ENERGY DEPOSITION AND ACTIVATION STUDIES OF THE ESSνSB HORN STATION

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on the behalf of the ESSνSB project

Abstract

The ESSνSB project foresees the production of a very intense neutrino beam to enable the discovery of leptonic CP violation. In addition to the neutrinos, a copious number of muons that could be used by a future Neutrino Factory and a muon collider will also be produced at the same time. This facility will use the world's most intense pulsed spallation neutron source, the European Spallation Source (ESS) in Lund. Its LINAC is expected to be operational by 2023, producing 2 GeV protons with a power of 5 MW. The primary proton beam line completing the linear accelerator will consist of one or several accumulator rings and a proton beam switchyard. The secondary beam line producing neutrinos and muons will consist of a four-horn target station, a decay tunnel and a beam dump. To detect the produced neutrinos a far megaton scale Water Cherenkov detector will be placed at a baseline of about 500 km in one of the existing active mines in Sweden. The estimation of the energy deposited and the activation within this secondary beam line are discussed in this paper.

ESSνSB PROJECT

The ESSνSB (standing for European Spallation Source Neutrino Super Beam) project proposes to use the high power LINAC of the ESS facility [1] based at Lund in Sweden as a proton driver to produce intense neutrino beams. A Water Cherenkov type detector, MEMPHYS [2, 3], will be located in a deep mine near the second neutrino oscillation maximum (540 km).

ESS will deliver a first proton beam for neutron production at the full design power 5 MW and energy 2.0 GeV by 2023 distributed in 14 pulses of 62.5 mA current with 2.86 ms time width per second. To allow the LINAC to generate a neutrino beam in parallel with the spallation neutrons, some modifications of the accelerator are necessary. A preliminary study of these modifications that are required to allow simultaneous acceleration of H^+ (for neutron production) and H^- (for neutrinos) ions at an average power of 5 + 5 MW has been made [4].

An accumulator ring compressing the pulses to about 1.5 µs time width is mandatory to reach the power dissipation requirements for the target station. A first estimation gives a ring having a circumference of about 400 m [5], compact enough to be located in the already allocated ESS area. Each pulse from the ESS LINAC will contain 1.1×10^{15} protons, which for a normalized rms beam emittance of 100 π mm mrad in the ring by multi-turn injection will lead to the space-charge tune shift of about 0.75. The H^- ions will be fully stripped during the injection into the accumulator using either stripping foils or a laser-stripping device [5, 6].

The interaction of the protons with the target material will lead to the production of short-lived mesons producing neutrinos by their decay. A packed bed of titanium spheres cooled with pressurized helium gas has become the baseline for the target design.

Other main components of the target station are the hadron collectors called magnetic horns, which focuses the produced hadrons coming out of the target towards the decay tunnel. This tunnel is designed long enough to allow the mesons to decay, but not as long as to allow for a significant amount of the muons to decay. The actual estimated length of this tunnel is 25 m. Figure 1 presents the facility layout concept.

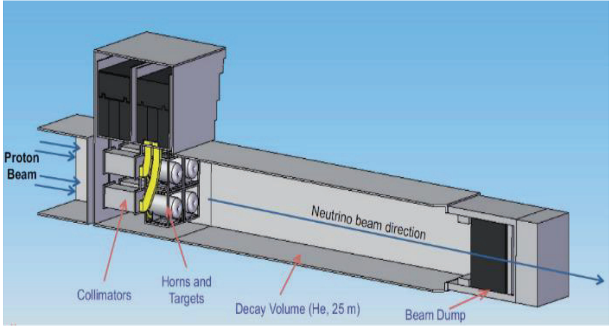

Figure 1: Schematic view of the target/horn station, the tunnel and the beam dump [7].

To mitigate the effects of the very high power of the proton beam hitting the target a system with four targets and four horns, studied in EUROν [7], sharing the full beam power between the four will be adopted here.

ENERGY DEPOSITION

The target/horn station, the decay tunnel, the beam dump and the surrounding parts have been integrated in FLUKA [8, 9] (Fig.2).

The overall power absorbed by the system is estimated to be 4.22 MW. This value represents 84.5 % of the 5 MW incoming beam power. The 15.5 % remaining is identified as "missing energy" in FLUKA. It refers to the energy which cannot be made available to detection, but which has been correctly considered in the process. In practice, this is the energy lost in nuclear binding, and it can be "large" for heavy nuclei targets.

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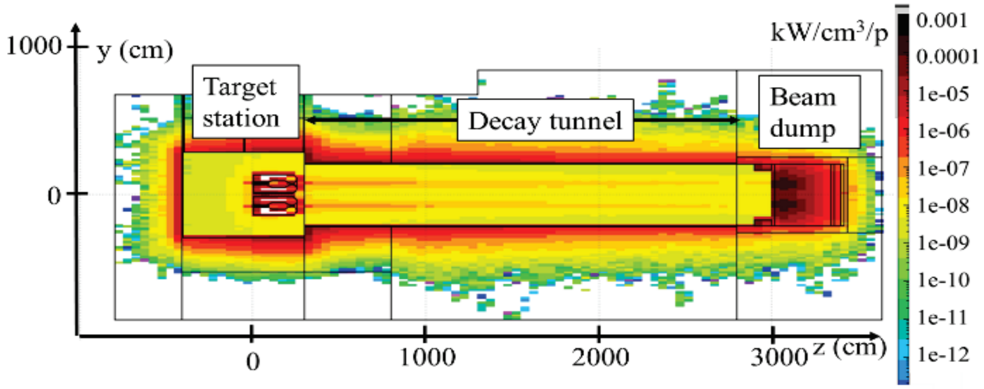


Figure 2: Power density deposited in the whole system.

Horn/Target

The power dissipated in the horn/target station and its distribution can be seen in Fig.2. Each target receives 1.25 MW. The main part of the power is absorbed upstream the target, following the interaction length distribution, and in the inner conductor around the target region where the particle fluence is maximal. Water sprays will be used for the horn cooling. The power deposited in each target and each horn is estimated to be 168 kW and 50 kW respectively.

Secondary charged particles coming out from the pulsed horn will go through the other horns. The total energy deposited on the other horns is less than 10 % of the pulsed one.

Beam Dump

The beam dump area follows the design developed in EUROν [7] and is foreseen to be 4 x 4 x 3.2 m^3. The core consists of a main graphite block and several shields to dump the remaining hadron particles and finally reduce the energy deposition outside the experimental layout. Figure 3 shows the distribution of the power deposited in the graphite part of the beam dump.

This latter absorbs all the remaining hadrons, preventing any other installations from being activated. According to the simulations 950 kW of power is deposited in the beam dump.

Decay Tunnel and Surrounding Iron

The decay tunnel area is surrounded by an iron vessel filled with helium gas and by an additional concrete layer to prevent from soil activation. The simulated geometry and the power densities of the surrounding material shielding the four-horn area and the tunnel are shown in Fig.2. From the simulations, a total power of 1566 kW is deposited in the tunnel including 424 kW and 467 kW in the iron vessel and in the surrounding concrete respectively.

In the entrance of the decay tunnel, an upstream iron-shield is foreseen to protect the areas above it. This will allow positioning the strip-lines and the horns' power supply above the beginning of the tunnel. This iron shield will absorb 640 kW of the overall incoming power.

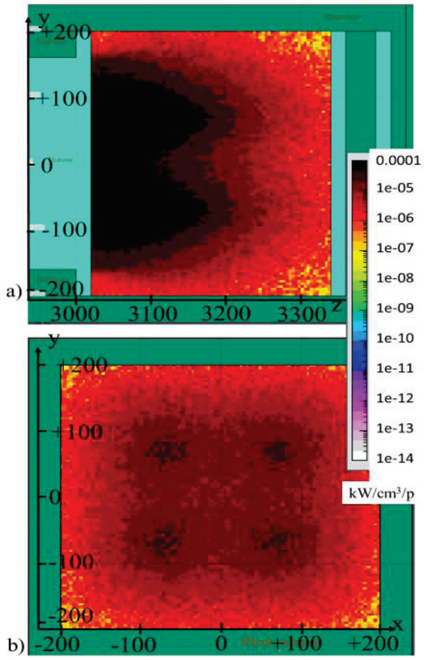


Figure 3: Longitudinal (a) and transversal (b) distributions of the power densities in the dump.

Table 1 summarizes the power distribution according to the location.

Table 1: Summary of the Power Absorbed

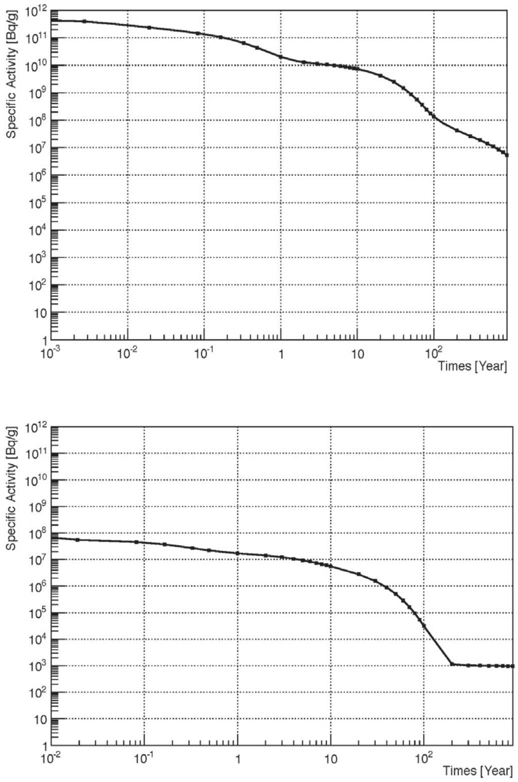
Location	Power absorbed (kW)
Target station (4 targets, 4 horns)	1497 (672, 200)
Decay tunnel (Iron shield)	1566 (640)
Beam dump (Graphite block)	1157 (950)
Whole system	4220

ACTIVITY STUDIES

The calculation has been done by considering 200 days of irradiation with a 2 GeV proton beam of 1.25 MW intensity impinging a solid target with a horn. The packed-bed target with titanium spheres chosen as the baseline target option is modeled as a homogeneous media with a reduced density of 3 g/cm^3.

Induced Activation

The evolution of the induced activation has been estimated for the target and the horn as function of cooling time (Fig.4). The value of the specific activity is obtained as a mean value over the total mass of the considered element.



a)

b)

Figure 4: Evolution of the specific activity of the target (a) and the horn (b) with cooling time.

The activation of the target is non-uniform and presents the most active part upstream of the target. The profile of the activation follows the energy deposition inside the target with respect to the beam profile.

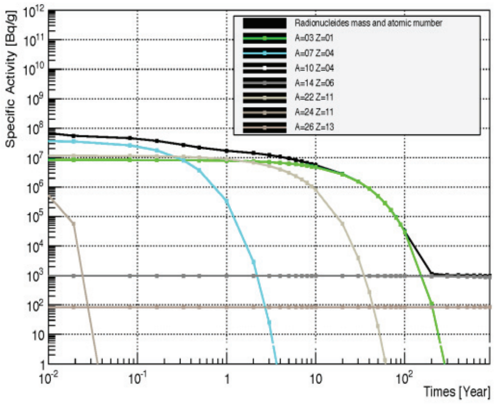


Figure 5: Evolution of the activation for one horn with cooling time.

After one year of cooling time, the remaining radionuclides contributing to the total activity of the horn is due to a significant amount of ^{3}H, ^{7}Be, ^{14}C, ^{22}Na and ^{26}Al. But, only gamma emitters have significant impact on the radiological aspect especially in the case of ^{7}Be, ^{22}Na and the long-lived isotopes ^{26}Al as shown on Figure 5. As in the case of the titanium target, the activation is not uniform inside the horn and presents the most active region in the inner conductor close to the target as expected.

CONCLUSIONS

The ESSvSB projet is aimed to study a new generation of neutrino superbeam for lepton CP violation in the leptonic sector. This facility will be able to use a proton driver at 5 MW power scale from the European Spallation Source in Sweden. The elaboration of this facility is challenging as this preliminary study shows due to the high energy deposition and an important radioactivity level. Further investigations and a full design study are required to take into account the extreme working conditions, the safety rules during beam operation and also the environmental requirements.

ACKNOWLEDGMENTS

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