CONCEPTUAL DESIGN OF THE ESS-BILBAO MATERIALS IRRADIATION LABORATORY*

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Abstract

The basic design for the first stage of the ESS-Bilbao proton linear accelerator up to 50 MeV is almost concluded and the linac is at present under construction. Several application laboratories have been envisaged in this first stage: three proton irradiation stations and a low intensity neutron source. In particular, the high intensity proton beam of 50 MeV will be used to test structural materials for fusion reactors under project named "Protons for Materials" (P4M), described in this contribution. The P4M irradiation room will be an underground facility located at the accelerator's tunnel depth. High levels of activation are expected in this irradiation room and its design presents challenges in both remote handling and independent operation from the other two surface laboratories. Thermal analysis of the beam power deposition over the target will be presented.

INTRODUCTION

The main goal of the ESS-Bilbao project [1] is to develop a high current proton linear accelerator able to provide proton beams for user applications. The main components of the proton linac are an Ion Source (IS), a Low Energy Beam Transport (LEBT) to match the beam to the acceptance of the Radio Frequency Quadrupole (RFQ). Then the RFQ accelerates the beam up to 3 MeV. Next, a Medium Energy Beam Transfer (MEBT) to transport the beam to a 3-tank Drift Tube Linac (DTL) that will accelerate the beam from 3 to 50 MeV that is the final energy of the first stage of the project. The main characteristics of the linac are presented in Table I.

Beam transfer lines (BTL) that will transport the beam from the output of the DTL to the user laboratories have been recently designed [2]. The BTL need to satisfy the operation requirements of all the applications projected in the first stage of the project. The 50 MeV proton beams will be used for both proton and neutron applications. The three proton application laboratories planned: Fusion Materials irradiation (P4M), Radiation Biology (P4B) and Space Radiation Testing (P4I), will allow research in different fields. Furthermore, a low intensity neutron source, based in nuclear Be(p,n) reaction, will enable experimentation with both high energy and cold neutrons for different purposes such as neutron Time of Flight (ToF) measurements for nuclear data, Neutron Scattering experiments and Space Radiation Testing with neutrons.

This contribution describes the conceptual design of the P4M laboratory.

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Table 1: ESS-Bilbao Linac Characteristics

Parameter	Value
Maximum peak current	75 mA
Final Energy	50 MeV
Pulse length	1.5 ms
Maximum repetition rate	20 Hz
Maximum duty factor	3%
Maximum average current	2.25 mA
Maximum beam power	112 kW
RF frequency	352.2 MHz

MATERIAL IRRADIATION LABORATORY (P4M)

Basic Requirements

According to theoretical calculations [3] and previous experiments, the irradiation of materials with protons of energy in the range from 20 to 100 MeV and average current about 1 mA is capable of simulating the effects of fusion neutrons (target atomic displacement damage and He&H production by nuclear reaction) with a reasonably fast dose rate, as it is presented in [4].

Moreover, proton beam experiments in this energy range allow homogeneous irradiation of thick samples (1 mm) in the usual fusion materials such as Eurofer97 and other low activation steels.

Therefore, the basic parameters expected for the operation of the ESS-Bilbao accelerator (table 1) match with the requirements of the proton irradiation experiments proposed to study radiation damage by fast neutrons in materials for fusion reactors.

The design of the P4M laboratory present several challenges regarding both the target heating by the beam power deposition and the sample activation.

Thermal Analysis

When a 50 MeV proton beam passes trough the 1 mm thick target (Eurofer97 used for this study) SRIM/TRIM Monte Carlo simulations [5] give a beam energy loss ΔE of about 7 MeV. The power is homogeneously deposited inside the target material. The instant volumetric power deposition is then:

$$\frac{d\dot{Q}}{dV}\left(\frac{W}{m^3}\right) = \frac{\Delta E(eV)\cdot I(A)}{t(m)\cdot \pi \cdot r^2(m^2)} \qquad (1)$$

where I is the beam current (75 mA@1.5 ms@20 Hz pulsed beam or 2.25 mA continuous beam), t the sample thickness (1 mm) and r the beam radius (28 mm). Therefore the current density is 0.1 mA/cm^2, that is a reasonable value for this kind of experiments [4].

The thermal effects of beam power deposition have been studied on a solid model using the COMSOL Multiphysics [6] finite element analysis code. Input data for the analysis are the geometry (a rectangular plate of 67 x 67 mm^2) and the beam deposition as a constant heat generation. Material properties used in the analysis for Eurofer97 are given elsewhere [7].

The following boundary conditions are imposed for the simulations:

- Internal heat generation in the beam footprint area.
- Constant temperature in the two edges (273 K) or in the rear surface (343 K). This is a first approach to the coolant effects but is realistic enough to evaluate the thermal evolution of the target and the cooling capacity needed.
- Surface to ambient radiation (simulation of vacuum conditions in the irradiation chamber) with surface emissivity 0.9.

Fig. 1 shows the temperature evolution in the central point of the sample during the first second of irradiation (20 initial pulses) when the sample is refrigerated only by two edges. As the thermal conductivity is low the heat is slowly evacuated during the beam off periods, so the temperature is raising up to very high equilibrium values, which will be evaluated using a continuous beam to save computing time (see Fig. 2).

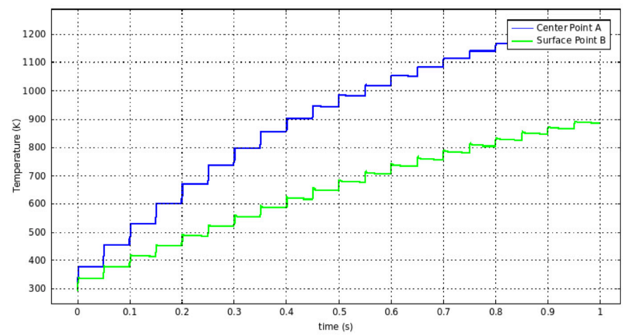
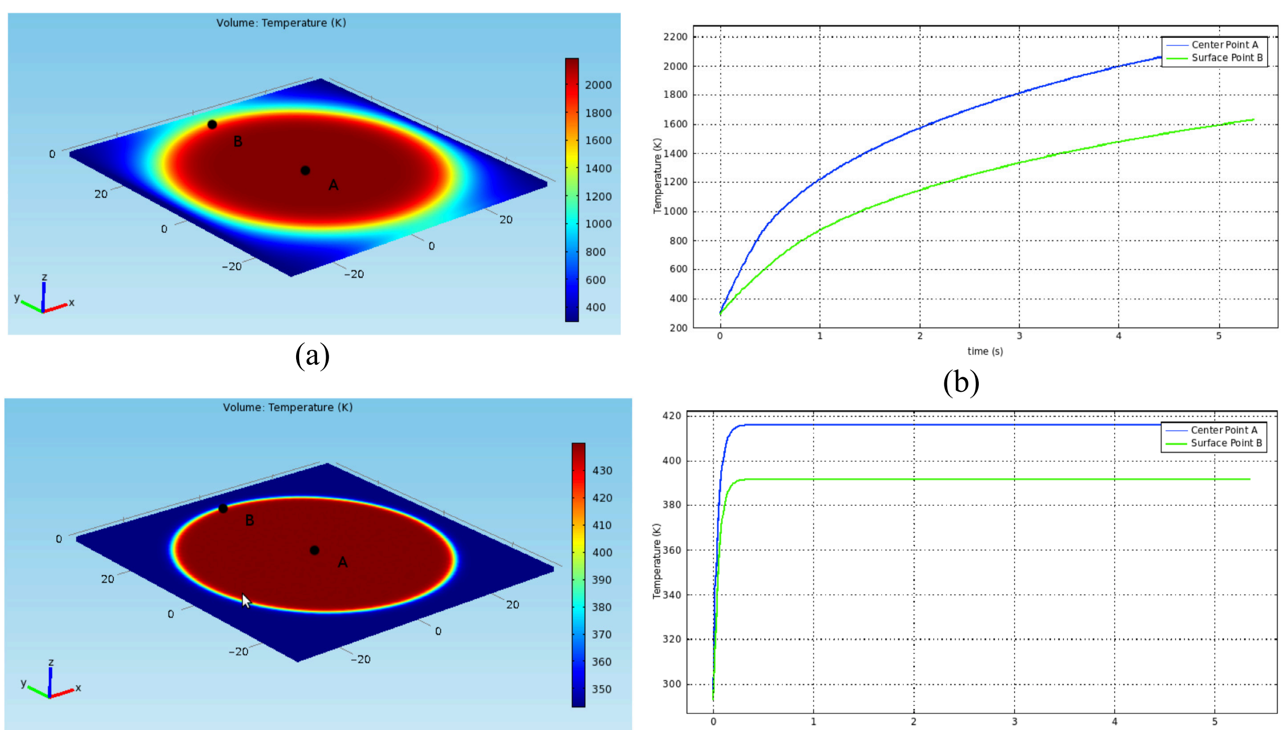


Figure 1: Temperature evolution in the central point (A in blue) and a point on the surface (B in green) during the first second of irradiation (20 pulses).

The results of the thermal simulations considering a continuous beam (applying the duty factor to the peak beam current) are presented in Fig 2.



(c) (d)

Figure 2: Temperature distribution in the sample during the equilibrium with active cooling in two edges (a) and with active cooling in rear surface of the sample holder (c). Temperature evolution in the central point (A in blue) and a point on the surface (B in green) during 5 seconds of irradiation when two edges temperature is kept at 273 K (b) or at 343 K (d) as a first approach to the cooling circuit.

The first second of the Fig 2(b) can be compared with Fig 1 to confirm the equivalence between simulations using pulsed beam or continuous beam.

These results show that if the sample is refrigerated only by two edges, as required for mechanical tests during irradiation, the temperature in the sample after several seconds of irradiation (Fig. 2 (a) and (b)) is too high for a feasible experiment.

However, the target temperature in mean equilibrium can be controlled with a cooling circuit in the sample holder located in the back surface of the sample plate (see Fig. 2 (c) and (d)).

Layout of the Laboratory

The basic layout of the P4M laboratory is illustrated in Fig. 3.

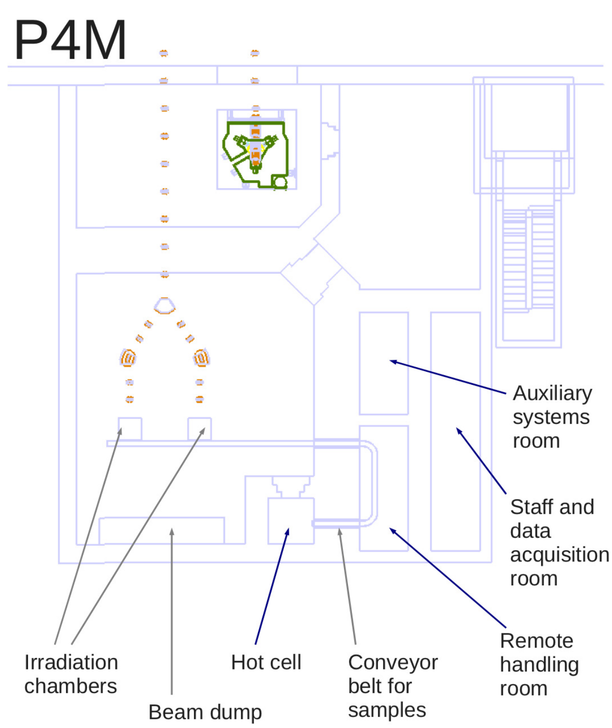


Figure 3: Basic layout of the P4M laboratory.

Due to the high levels of activation expected during the irradiations, the P4M laboratory consists of several separated areas: irradiation room, remote handling room, auxiliary systems room, data acquisition and staff room and hot cell. All these areas will be located at the accelerator level (-10 m). At the entrance of the irradiation room the beam will be deflected by a dipole magnet to the two-projected irradiation chambers, one of then dedicated to *in-beam* experiments (physical properties such as optical, electrical, transport and thermal measurements), and the other one to *off-beam* experiments (material characterisation and mechanical testing of the irradiated samples).

CONCLUSIONS

The conceptual design of the P4M laboratory projected within the ESS-Bilbao project has been presented in this contribution. In this laboratory high current (about 2 mA) 50 MeV proton beams will be used to simulate experimentally radiation damage in fusion materials. Thermal analysis has shown that heating of the sample can be managed with a cooling circuit in the sample holder and the basic layout of the laboratory is already designed.

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