Post-Irradiation Examination (PIE) for High Power Targetry at Fermilab

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Background

Reliable high-power target systems, optimized for maximum physics production, are critical to the future of High Energy Physics (HEP) experiments. The current target technology tolerates a beam power up to 1 Mega Watt (MW). Future neutrino facilities, like LBNF (FNAL) [1] and Hyper-K (KEK/J-PARC) [2], are planning 1-3 MW proton beams delivered to neutrino targets. This beam power range is comparable with proposed muon collider and neutrino factory facilities [3], which utilize 2-5 MW proton beams.
In the recent past, major accelerator facilities have been limited in beam power not by their accelerators, but by the beam intercepting device survivability. The targets must endure high power pulsed beam, leading to high cycle thermal stresses/ pressures and thermal shocks. Repeated pulses create a cyclic loading environment that can be damaging to the material even at stress levels well below the failure strength of the material (fatigue failure). The increase in beam power will also create significant challenges such as radiation damage and radiation accelerated corrosion which physically alter the atomic structure of target materials. The radiation-induced defects will degrade the mechanical and thermal properties of the targets during irradiation, leading to premature failure of targets and beam intercepting devices. Therefore understanding radiation damage and thermal shock effects of high energy, pulsed proton irradiation on candidate target materials is necessary to optimize physics production for both currently operating and future accelerator target facilities.
Fermilab, within the HPT R&D program group, has the expertise to perform such studies and it currently performs several studies on low-activated material on-site such as a activated Ti-alloy fatigue test. Although Fermilab operates a large hot-cell for repair and autopsy of NuMI targets, it does not have a dedicated hot cells or Post Irradiation Examination (PIE) capabilities to perform characterization and thermo-mechanical tests on activated materials.
However, Fermilab has recovered target and beam window materials (graphite and beryllium) from spent NuMI targets, which have been the subject of extensive PIE studies at hot-cell or activated instrument enabled RaDIATE [4] institutions (Pacific Northwest National Laboratory (PNNL) [5], Brookhaven National Laboratory (BNL) [6], and the Material Research Facility (MRF) at Culham-UK [7]). These under-developed capabilities, relative to those of the global HPT and nuclear materials communities, create vulnerabilities that must be addressed to ensure continued Fermilab leadership in High Power Targetry and the successful operation of multi-MW target facilities in the future. The laboratory has been the RaDIATE collaboration's program coordinator since its beginning and has successfully guided collaboration activities to gain a better understanding of radiation damage effects on selected targetry materials.
The goal of the High Power Targetry program is to develop the knowledge and the infrastructure necessary to support multi-MW target facility operations as a core competency at Fermilab.

Post Irradiation Examination at Fermilab

In order to provide adequate support for LBNF-DUNE construction (and eventual operation) while maintaining operation of Fermilab's target facilities, plans are under development for a new Target Systems Integration Building (TSIB). This building is currently envisioned to be built adjacent to the existing MI-8 facility and roughly doubles the workspace. TSIB will provide the following (in addition to what is existing at MI-8) for support of operations and LBNF construction: a 60-ton overhead bridge crane; an assembly areas for all 3 LBNF horns and large support modules; a LBNF horn pulse testing stand with power supply; AP-0 Target Facility operations support area; and several lab areas for assembly and prototyping.

TSIB will also be home to new HPT R&D laboratory spaces including areas as following:

- Hot lab area including a hot-cell suite for mechanical and physical property testing of activated materials;
- Microscopy lab (including optical, SEM/EBSD, AFM, Nano-indenter) capable of accepting activated small samples;
- Remote Handling prototyping and Robotics R&D Lab area;
- Cold specimen testing lab area where thermal and mechanical testing can be performed on numerous materials to support HPT R&D program.
- Novel material and technology development area

It is envisioned that microscopy instruments at the SRF Materials Science Lab will be used for non-activated materials, but that activated material microscopy studies will be conducted at TSIB in a lab designed for such work. Advanced microscopy and micro-mechanics work, due to the operational overhead and infrequent use of highly delicate instruments, is envisioned to continue to be outsourced to collaborating national labs and universities that have existing infrastructure and expertise. Advanced microscopy includes TEM, FIB, , XRD, and Atom Probe Tomography.

Education platform for radiation damage effects in material and High Power Targetry development

Today, Fermilab is recognized globally as a leader in reliable operation of accelerator target facilities and in High Power Targetry R&D. High Power Targetry is a small community and it covers not only HEP but also heavy ion production and neutron production (BES and NP). Today, all around the world, the expertise on Targetry development for accelerators is only maintained internally by engineers or technicians or within collaborations such RaDIATE but there is no general school to educate future generation of graduate students to support HPT R&D.

Fermilab could have the capability in the future to propose an educational platform including irradiation station and PIE facility to support High Power Targetry.

Recommendation

The addition of PIE facility at Fermilab will be beneficial for HPT R&D capabilities and it will be critical to the future of HEP. Creating an educational platform to educate future generation of students will also reinforce the leadership role of Fermilab in the global community for radiation damage effects in accelerator target materials.

References

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