4 Accelerator R&D

Personnel: Prof. K.T. McDonald, *with H.G. Kirk and N. Simos (BNL)*

Prof. has been involved for many years in R&D on muon-based accelerators, lately in the context of the Muon Accelerator Program. Following the recent recommendations of the HEPAP P5 Committee, the Muon Accelerator Program (MAP) is being phased out over the next three years. Prof. McDonald will continue some MAP activity during this period, related to conceptual designs of a target station to produce an intense muon beams, but seeks to renew his involvement in hardware R&D on target materials, as proposed below.

4.1 Study of Limitations to Carbon-based Targets

This proposal is to characterize the physical limitations of fixed targets for intense, pulsed proton drive beams, with pulse length ≈ 10 μs as for a future LBNF,[6] or < 10 ns as for a Neutrino Factory.[7] The issues include:

- Radiation damage.
- Fatigue resulting from pulsed beams.
- Phase transformations (such as melting) due to deposited energy.
- Oxidation and/or corrosion.

The particular objectives of the proposed three-year study are:

- Characterization of damage to irradiated targets by x-ray diffraction, which technique is as yet little used in the high-power-target community.
- Characterization of enhanced survivability of targets when operated at very high temperature.
- Development of numerical model of effect of the beam-target interaction to permit extrapolation of results beyond the experiment data collected.

This effort will initially be for carbon-based targets, but could readily be extended to consider other solid target materials

To identify the limit states for carbon-based targets associated with intensity-frontier proton beams we propose a suite of studies consisting of: intense beam-target interaction experiments, microscopic characterization experiments and augmenting numerical simulations.

[6] LBNE Collaboration, *The Long-Baseline Neutrino Experiment: Exploring Fundamental Symmetries of the Universe*, (Apr. 22, 2014), `http://arxiv.org/abs/1307.7335`

[7] J.S. Berg *et al.*, *The International Design Study for the Neutrino Factory* (Aug. 2011), `http://icfa-usa.jlab.org/archive/newsletter/icfa_bd_nl_55.pdf`

4.1.1 Beam-Target Experiments

Carbon-based targets (graphite, carbon-fiber composites, *etc.*.) will be exposed to intense, short, 440-GeV proton pulses on using the CERN SPS at the HiRadMat facility.[8] This facility features up to 4.9×10^{13} protons per spill with rms beam radius as small as 0.1 mm.

Both non-irradiated and previously irradiated carbon-based target materials will be used to intercept the SPS beam as a function of pulse intensity and pulse length. The previously irradiated materials are from earlier work by the proponents using 200 MeV protons at the BNL Linac.[9]

Carbon targets in MW proton beams could be radiation cooled, operating at temperatures $\approx 1700^\circ$ C,[10] which high temperature is favorable for annealing of radiation damage, permitting much longer target lifetime. Even the moderate temperatures of the air-cooled CNGS target[11] have led to considerably longer target life than for the water-cooled NuMi target,[12] both in $\approx$ 300 kW beams. A key feature of the present proposal is to irradiate carbon samples at various temperatures.

The proponents have performed experiments of a similar nature to those proposed here, but at lower energies and intensities, using 24-GeV protons at BNL AGS (AGS E-951) incident on graphite and carbon-fiber-composite targets,[13] and on several other medium-Z target materials.[14]

In addition, studies of extreme thermal shock to target materials will be performed using the electron beam of the BNL Accelerator Test Facility (ATF), as well as with high-power lasers of the BNL Instrumentation Division.

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[8] HighRadMat home page: `https://espace.cern.ch/hiradmat-sps/Wiki%20Pages/Home.aspx`
I. Efthymiopoulos, *HighRadMat, A Facility at CERN for Material & Component Testing*,
`https://indico.cern.ch/event/259596/session/3/contribution/10/material/slides/0.pdf`

[9] N. Simos *et al.*, *Irradiation damage studies of high power accelerator materials*, J. Nucl. Mat. **377**, 41 (2008), `http://puhep1.princeton.edu/~mcdonald/papers/simos_jnm_377_41_08.pdf`

[10] K.T. McDonald *et al.*, *Target System Concept for a Muon Collider/Neutrino Factory*, Proc. IPAC 2014 (Dresden), `http://accelconf.web.cern.ch/AccelConf/IPAC2014/papers/tupri008.pdf`

[11] E. Gschwendtner *et al.*, *CNGS, CERN Neutrinos to Gran Sasso, Five Years of Running a 500 Kilowatt Neutrino Beam Facility at CERN*, Proc. IPAC 2013 (Shanghai),
`http://accelconf.web.cern.ch/AccelConf/IPAC2013/papers/mopea058.pdf`

[12] J. Hylen, *Neutrino Beam Facilites*, 5th High Power Targetry Workshop (Fermilab, 2014), slide 33,
`https://indico.fnal.gov/getFile.py/access?contribId=111&sessionId=0&resId=0&materialId=slides&confId=7870`

[13] N. Simos *et al.*, *Study of Graphite Targets Interacting with the 24 GeV Proton Beam of the BNL Muon Target Experiment*, Proc. EPAC 2002 (Paris),
`http://accelconf.web.cern.ch/AccelConf/e02/PAPERS/TUPDO024.pdf`

[14] N. Simos *et al.*, *Thermal Shock Analysis of Windows Interacting with Energetic, Focused Beam of the BNL Muon Target Experiment*, Proc. PAC 2001 (Chicago),
`http://accelconf.web.cern.ch/AccelConf/p01/PAPERS/TPAH085.PDF`
Super-Invar as a Target for Pulsed High-Intensity Proton Beams, Proc. PAC 2003 (Portland),
`http://accelconf.web.cern.ch/AccelConf/p03/PAPERS/TPPB002.PDF`
Experimental Studies of Targets and Collimators for High Intensity Beams, Proc. Hadron Beams 2006 (Tsukuba, Japan), TUBZ04, `http://accelconf.web.cern.ch/AccelConf/abdwhb06/PAPERS/TUBZ04.PDF`

4.1.2 Microscopic Characterization of Irradiated Materials

Characterization of crystalline-to-amorphous transitions in irradiated target materials will be carried out using 3D Energy Dispersive Diffraction (EDXRD) in the X17B1 beamline of the BNL Synchrotron Light Source.

Transmission and scanning electron microscopy performed at the BNL Center of Functional Nanomaterials will complement thex-ray diffraction studies.

4.1.3 Numerical Simulations

The experimental studies will be supplemented by a series of numerical simulations of particle transport and interaction with matter, extending our previous efforts of this type.[15]

4.1.4 Budget for the Proposed Work

The Princeton budget for the proposed three-year effort is, in each year, for 1/3 of Prof. McDonald's summer salary, $10k travel (for data taking in CERN test beams), and $10k for M&S to fabricate target test fixtures. *The proposed BNL effort on this study is about $140k/year.*

[15] N. Simos *et al.*, *Thermal Shock Induced by a 24 GeV Proton Beam in the Test Windows of the Muon Collider Experiment E951 – Test Results and Theoretical Predictions*, AccApp'01 (2001), `http://www.hep.princeton.edu/~mcdonald/mumu/target/simos/e951_windows_AccAPP2001.pdf`