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THE CONCEPTIONAL DESIGN OF THE SHIELDING LAYOUT AND BEAM ABSORBER AT THE PXIE*

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Abstract

The Project X Injector Experiment (PXIE) is a prototype of the Project X front end. A 30 MeV 50 kW beam will be used to validate the design concept of the Project X. This paper discusses a design of the accelerator enclosure radiation shielding and the beam dump.

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The Project X Injector Experiment (PXIE) is a prototype of the Project X front end. A 30 MeV 50 kW beam will be used to validate the design concept of the Project X. This paper discusses a design of the accelerator enclosure radiation shielding and the beam dump.

INTRODUCTION

Project X is a high intensity proton facility conceived to support a world-leading physics program at Fermilab [1]. Project X will provide high intensity beams for neutrino, kaon, muon, and nuclei based experiments and for studies supporting energy applications. PXIE will be a prototype of linear accelerator frontend. The construction and successful operation of PXIE will validate the concept for the Project X front end, thereby minimizing a large portion of the technical risk within Project X.

Main sections of the PXIE accelerator are shown in Figure 1. They are: Ion Source (IS), Low Energy Beam Transport (LEBT), Radio Frequency Quadrupole (RFQ) accelerator, Medium Energy Beam Transport (MEBT), Half Wave (HW) and Single Spoke Resonator 1 (SSR1) superconducting cryomodules, Diagnostic Section (DS), and Beam Dump (BD) area.

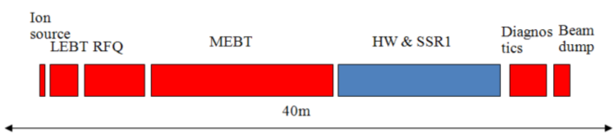

Figure 1: PXIE accelerator concept.

Each of PXIE accelerator section is characterized by different values of the beam current and energy (Table 1).

Section	Energy, MeV	Current, mA	Power, kW
IS	0.03	10	0.3
LEBT	0.03	10	0.3
RFQ	2.1	10	21
MEBT	2.1	10	21
HW	11	2	22
SSR1	30	1.7	50
DS	30	1.7	50
BD	30	1.7	50

Table 1: PXIE beam power summary.

PXIE will be installed and operated inside a new concrete enclosure at the Cryomodule Test Facility (CMTF) building located near the New Muon Lab (NML) building. Plan view of the enclosure is shown in Figure 2.

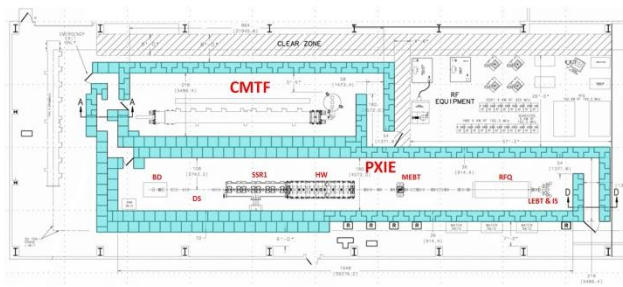

Figure 2: Plan view of PXIE accelerator in concrete enclosure within CMTF.

The PXIE enclosure includes two entrances with labyrinths located: at the high and low energy end. The low energy entrance will serve as the main entrance to the PXIE enclosure. Two cryogenic penetrations will enter the enclosure vertically through the ceiling upstream of the HW and SSR1 cavities. RF transmission lines and supporting signal and instrumentation cables will enter the PXIE enclosure through labyrinths designed for adequate radiation attenuation at both sides of the enclosure low energy end.

The concrete enclosure will be built with overlapping, prefabricated concrete shielding blocks. The low energy end walls and the entire enclosure ceiling will be a minimum of 3 feet thick. A section of the ceiling above the diagnostic section where prolonged beam loss may be feasible is 4.5 feet thick. The high energy end walls will be 6 feet thick.

PXIE SHIELDING REQUIREMENTS

The normal and accident condition design goals for the PXIE shielding assessment are variable and are defined by section assignment in the PXIE structure. Functionally, each section of PXIE differs. Some sections, having beam dumps and collimators, are designed to accept the beam loss. Other sections are expected be low loss. Significant losses in these sections cannot be tolerated due to damage to accelerator components.

Normal and accident beam loss conditions

The normal and accident beam loss conditions are defined in Table 2.

The HW and SSR1 accident condition losses are driven by the limitation of the cryogenic cooling specified to be 50 watts at 2 ^{0}K.

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The losses at the high energy part are expected to be below 0.1% at normal operations. The 100% beam loss is envisages at the accident condition in this section.

Section	Normal condition losses	Assidental condition losses
IS	-	100%
LEBT	Up to 90%	100%
RFQ	Up to 90%	100%
MEBT	Up to 90%	100%
HW	<< 0.23%	<< 0.23%
HW/SSR1 interface	0.1%	100%
SSR1	<<0.1%	<0.1%
DS	0.1%	100%
BD	100%	100%

Table 2: Normal and accident beam loss conditions.

The beam dump is to be designed for continuous operation at 50 kW so that the beam directed to the dump would not generate radiation exceeding 0.1% of radiation corresponding to 100% loss in the DS end.

Radiation Dose Rate Design Goals

The locations and intended Radiation Dose Rates Limits (RDRL) for normal and accident conditions are included below in Table 3.

Location	Condition	RDRL, mrem/hr	Permitted FRCM [2] Occupancy	Required FRCM [2] Posting
Perimeter at floor level around PXIE enclosure	Normal	<0.05	No precautions needed	No posting required
	Accident	<1		
PXIE enclosure ceiling	Normal	<0.25	No occupancy limits imposed	Controlled area
	Accident	<1	No precautions needed	None

Table 3: Normal and accident beam condition radiate dose rate design goals.

SHIELDING ASSESSMENT RESULTS

The main results of the shielding assessment of the PXIE enclosure are as follows:

- The PXIE accelerator preliminary shielding assessment is evaluated for a maximum power of 50 kW.
- The proposed shielding wall thicknesses, ceiling thicknesses, labyrinths, and various penetration designs are acceptable for the anticipated normal, 50 watt beam loss.
- Two to three interlocked radiation detectors are necessary to provide protection against any accident conditions, e.g., > 0.1% beam loss.
- The building in which the PXIE accelerator is to be contained is not large enough to add sufficient passive shielding to negate the need for interlocked radiation detectors.
- Intended occupancy on the ceiling of the PXIE enclosure is minimal occupancy with a peak dose rate of 0.25 mrem/hr. The ceiling area will require the Controlled Area posting and would have no occupancy limitations.
- Occupancy at the perimeter of the PXIE enclosure walls is unlimited since calculated normal dose rates are below 0.05 mrem/hr.
- A radiation safety system will be required to exclude personnel access to the PXIE enclosure whenever operation may produce significant ionizing radiation. This will include the operation of the RFQ, HW cryomodule, and the SSR1 cryomodule.

BEAM DUMP DESIGN

As a prototype for the body was examined High Intensity Neutrino Source (HINS) beam absorber [3] shown in Figure 3. Also shown are the parameters of beams for both devices.

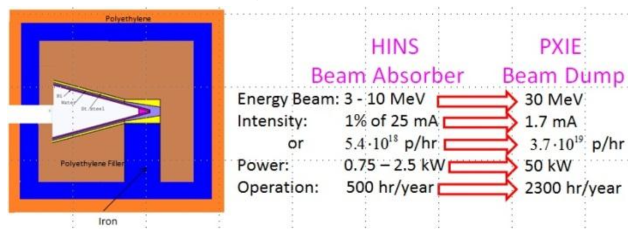

Figure 3: Prototype of PXIE beam dump.

As a result of the analysis was chosen such geometry of the dump, in which two sweep magnets are used to distribute the beam on the inner cylindrical surface of the absorber. The scheme of that is shown in Figure 4 and next Figure 5 shows the corresponding power beam distribution over this surface.

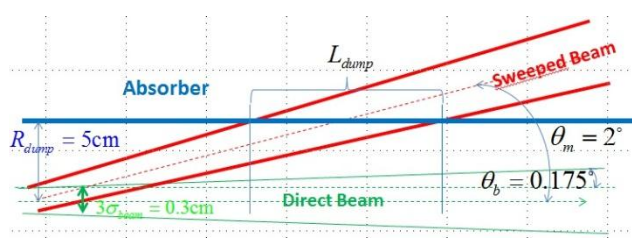

Figure 4: Sketch of the PXIE beam dump.

Due to simulation the following main characteristics of the dump were chosen: nickel as absorber, inner radius R_{dump} = 5 cm, sweep angle $\theta_{sweep} = 2^o \approx 35$ mrad, surface area of absorption of the beam $S_{dump} \approx 1250$ cm^2, average power of the beam on this surface $<P_{beam}> \approx 40$ W/cm^2. Evaluations of the cooling system for this beam dump confirmed the absence of serious problems in the implementation of such a device.

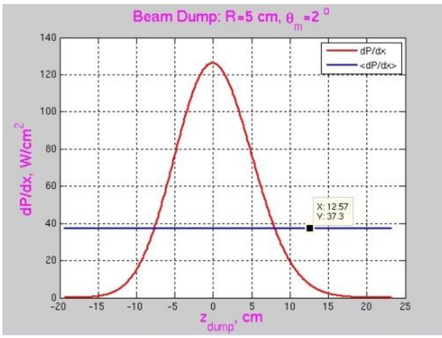

Figure 5: Beam power distributions on the absorber surface. Total power of the beam 50 kW.

The oblique (almost grazing) incidence of the beam on the surface of the absorber is accompanied by beam reflection due to multi back scattering. Code SRIM [4] was used to analyze this effect. Simulation shown that were reflected about 25% of the initial protons. These particles are carried away about 6% about 25% of the total beam power. The distribution of the "reflected power" (Figure 6) shows that short range about 7^0 contents main part of this power.

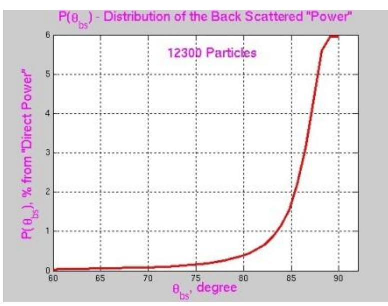

Figure 6: Distribution of the back scattered "power" of the beam due to multi back scattering effect.

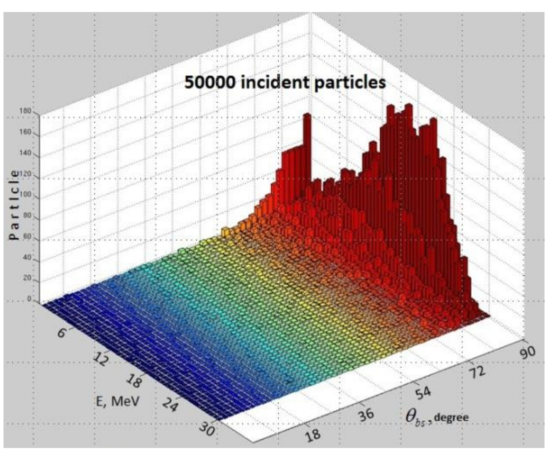

Figure 7: Distributions of the back scattered protons. Incident beam: $\theta_{grazing} \approx 35$ mrad, $\theta_{beam\ spread} \approx 3$ mrad.

Figure 7 shows the distributions of the reflected particles over their energies and angles of the back scattering. Can be seen all values of the energy are presented in the reflected beam. Naturally, most part of the particles reflects to the small range of the angles (about 10^0).

The problems of sputtering and blistering must be taken into account due to during prolonged operation of the beam dump and the high intensities of the absorbed beam. Comparison of the maximal depth (MD) of the penetration of particles into the surface is presented in Figure 8. These distributions show that for absorbed particles $MD_{ab} \approx 86 \pm 56$ μm and this depth for back scattered particles is less significantly: $MD_{bs} \approx 14 \pm 12$ μm. So, problems of sputtering and blistering under progress in more details.

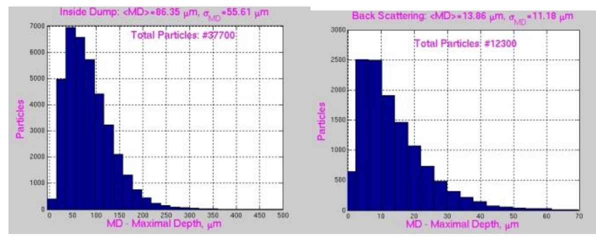

Figure 8: Distributions of the absorbed and back scattered protons.

As mentioned earlier the beam directed to the dump would not generate radiation exceeding 0.1% of radiation corresponding to 100% loss in the DS end. The different kind of local enclosure of the beam dump has been investigated.

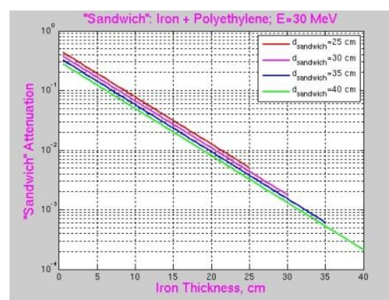

Figure 9: Comparison of "sandwich" type of local enclosure of the beam dump.

Data in Figure 9 shows that "sandwich" from ≈ 40 cm of iron and about 10 cm of polyethylene will ensure the desired level attenuation 0.1% of the radiation due to beam absorption in the beam dump.

REFERENCES

[1] Project X Front End R&D Program – PXIE, Project X document 966-v3.

[2] "Fermilab Radiological Control Manual": Section 2.3, (2010).

[3] R. C. Webber et al., "Overview of the High Intensity Neutrino Source Linac R&D Program at Fermilab," LINAC08, Victoria, Sept. 2008, MO301.

[4] "SRIM – the Stopping and Range of Ions in Matter"; http://www.srim.org