Neutron applications laboratory for ESS-BILBAO

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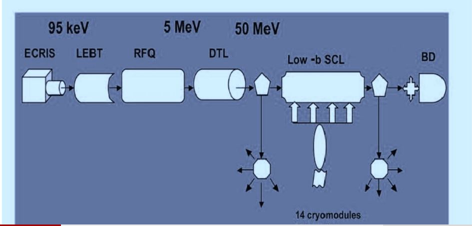
Table of contents

Introduction

The ESS-BILBAO Accelerator Center site at the Lejoa UPV/EHU campus, will be provided with a proton accelerator up to 300-400 MeV. In the first construction phase, a beam extraction will be set at the end of the DTL, which will provide a 50 MeV proton beam with an average intensity of 2.25 mA and 1.5 ms pulses at a frequency of 20 Hz. These beam characteristics allow to configure a low intensity neutron source based in the Be (p, n) reaction, which enables experimentation with cold neutrons similar to that of LENS. The total beam power will be 112 kW, so the configuration of the neutron production target will be based on a rotating disk of beryllium slabs perpendicularly facing the beam on one side and a cryogenic methane moderator on the other, with the target-moderator system surrounded by a beryllium reflector. In this paper, first estimates will be presented for thermomechanical conditions of the target cooling scheme, neutron source intensities, cold neutron pulses, operating dose rates, generated activity and tritium production.



Source term definition

The table shows the comparison between the experimental results and the nuclear models (CEM, Isabel, INCL, and INCL-ABLA). The best fitting model is the Isabel-Dresner, with a relative error around 10 % in all the range of relevant energies, which can be considered as adequate. The results of the ENDEF-VII cross-section show a sharp drop when going above 55 MeV, which is produced due to neutron emission data not being available, and thus are completely discarded.

Energy	I. Tilquin	CEM	Isabel	INCL	INCL-ABLA	ENDEF
$45 MeV$	$0,056$	$0,064$	$0,062$	$0,066$	$0,066$	$0,064$
$55 MeV$	$0,078$	$0,084$	$0,080$	$0,089$	$0,088$	$0,077$
$65 MeV$	$0,104$	$0,106$	$0,103$	$0,116$	$0,081$	$0,059$

Source Term analysis (n/proton)

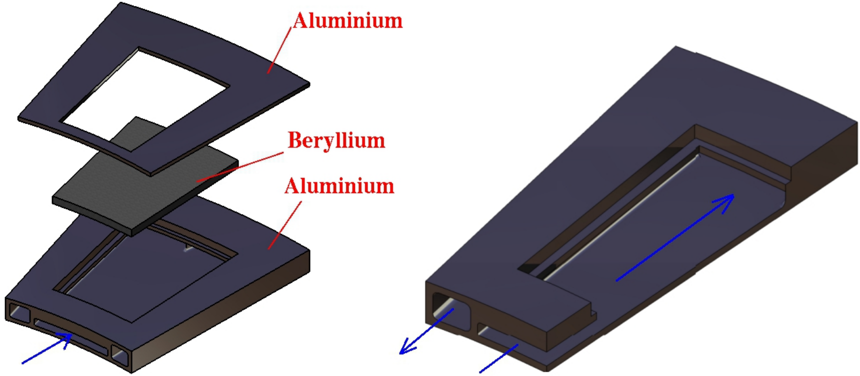
Target Materials

The table shows the total neutron production estimated using Isabel model, for 50 MeV protons hitting different materials. The material that achieves the highest neutron production rates is Beryllium, and thus, it will be the selected material. Lithium produces neutrons with a high energetic level, and therefore, it could be interesting for some applications.

Material	Neutrons/Proton	Average Energy (MeV)
Carbon	$7.54E-3$	8.04
Lithium	$4.27E-2$	13.15
Beryllium	$6.49E-2$	7.76

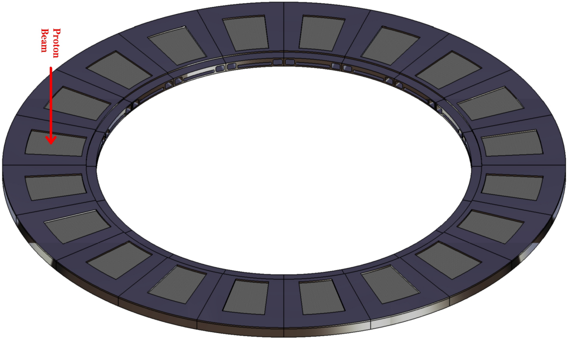
Themomechanical analysis: Rotating target

From a mechanical point of view, projecting the beam to a single sheet is not possible without reaching temperatures and tensions outside the acceptable range in beryllium. In order to reduce temperature and tensions, we chose to distribute the beam between 20 to 40 sheets, arranged in a disk that would turn synchronized with the accelerator pulses.



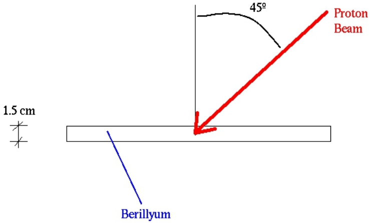
Themomechanical analysis: Rotating target

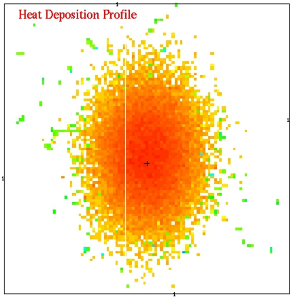
The figure shows a proposed schematic for the arrangement of the beryllium sheets (20 elements), with the proton beam normal to the sheets, and parallel to the disk axis.



Themomechanical analysis: Beam angle

In order to avoid high energy neutrons incidence in the thermal neutron experiments, leaning the beam to the experimental lines will be mandatory. By leaning the beam, the material section can be reduced without altering the thickness seen by the protons and also the footprint of the been will be increased. Both effects will allow to reduce stress and temperatures. Figure shows temperature and stress distribution for 20 elements and 20 Hz of beam frequency.

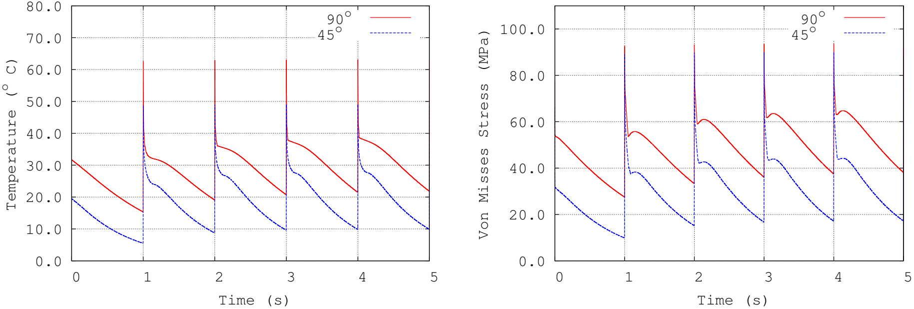




Themomechanical analysis: Beam angle

As shown in the figures, tension and temperature raise reductions are not very sharp. This is due to three opposed effects: By increasing the slope we can reduce the material thickness, and the beam drops its energy in a greater ellipse, but the energy deposition per volume unit increases as the path in the material does.

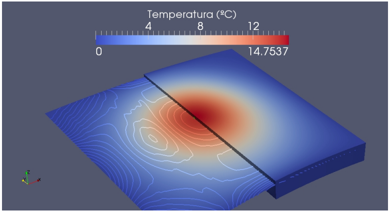
Temperature and thermal stress

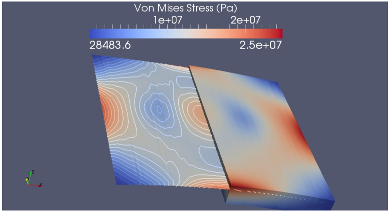


Themomechanical analysis: Beam angle

The proton beam hits the sheet at a 45^o angle so it produces an elliptical heat deposition profile. Thus, an elliptical temperature and stress distribution will be produced. An stress accumulation in the edges can be noticed so it could be possible to reduce stress if they were rounded.

Temperature and thermal stress at t = 0.25 s

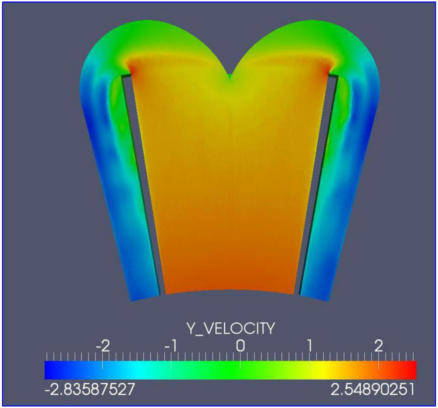




Themomechanical analysis: Cooling channel

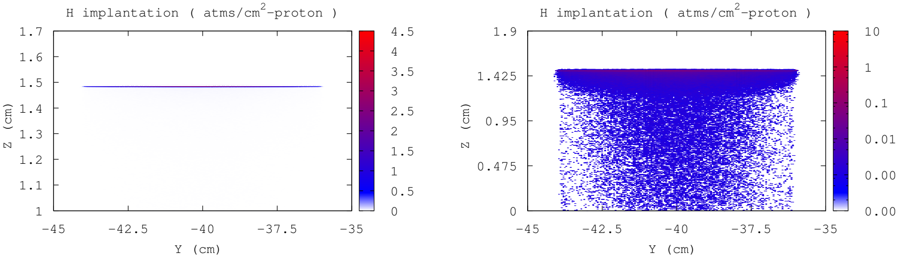
In order to conclude target themomechanical analysis, a preliminary CFD evaluation of cooling channel has been performed. A pressure drop of 5000 Pa will ensure enough velocity to remove heat deposited on beryllium sheep. So, the refrigeration conditions are not very severe.

Figure shows velocity profile on radial direction. Pressure drop could be reduced if edges were rounded.



Gas implantation

Only a small fraction of protons from the beam will suffer nuclear interactions, and due to it, a large amount of free protons will be introduced in the target material. These free protons will get an electron and will become hydrogen. Hydrogen inside a metallic matrix will produce swelling and finally the mechanical failure as in LENS case.



Gas implantation

The LENS beryllium target has an operating time of 156 h for the parameters shown on the table, so the results were extrapolated, and for lack of a more thorough study, a life of over 3000 operating hours can be considered for ESS-BILBAO target. This value is roughly a full year operating the facility, which seems entirely reasonable for planning the upkeep and wheel substitution.

	LENS	ESS-B	ESS-B 20 elements
Average Intensity (mA)	$0,62$	$2,25$	
Operation time (h)	156	171	3420
Implantation ($atms/cm^3 - p$)	18	$4,5$	

Evaluation for ESS-BILBAO target life time for 50 MeV protons

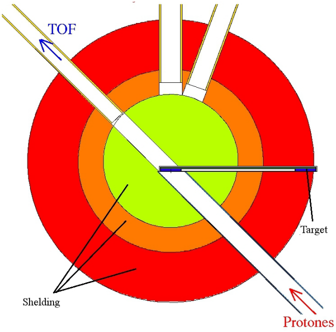
Applications: High energy and Cold neutrons

Taking into account the source term analysis, a multipurpose experimental facility is proposed with three experimental lines, two of them for cold neutrons and one for high energy neutrons.

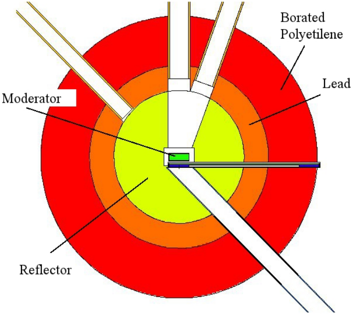
- *High energy neutron line:*
  The main objective of this line will be measuring of high energy cross sections and test of instruments and detectors in this energy range. In order to maximize fast neutrons flux, the high energy line has to be oriented in the beam direction
- *High energy neutron for aerospace irradiations:*
  Electronic devices for aerospace applications have to be tested on high atmosphere radiation conditions. These conditions can be reproduced at ESS Bilbao in order to perform accelerated irradiations.
- *Materials irradiation*
  Several components of fusion and fission nuclear reactors have to be studied in medium and low irradiation conditions that could be reproduced on ESS-BILBAO facilities.
- *Cold neutrons lines:*
  Low energy neutrons lines will be used in close collaboration with the ESS project in order to test components such as moderators, neutron lines, choppers or instrumentation. The ESS-BILBAO neutrons laboratory could be the test stand for ESS neutronics components.

Applications: High energy and Cold neutrons

In order to have a versatile installation, two operational modes have been studied to produce either fast or thermal-cold neutron flux in the experimental lines. In the high energy mode, reflector material could be part of the shielding in order to minimize dose ratio outside the target area.



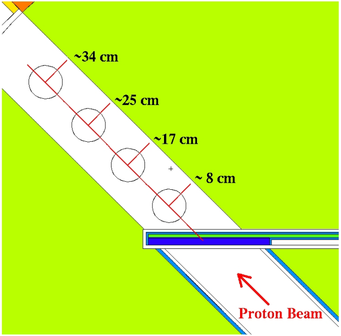
Fast neutrons mode



Cold and thermal neutrons mode

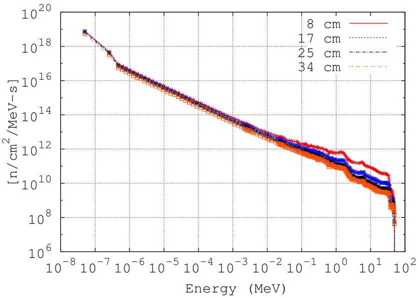
Applications: Material Irradiation

The area close to the target in ESS-Bilbao could be very interesting for testing materials in medium and low irradiations conditions. It will not be enough for structural materials high irradiation analysis, but it could be representative for several materials (Inertial fusion lens, ITER magnets, ESS bearings or seals).

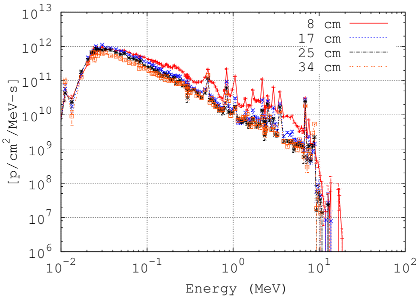


Applications: Material Irradiation

Neutron flux produced is a mix of high energy neutrons directly from the target, and neutrons moderated on reflector and shielding. At 8 cm from target surface neutron flux is $6.1 \cdot 10^{12} [n/cm^2 - s]$ with and average energy of 5.6 MeV.



Neutron flux in several irradiation positions



Photon flux in several irradiation positions

Applications: High energy neutron for aerospace irradiations

Electronic components destined to aerospace applications have to be tested in high energy neutrons environment. CHIPIR instrument in ISIS is focused on testing this type of devices. The tables shows ISIS-CHIPIR high energy flux ($> 10 MeV$).

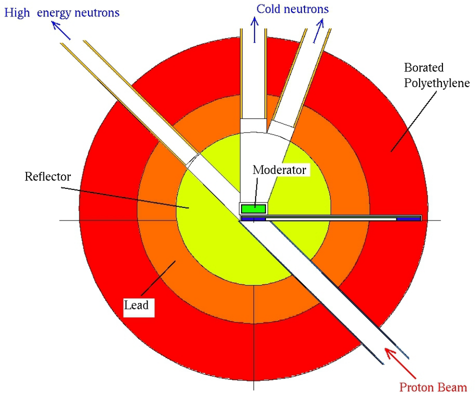
Instrument	Mode	Flux $[n/cm^2 - s]$	Max Energy (MeV)
ISIS-Chipir	Pencil Beam	$4 \cdot 10^7$	800
ISIS-Chipir	Flood Beam	$3 \cdot 10^5$	800

An irradiation area placed at 6 m from ESS-BILBAO target in the TOF line cold produce a similar neutron flux than ISIS-Chipir, the main difference will be that ESS-BILBAO average neutron energy will be lower (7-8 MeV compared with 9-10 MeV).

Distance to Target (cm)	Flux $> 10 MeV [n/cm^2 - s]$
300	6,0E+8
500	2,1E+8
700	1,1E+8

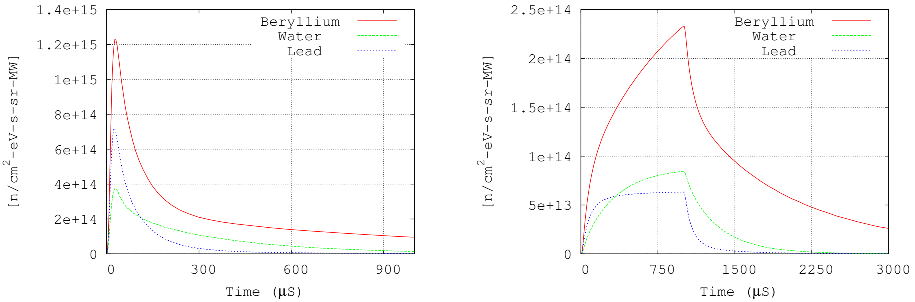
Applications: Cold neutrons

The moderator in duty of producing cold neutrons will be a methane "box" at 22k, with a Aluminum cladding, with some leaning on the beryllium rotating disk axis. The aim of such an orientation is reducing the high energy neutron flux in the experimental lines, so we must avoid placing the experiments in the beam projected line.



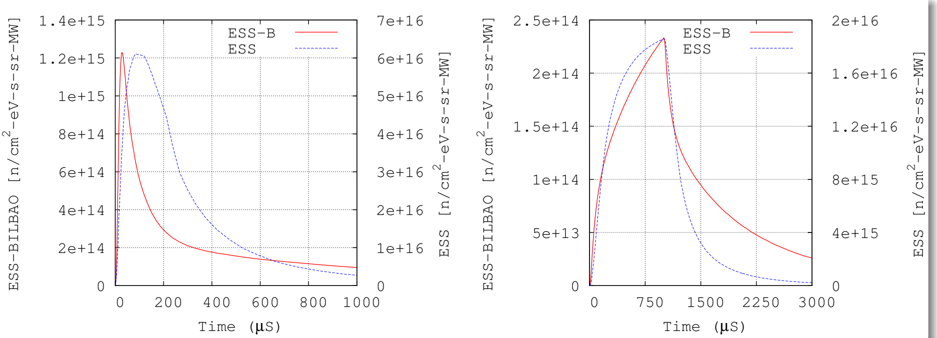
Applications: Cold neutrons

The reflector has a key effect in the shape of the pulse obtained at the moderator (Figures shows 5 meV neutrons). Unlike beryllium, lead produces no neutron moderation, and thus tends to reduce brightness and tail, generating a much more “square” pulse.



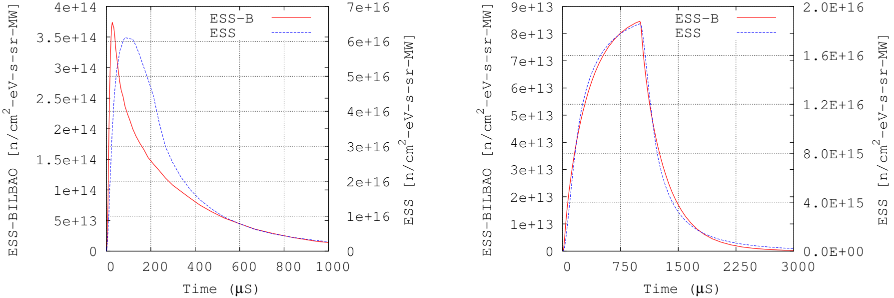
Comparison with beryllium reflector

ESS-BILBAO peak brightness is a factor of 50 under the peak brightness of ESS-LAN for short pulse, which is a very good result, considering our neutron generation efficiency is about 500 times lower. Considering the power difference between both installation (0.1 MW for ESS-BILBAO and 5MW for ESS), we can conclude that the short pulse peak of our installation would be about 2500 times less than that of ESS. Analyzing a long pulse, we observe a peak factor of 80, so we may evaluate the difference between both installation in a 4.000 factor.



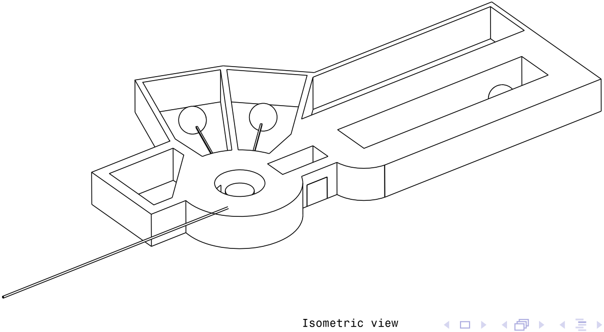
Comparison with water reflector

The figure shows a compared distribution for a 1 ms pulse duration with a water reflector, where we can notice an entirely analogous profile between both sources, just scaled a factor 220. This is the scaling factor that shows us that we are using a more efficient moderator-reflector system than ESS, but 4 times worse than the Beryllium one. Power difference notwithstanding, we can conclude that it is possible to achieve the same pulse as ESS, just scaled a factor of 10000.



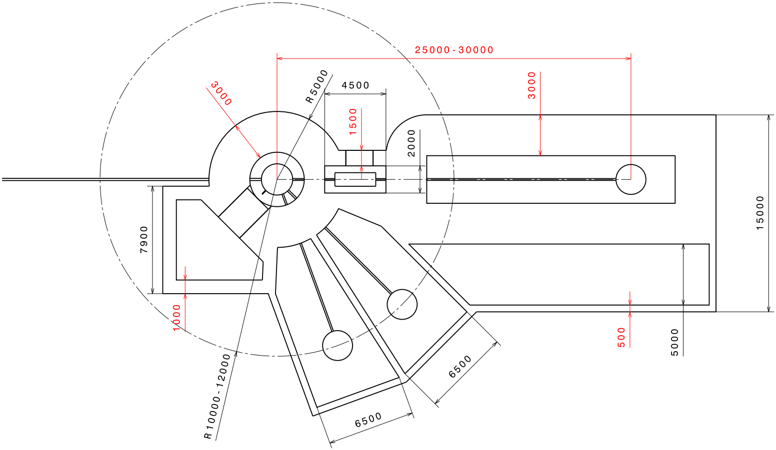
Laboratory layout

With the former results, a first approach of the laboratory configuration can be composed. The target and the reflector system will be installed in a heavily shielded central room. This room will have 4, 10cm radius holes. One for the beam entry, and 3 for the experimental lines exits. Experimental areas could be separated by modular concrete panels in order to be able to adapt the configuration.



Laboratory layout

ESS BILBAO Neutrons laboratory



Conclusions

As conclusions for the studies carried out related to ESS-BILBAO neutronic applications laboratory, the following highlights can be summarized:

1. A multipurpose facility for high and low energy neutrons is being designed for ESS-BILBAO accelerator research center.
2. A solid beryllium rotating target cooled by water can guarantee one operation year in safe thermomechanical conditions.
3. High energy neutron line could reproduce atmospheric irradiations conditions for electronic components
4. Irradiation conditions close to the target cold be adequate for medium and low neutrons irradiation for material characterization
5. Cold neutrons produced with a water reflector and methane moderator can reproduce the pulse shape of ESS scaled by a factor 10.000. This neutron brightness could be enough to test ESS components as moderators, instruments, choppers and neutron guides.