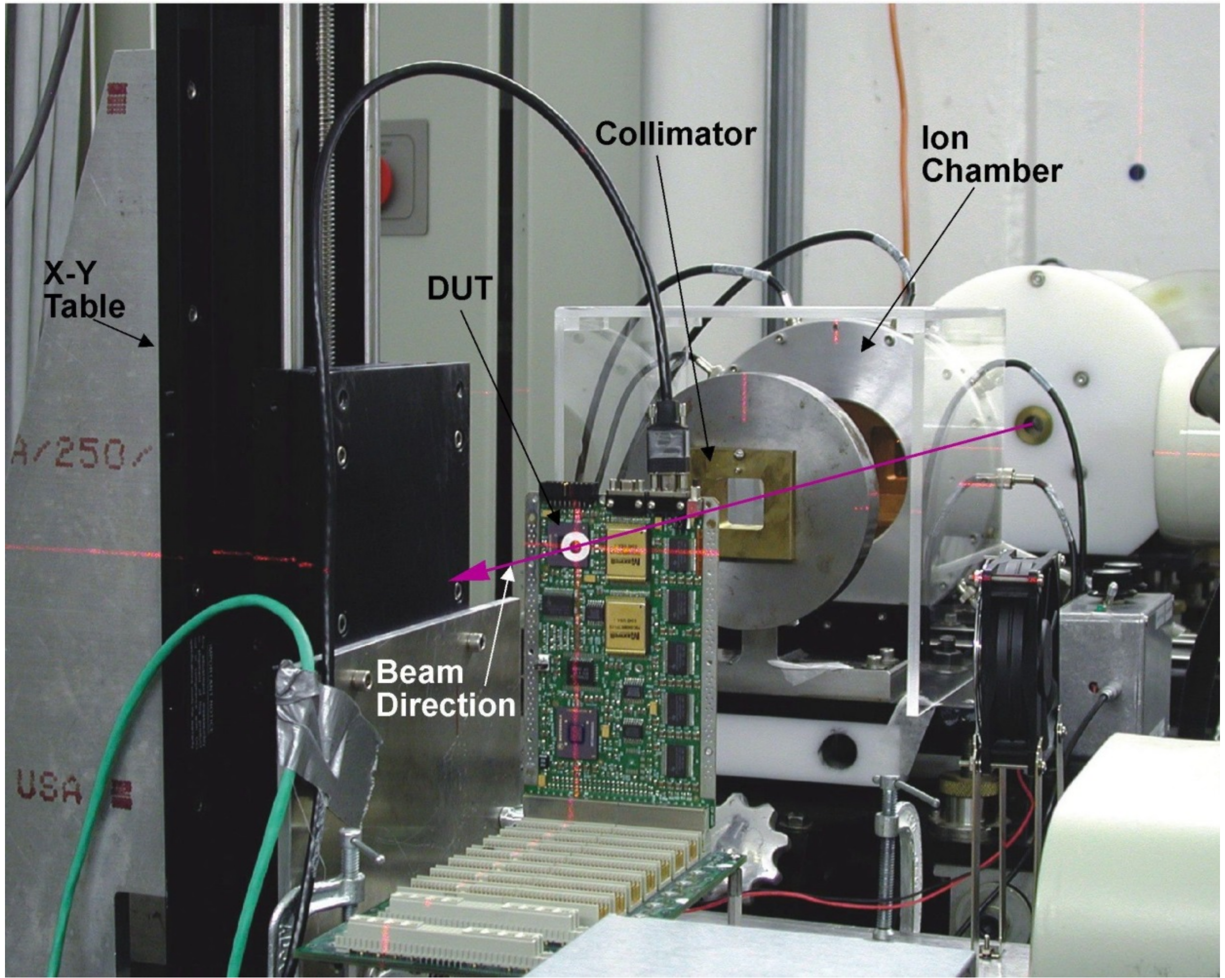
Commercial use by hour

Proton Testing at TRIUMF

Proton Test Setup – BL2C **Test energy: 5-105 MeV**

Features

- Collimator for beam size
- X-Y table for moving DUT
- Laser alignment
- Range shifter for energy changes
- Ion chamber for dosimetry
- Similar setup on BL1B but higher energy

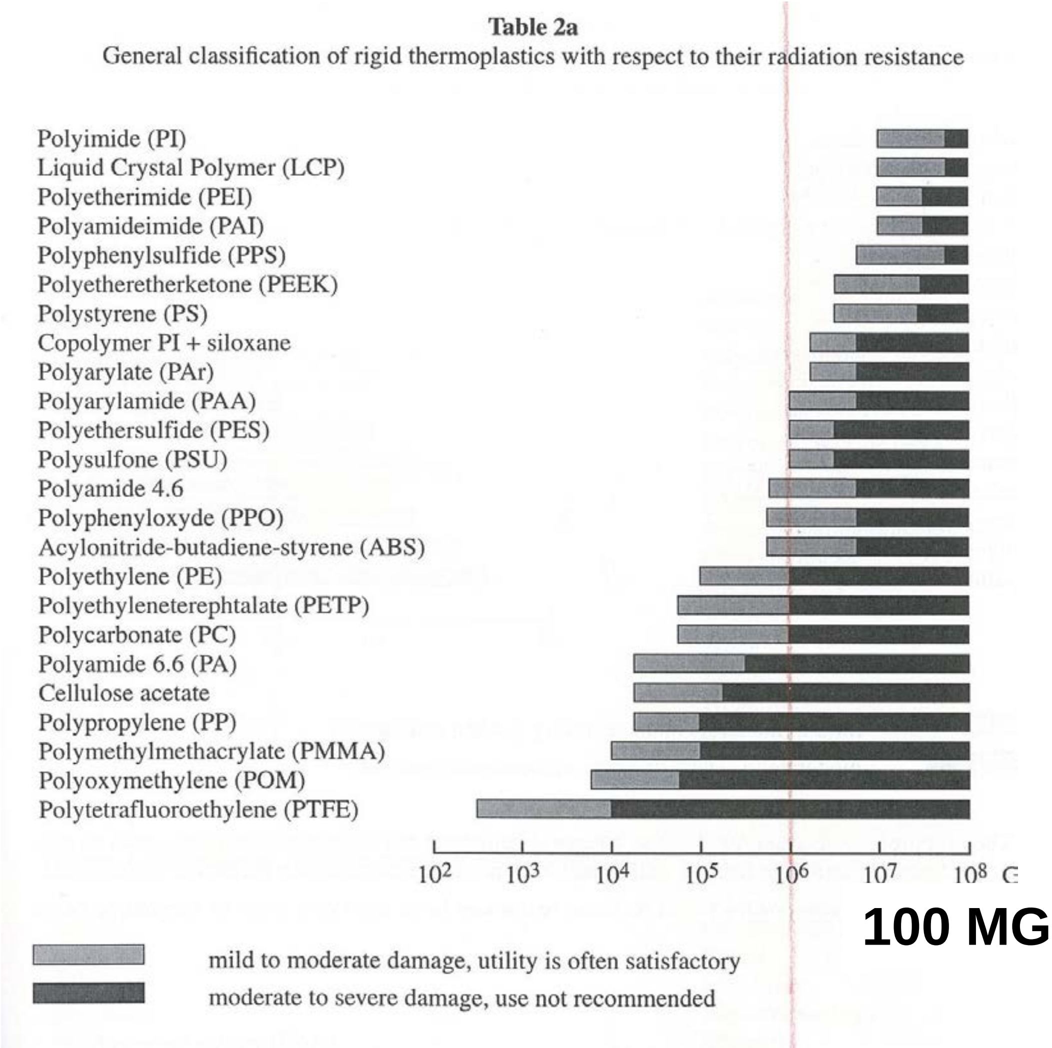


Acknowledgement

Many groups at TRIUMF have contributed to these developments over the 40 years of high intensity operations.

- Target/beam dump engineering and manufacture
- Remote handling, shielding & hot cell design
- Beam diagnostics and controls
- Beam physics and operations
- Safety and radiation monitoring
- Original beam line design concepts

CERN Radiation Damage to Plastics



100 MGy