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Proton irradiation facilities envisaged for the ESS-Bilbao project

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Abstract

The ESS-Bilbao (ESS-B) proton linear accelerator has been conceived as a multipurpose machine that will support experimental facilities using both proton and neutron beams.

Concerning proton applications, three main irradiation laboratories are currently under design: radiation biology (P4B), radiation testing of aerospace industry components (P4I) and fusion materials (P4M). The P4B and P4I facilities require the use of low intensity beams and will be set up in the first phase of the ESS-B project. However, the P4M laboratory, projected for the second stage, will make use of the high proton beam fluxes available at the ESS-B linac, to study experimentally the radiation damage in materials for future fusion reactors.

The scientific case and the conceptual design of the three proton irradiation facilities will be presented in this contribution.

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Keywords: proton irradiations; radiation biology; radiation testing; fusion materials.

1. Introduction: general vision of the project

The ESS-Bilbao (ESS-B) project aims to develop a standalone facility envisioned as a source of proton and neutron beams provided by a high current proton linear accelerator. These proton and neutron beams are expected to serve to a local community of users working in different research fields. The main parameters of the ESS-B accelerator are summarized in the Table 1.

The baseline design of the main accelerating elements i.e., injector, resonator based on Radio Frequency Quadrupole (RFQ) technology and Alvarez-type Drift Tube accelerator (DTL) is already finished. At the moment, the linac com-

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Table 1. Main parameters of the ESS-Bilbao accelerator.

Energy	50	MeV
Peak current	75	mA
Repetition rate	20	Hz
Pulse length	1.5	ms
Duty factor	3	%
Average current	2.25	mA
RF frequency	352.2	MHz

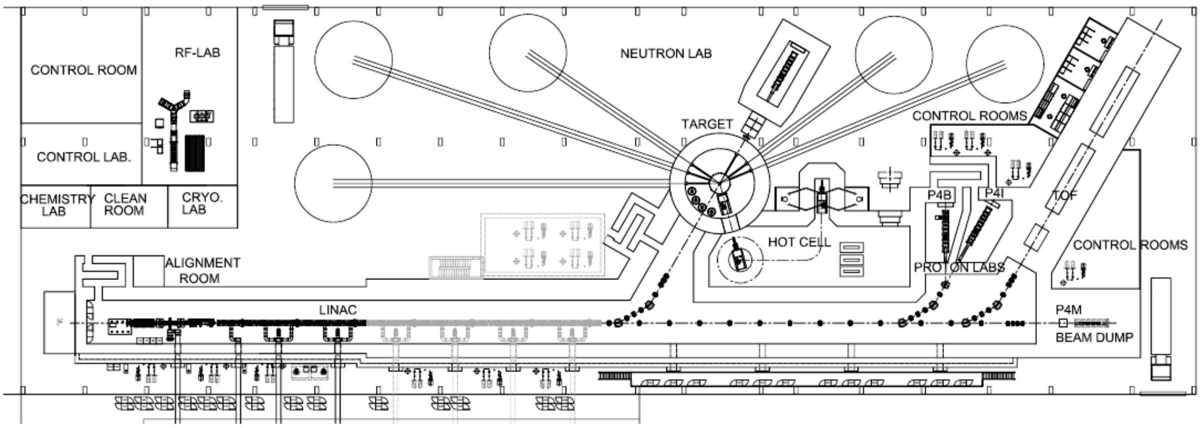

Fig. 1. Preliminary layout of the ESSB facility

ponents are either under prototyping and construction, mainly by the local industry, or the early ones already under assembly and commissioning Abad (2011).

At the same time, a neutron target based in 9Be(p, n) direct nuclear reaction has been designed Terrón (2011). Various research lines are envisioned that will allow performing experiments with high- and low-energy neutrons; training technical personnel specialized in neutron experimentation; and testing components intended for large European neutron facilities.

Concerning proton beam applications, three main irradiation laboratories are currently under design: radiation biology (P4B), radiation testing of aerospace industry components (P4I) and fusion materials (P4M). The P4B and P4I facilities require the use of low intensity beams, whereas the P4M laboratory will make use of the high particle beam fluxes available at the ESSB linac.

The ESSB facility will be located in the UPV/EHU (University of the Basque Country) at the Leioa-Erandio Campus. Fig. 1 shows the preliminary layout of the facility.

The present document reports on the status of the projected proton irradiation laboratories. In particular their scientific case, conceptual design and preliminary layout will be presented.

2. Proton irradiation facilities

The Radiation Biology Laboratory (Protons-for-Biology or P4B) has been proposed Huerta-Parajón (2012) with the objective of studying the response from biologic materials (cells, tissues, or organs) to ionizing radiations, a rele-

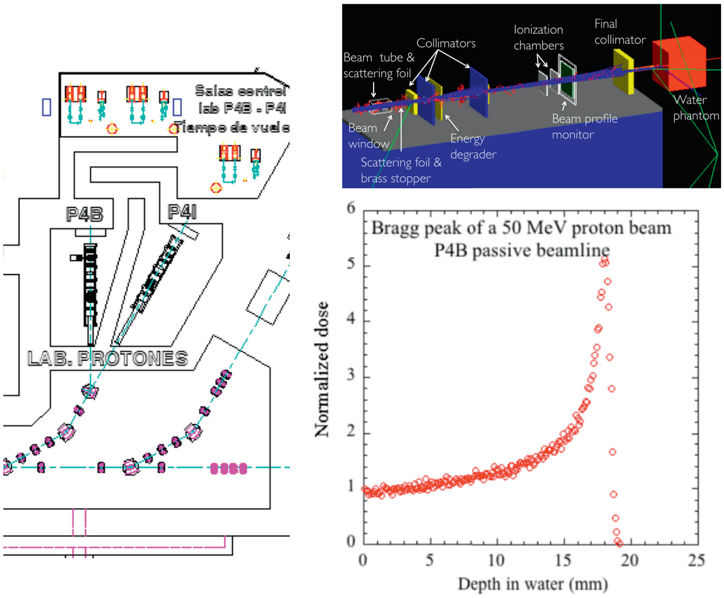

Fig. 2. Preliminary layout of the P4I and P4B laboratories (left). Tentative disposition of the P4B passive beam line elements (upper right). Bragg peak in water of a 50 MeV proton beam though the P4B passive beam line calculated with Geant4 (lower right).

vant issue in biomedical research intended for designing and optimizing ion radiotherapy in oncology.

Hadron therapy exhibits higher efficiency than conventional radiotherapies in many types of tumors, especially in cases where the cancerous tissue is close to a vital organ. This is caused by the high levels of accuracy that can be reached through ion beams, due to the different propagation properties of heavy particles compared to those of X-ray. Ions exhibit a well-defined range and deposit most of their energy at the end of the path known as the Bragg peak, whose exact localization can be adjusted to fall within the tumor. Furthermore, through superposition of several peaks (each modulated at a different energy), it is possible to extend the Spread Of Bragg Peaks (SOBP) in order to obtain a uniform dose in a volume of interest. A drastic reduction of late after effects on surrounding healthy tissue is particularly important, especially for the treatment of tumors affecting the eyes, the prostate, certain areas of the brain, or in children, and in general for solid tumors in which the use of conventional radiotherapy is risky. However, the whole potential of this therapy can only be achieved by a better understanding of the radiobiological mechanisms involved through the study of in vivo phenomena at a tissue level or response of complete organs in animal models.

Currently, preliminary studies are in progress on deposited energy profiles and dose rate on target using Monte-Carlo codes, in particular the Hadrontherapy model Agostinelli (2003), included in GEANT4 Cirrone (2005). Using this model, beam line elements (beam window, scattering foils, energy degraders, modulators, monitors and collimators) can be simulated and the position of each element can thus be planned. Figure 2 presents the tentative layout of the laboratory and a design for a passive beam line for the P4B Laboratory created using the above-mentioned model, together with the energy deposition profile of a 50 MeV proton beam in a water phantom.

As results of these studies, basic operating parameters were proposed for the P4B Laboratory as shown in Table 2.

The P4B laboratory will be oriented, among other studies, to activities related to:

- Increase treatment effectiveness understanding of the biological mechanism involved.

Table 2. Basic beam parameters of the P4B facility.

Energy range	5-50	MeV (by degraders)
Maximum average current	1-100	nA
Beam dimensions	1-10	cm
Irradiation conditions	In air/ horizontal	
Additional requirements	Biology laboratory (bio-safe level 1)	
	Reference Source (X-ray bio irradiator 200 kV)	

- Tissue, organs and animal models response to different biology-based treatment strategies (chemo-radio-therapy combination, fractioning, intensity-modulated ion therapy).
- Healthy tissue response.
- Detector and dosimetry development and testing for in-beam monitoring techniques.

2.1. Space Radiation Testing

The Proton Irradiation Laboratory (Protons-for-Industry or P4I), has been planned with the objective of performing radiation assays on components and systems used in aerospace industry.

Ground base measurements with accelerator produced proton, as well as heavy ion and neutron beams provide important data for understanding and predicting the behavior of the microelectronics components and systems in space or other radiation environment. Therefore, there are several facilities worldwide at which Space Radiation Testing can be performed. In particular, proton testing for space applications is the most common type of experiment, since protons are the most abundant ion species in the space. Therefore, a Proton Irradiation (P4I) laboratory for Space Radiation Testing is also being designed at the ESS-B facility Abad (2011), see preliminary layout in Fig. 2. The basic operating parameters were proposed for the P4I Laboratory as shown in Table 3 and the facility will be dedicated to perform studies oriented to:

- Studies on radiation hardness of microelectronic devices and systems prior to be used for space instrumentation.
- Testing and calibration of detector components for space missions.
- Radiation biology studies in order to investigate radiation damage and risk assessments for long-term space manned missions.

Table 3. Basic beam parameters of the P4I facility.

Energy range	10-50	MeV (by degraders)
Maximum average current	1	nA
Flux range	1010-101	$p/cm^2 s$
Beam dimensions	5-20	cm
Irradiation conditions	In air/ horizontal	
Sample positioning	X-Y table and sample frame	
Additional requirements	Electronic laboratory	

2.2. Fusion Materials

The Materials Irradiation Laboratory (Protons-for-Materials or P4M), has been proposed in order to study experimentally the radiation damage in materials for future fusion reactors, both through magnetic and inertial confinement, and other hard radiation environments.

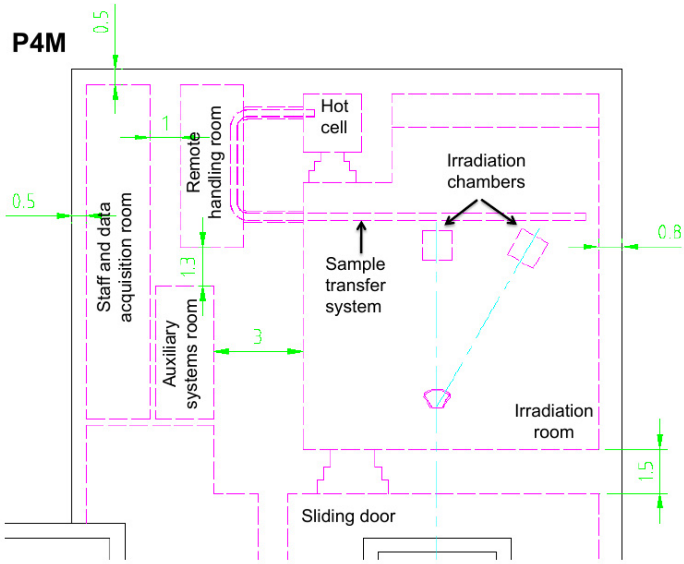

Fig. 3. Preliminary layout of the P4M laboratory. The estimated shielding thicknesses in meters are given and indicated by arrows in the figure.

Materials irradiation by protons is capable of simulating the effects of fusion-generated neutrons (displacement damage and H and He production) with a reasonably fast dose rate, as predicted by theoretical calculations and previous experiments.

The preliminary design study of the P4M laboratory for fusion materials at ESS-B have been reported elsewhere García-Cortés (2012). This work appraises the scientific feasibility of performing fusion relevant experiments as well as the tests that can be conducted during and after sample irradiation. Special emphasis is placed on material damage parameters, the beam power deposition in the sample and the consequences of material activation for the laboratory design. As first results, the consequences of high power deposition and severely activation of the specimens make essential an adapted cooling system and remote handling operation.

The main results of this initial scientific feasibility study can be summarized as:

- The 50 MeV proton beam is a useful tool for reproducing radiation damage by fusion neutrons in reactor relevant materials. The use of an energy-beam degrader could also help to adapt the irradiation conditions to neutron damage in different scenarios.
- Proton irradiation with a current density of 0.1 mA/cm^2 yields a ratio of He production to displacement damage similar to that predicted for fusion neutrons.
- For a 0.1 mA/cm^2 beam, active cooling of the rear of the sample is essential in order to dissipate the thermal load (about 0.7 kW/cm^2 in the sample). A prototype of an Al sample holder with a water cooling channel, based on the thermal studies results presented, is being designed.
- Due to the predicted thermal load the mechanical tests foreseen during irradiation are not possible using water-cooling in the sample holder. However, simulations using helium gas under pressure as the cooling medium are in progress.
- Dosimetry during irradiation and activation of sample and holder has been estimated. The results are crucial for defining the experimental conditions and the design of the laboratory.
- A room for remote handling operations has been reserved in the preliminary layout of P4M laboratory (shown in Fig. 3) because of the high levels of dose and activation expected during/after irradiation experiments.

3. Concluding remarks

One of the objectives of the ESSB project is to develop the user facilities for the exploitation of light ion and neutron beams generated in ESSB and to promote the applications in diverse research fields such as biomedical, energy or material sciences. The selection of the group of applications described in this contribution was based on contacts held with and proposals made by potential user communities. The 50 MeV proton beams will be used for radiation biology (P4B), aerospace testing (P4I) and fusion materials qualification (P4M).

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