Targetry Challenges At Megawatt Proton Accelerator Facilities

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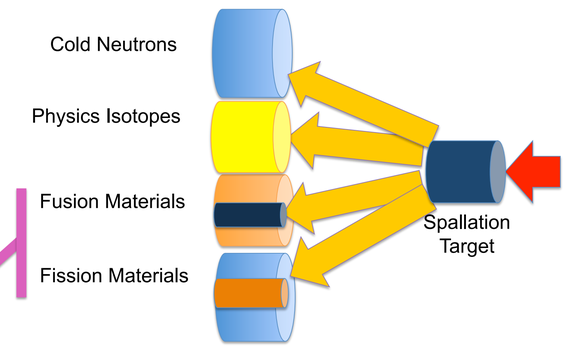
Abstract

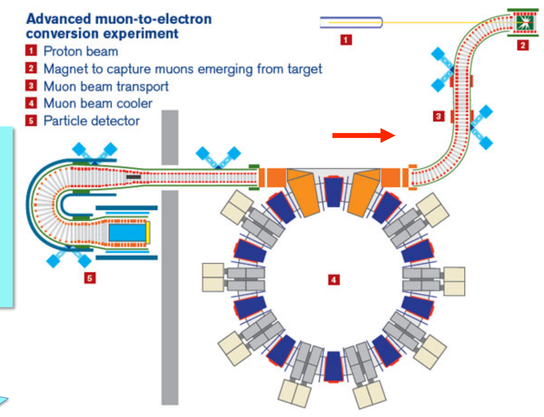
High intensity, multi-megawatt proton accelerator facilities, such as the proposed Project X at Fermilab, offer the opportunity to explore science in multiple experiments and programs simultaneously. The reliable operation of the associated target facilities is as critical to the success of the experimental program as the high intensity proton accelerator itself. The targetry requirements for the Project X experimental program range from 1 GeV, 1 MW, CW proton beam on a high-Z target (possibly liquid metal) to 120 GeV, 2.3 MW, pulsed proton beam on a low-Z target and include stringent, experiment-specific operating environments such as high magnetic fields from super-conducting magnets and/or moderator arrays for optimal neutronic production. Meeting the challenges presented by such wide-ranging and intertwined requirements calls for coordinated and cross-cutting R&D activities. Areas of interest applicable to many of the experimental facilities includes radiation damage, thermal shock, radiological protection, and target instrumentation. Descriptions of these challenges and Fermilab R&D activities to overcome these difficult challenges are presented.



- 1 MW
- 1 GeV
- CW
- 1-2 cm sigma
- Pb-Bi liquid target
- Or rotating tungsten target

Spallation Source For Nuclear Materials Irradiation And Particle Physics

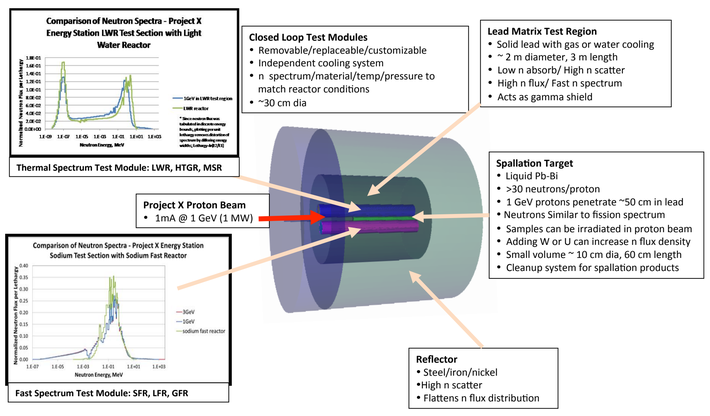
1 MW

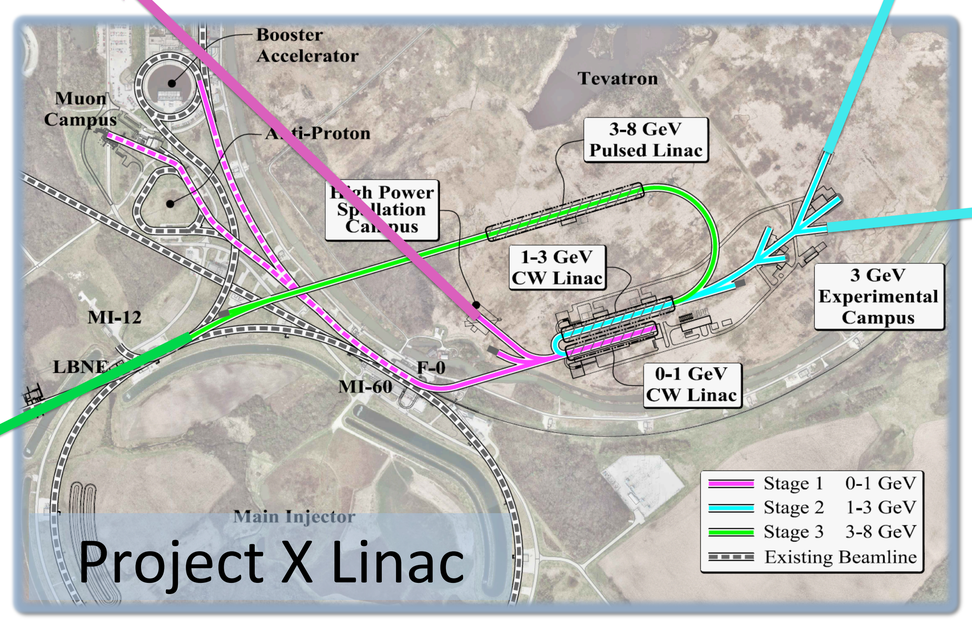


- 1 MW
- 1 GeV
- CW
- <1 cm sigma
- Rotating graphite target

1 MW

High Intensity Muon Facility

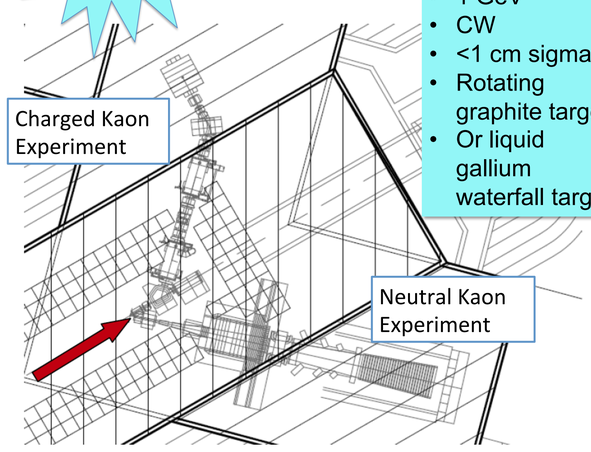




Project X Linac

High Intensity Kaon Facility

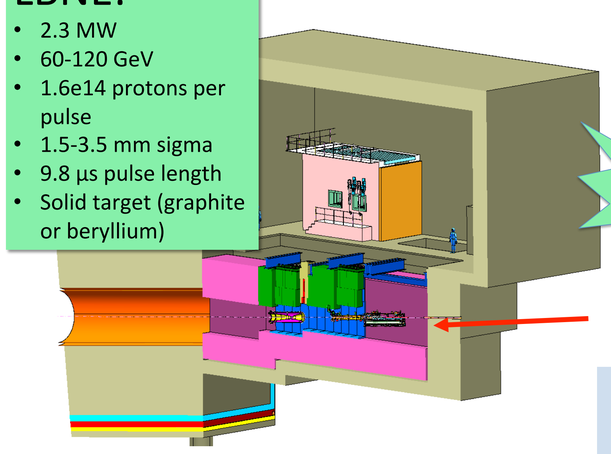
1 MW



- 1 MW
- 1 GeV
- CW
- <1 cm sigma
- Rotating graphite target
- Or liquid gallium waterfall target

LBNE:

- 2.3 MW
- 60-120 GeV
- 1.6e14 protons per pulse
- 1.5-3.5 mm sigma
- 9.8 μs pulse length
- Solid target (graphite or beryllium)

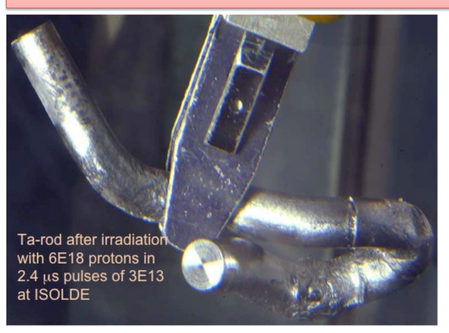


2.3 MW

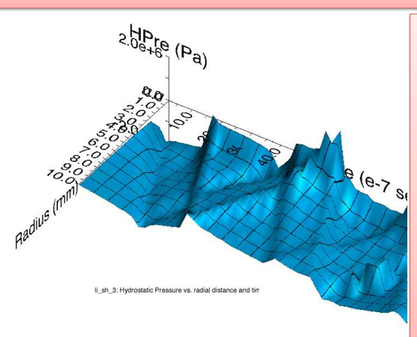
The High Intensity Frontier Presents Critical Targetry Challenges:

Thermal Shock | Remote Handling | High Heat Flux Cooling | Radiation Protection | Liquid Metal Technology | High Intensity Beam Windows | Radiation Damage

Thermal Shock

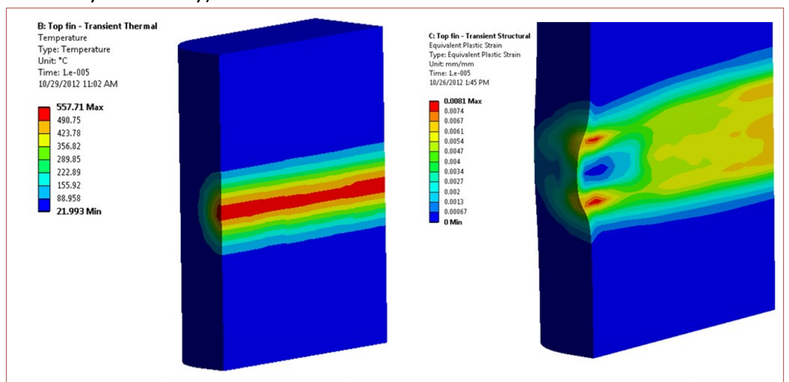


Ta-rod after irradiation with 6E18 protons in 2.4 μs pulses of 3E13 at ISOLDE (photo courtesy of J. Lettry)

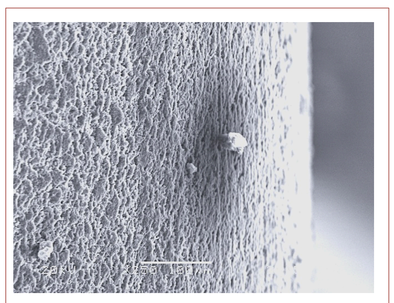


Simulation of stress wave propagation in Li lens (pbar source, Fermilab)

Fast expansion of material surrounded by cooler material creates a sudden local area of compressive stress generating stress waves (not shock waves) moving through the target



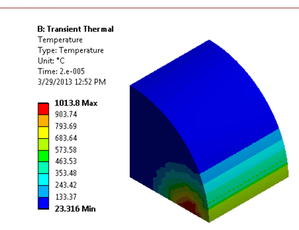
Simulation of 120 GeV protons (1.03e13 ppp, 0.16 x 0.22 mm sigma) on Be fin showing temperature and plastic strain.

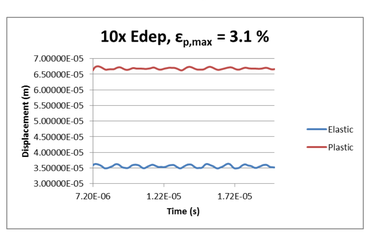


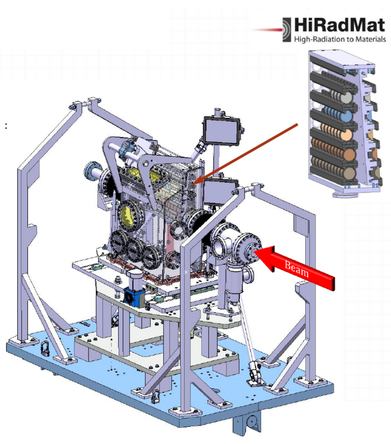
SEM image of possible beam spot after ~180 pulses (NuMI 1999 test)

Test at CERN's HiRadMat

- Intense pulses on beryllium targets and windows
- Verify simulations, material properties & failure mechanisms
- Measure onset of plastic deformation
- Detect beam window failure
- Similar to HRMT-14 test
- See THPFI055 (A. Fabich et al, CERN)





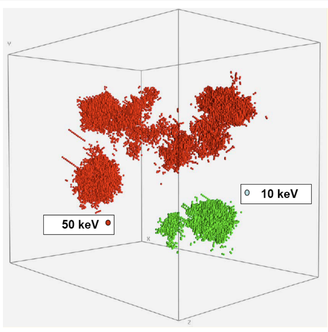


HRMT-14 Collimator materials test rig (image courtesy of A. Fabich, CERN)

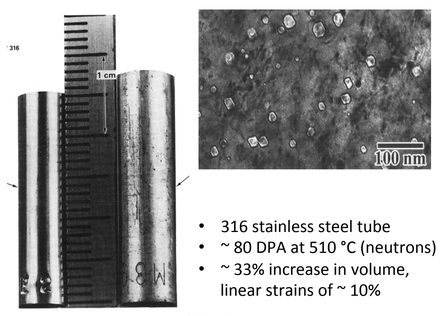
Radiation Damage

Typical Effects:

- strength
- ductility
- He embrittlement
- thermal & electrical properties
- creep
- oxidation
- dimensional changes sonic velocity
- gas production (from transmutation)

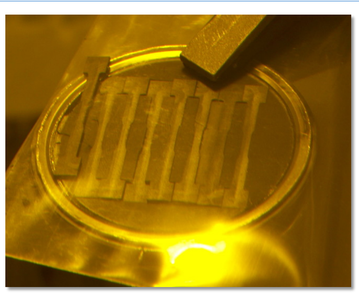


Simulations of peak damage state in iron cascades at 100K. (R. E. Stoller, ORNL)



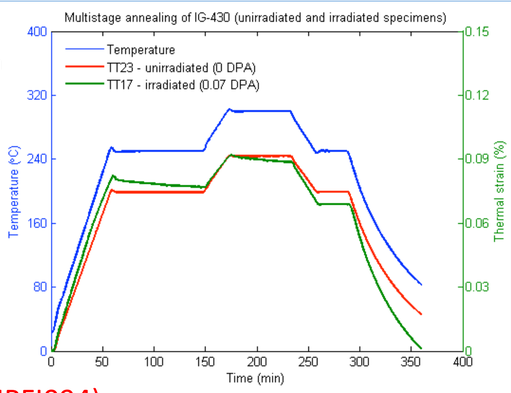
- 316 stainless steel tube
- ~ 80 DPA at 510 °C (neutrons)
- ~ 33% increase in volume, linear strains of ~ 10%

Straalsund et al., 1982



Graphite samples after 181 MeV proton irradiation at BLIP

Annealing at temperatures higher than irradiation temperature reverses many radiation damage effects. Thermal expansion annealing is shown to the right. The sample length decreases as the temperature is held constant.



(See THPFI083 & THPFI094)

$n \neq p$

1-14 MeV 100+ MeV

Effects from low energy neutron irradiations do not equal effects from high energy proton irradiations. Table compares typical irradiation parameters.

Irradiation Source	DPA rate (dpa/s)	He gas production (appm/DPA)	Irradiation Temp (°C)
Mixed spectrum fission reactor	3e-7	0.1	200-600
Fusion reactor	1e-6	10	400-1000
High energy proton beam	6e-3	100	100-800

RaDIATE Collaboration

(see side board)

- Radiation Damage In Accelerator Target Environments
- Beryllium (beam windows)
- Graphite (neutrino targets)
- Tungsten (spallation targets)
- FNAL, BNL, PNL, STFC, Oxford
- Please see side board

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