NEUTRONS AND PHOTONS FLUENCES IN THE DTL SECTION OF THE ESS LINAC

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Abstract

The last section of the normal conducting front end of the ESS accelerator is composed by a train of 5 DTL tanks. They accelerate the proton beam from 3.6 until 90 MeV. The evaluation of the radiation field around these beam elements gives a valuable piece of information to define the layout of the electronic devices to be installed in the surrounding tunnel area. Indeed the risk of SEE and long term damage has to be considered in order to maximize the performance of the ESS accelerator and to avoid possible long down time. A conservative loss distribution is assumed and FLUKA results in term of neutrons and photon fluence are presented.

INTRODUCTION

The European Spallation Source European Research Infrastructure Consortium ESS-ERIC is a joint European organization committed to constructing and operating the first long-pulse neutron spallation source in the world. The facility started its construction in summer 2014 and it is composed of a linear accelerator in which protons are accelerated and collide with a rotating helium-cooled tungsten target. The first beam at 572 MeV on target is foreseen for June 2019 and the nominal average linac beam power of 5 MW will be reached for 2023 [1,2].

ESS LINAC

The ESS linac accelerates 62.5 mA of protons up to 2 GeV in a sequence of normal conducting and superconducting accelerating structures.

In details the normal conducting part starts with the Microwave Discharge Ion Source that produces a proton beam transported through the Low Energy Beam Transport (LEBT) section to the Radio Frequency Quadrupole (RFQ). The RFQ accelerates, focuses and bunches the continuous 75 keV beam up to 3.6 MeV. It is followed by the Medium Energy Beam Transport (MEBT) system where beam characteristics are diagnosed and optimized for further acceleration in the Drift Tube Linac (DTL) section. The Superconducting linac follows the DTLs: 26 Double-Spoke, 36 Medium Beta and 84 High Beta cavities in cascade accelerate the beam up to 2 GeV. Finally, in the High Energy Beam Transport section, the beam is rastered on the tungsten target, using an active fast magnet beam delivery system.

One of the target characteristics of ESS linac is its high availability per year (95%) as following the facility users program main requirements [3]. As a consequence, a limit of 1 W/m in beam losses for the entire linac was set as design parameter in order to allow the required hands-on maintenances. This restriction means that the relative amount of losses that can be accepted are in the range of 10^{-4}:10^{-7} per meter, with respect to the beam energy where the losses happen [4].

DTL SECTION

The DTL section is where the normal conducting structure ends. It is composed of 5 tanks, each more than 7 m long. They will be installed in the first part of the ESS linac tunnel, starting about 20 cm inside the Front End Building, where the Ion Source, the LEBT, the RFQ and MEBT will be located.

Exactly the DTLs accelerate protons from 3.62 MeV up to 86.5 MeV. The five tanks are independently powered by a 2.8 MW klystron each. Permanent Magnet Quadrupoles (PMQ) in every second drift tube provide the transverse focusing. Steerers and Beam Position Monitors (BPM) are spread out in some of the empty drift tubes to correct and measure the trajectory.

The DTL is being designed and built by the INFN-LNL, Legnaro, Italy [5].

FLUKA CALCULATIONS

The FLUKA Monte Carlo code [6,7] is used for the evaluation of the prompt radiation around the DTLs, assuming 1 W/m proton losses uniformly distributed along the DTL section, taking into account the different beam energies. As a conservative approach the emission angle is set to 3 mrad with respect to the beam direction.

In order to provide realistic results, detailed FLUKA models of the five DTLs were developed. In particular each drift tube was modelled separately and their lengths were set with respect to the last version of the ESS optics design (see Fig. 1) [8].

The DTL models were then integrated in an updated version of the FLUKA geometry of the ESS accelerator [9]. The updated FLUKA linac model can be used to support integration and operation of the machine as well as to compare results from MCNPX code (used for the low energy part until DTLs [10]) or from MARS code (used for the high energy part [11] starting from DTLs), if needed.

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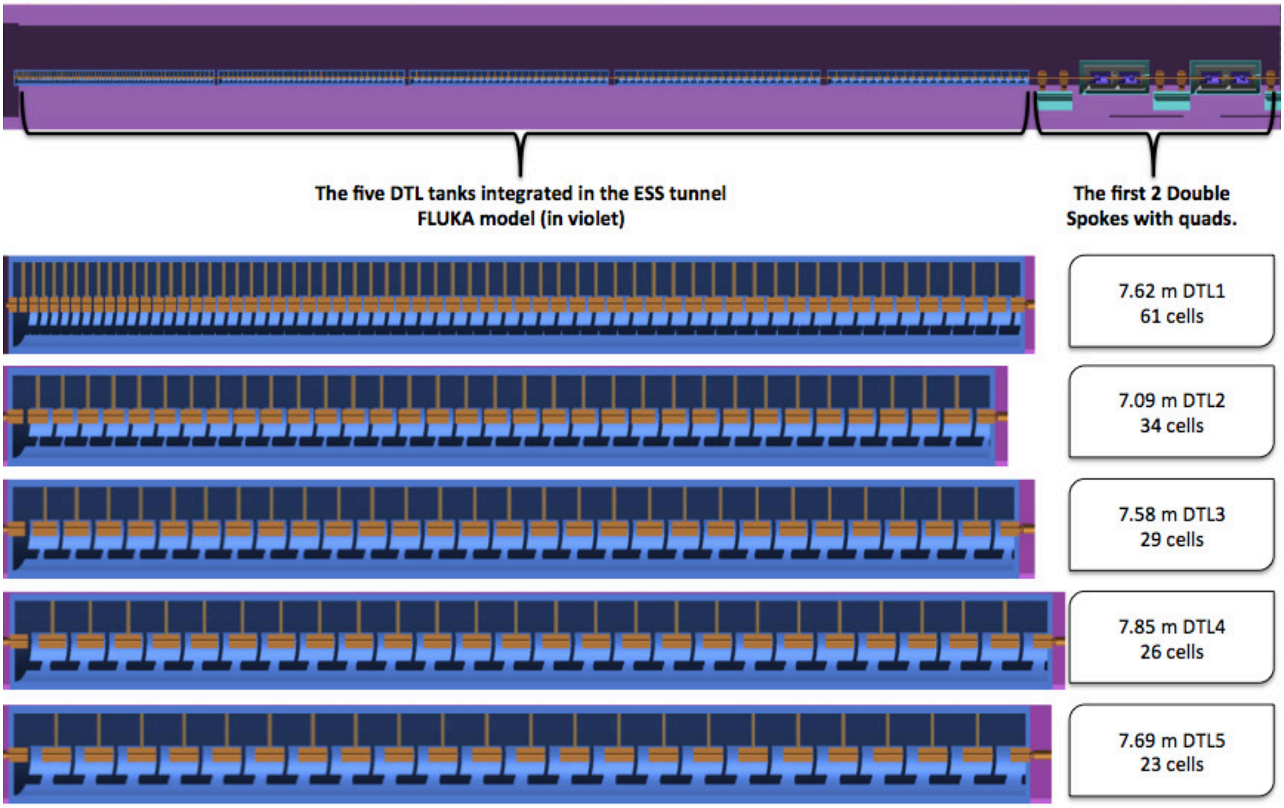

Figure 1: FLUKA model of the DTLs cells in copper. The beam is moving from DTLs to Spokes section. Two of the 13 double-spoke cryo-modules and two of the 12 warm pulsed quadrupoles doublets in between the spokes were also taken into account in the simulations. The purpose of including these additional beam elements is to check the present results with past calculations [9].

FLUKA RESULTS

The area covered in this study is in the range of beam energy from 3.62 MeV to 106 MeV. In details, 3.62 MeV is the RFQ exit beam energy, while 106 MeV is the beam exit energy from the second double-spoke cryo-module, with respect to the beam direction (see Fig. 1). Results are normalized to the total power of protons lost along the length of the beam line simulated i.e. 48.45 m. Assuming constant power loss, the average energy of the proton lost in the section is about 32 MeV.

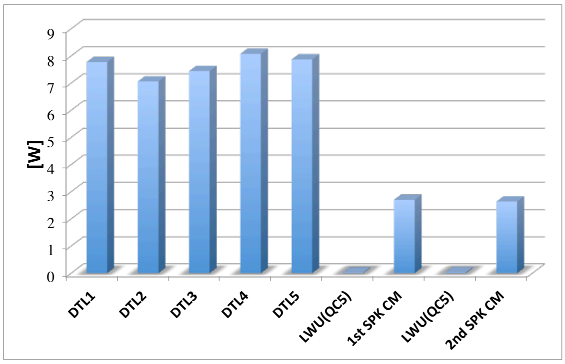

Figure 2: Integrated power on beam elements. Statistical errors are less than 1%.

A comparison between results in figure 2 and those in figure 4 in reference [9] shows that the power absorbed in the DTL is higher than the power deposited on each ESS cryo-module of the superconducting part of the linac. Moreover, the power deposited on the first downstream spoke cryo-modules get increased as a consequence of the particle shower developed in the DTLs.

Outside the DTLs, neutrons dominate, while the other particles produced through beam interactions with DTL cells are mainly adsorbed inside these beam elements (see Fig. 3). This absorbing effect makes the area external to the DTLs section the least hot one surrounding the ESS accelerator line (results are in line with those from MARS15 for prompt radiation presented in [11]).

However this promising scenario can still be an issue for location of electronics, in particular during the stages of DTL beam commissioning [12], where the devices could be temporary or not installed in the final possible shielded location. Three different types of radiation damages can potentially occur: displacement damage, damage from Total Ionization Dose (TID) and so-called Single Event Effects (SEEs). The first two have a cumulative nature and the device failure can be predicted evaluating the damage coming from dose deposition or from atom displacements inside the crystalline lattice, generally quantified through accumulated 1 MeV neutron equivalent fluence. On the other hand the SEEs has a stochastic nature and the perturbation of the device operation can be only characterised in terms of probability to occur as a function of accumulated High Energy Hadron Fluence and intermediate energy neutrons, relevant for the case under study (i.e. the so-called high-energy hadron equivalent fluence).

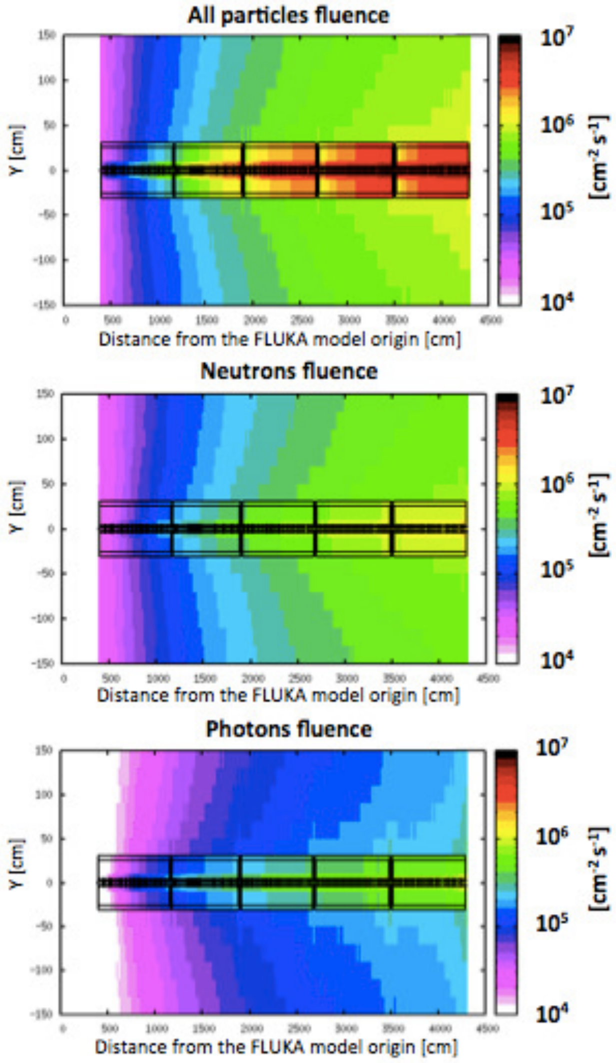

Figure 3: Fluences of neutrons (central plot) and photons (bottom plot) are compared to the fluence of all particles (top plot) outside the five DTL tanks. Beam direction from left to right. Binning used for scoring 20x20x20 cm.

Figure 4 shows the results for dose, 1 MeV equivalent neutrons fluence and high-energy hadrons (mostly neutrons) fluence for the scenario under study at the height of beam pipe. If proton losses are close to 1 W/m and constant for a timeframe of the order of few months, (such as during some beam commissioning stages [12]), commercial electronics could fail. In particular this could happen if they are installed too close to the DTLs at the beam pipe level and in particular close to the end of the fourth DTL tank [13]. In addition to the possible failure events, it has to be pointed out that activation issue could make complex the substitution of the devices or require some long radiation cooling time. The dose and fluence maps in figure 4 can be used as guideline for reducing the risk of electronics failures during beam commission and operation in the DTL section.

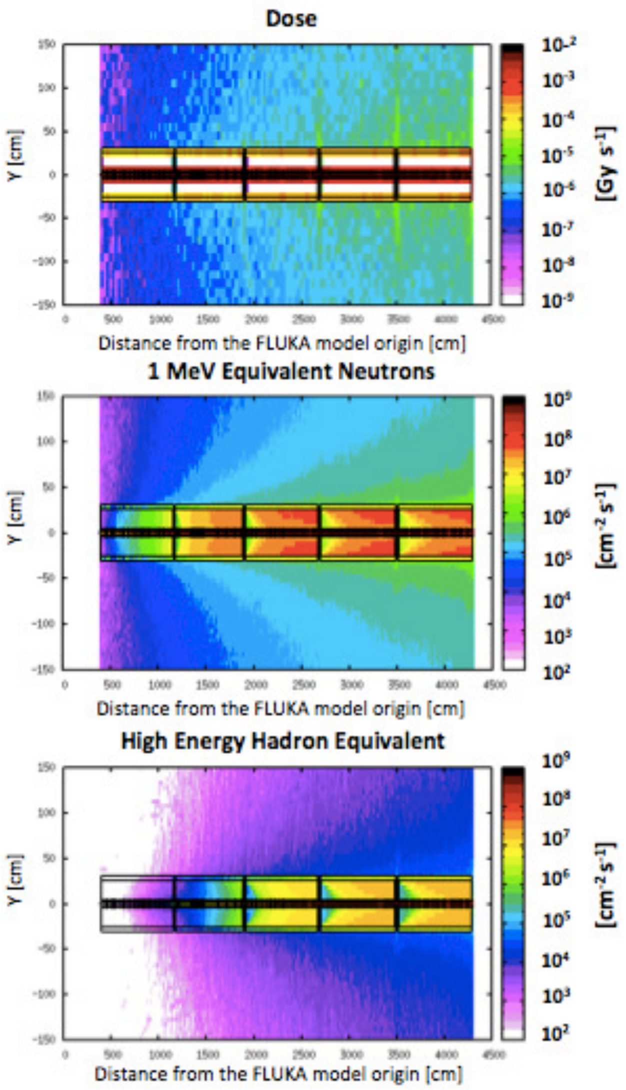

Figure 4: FLUKA maps for dose, 1 MeV equivalent neutrons and high-energy hadrons equivalent at the height of the beam pipe along the DTLs. The analysis of transverse cuts indicates a circular symmetry. Different scoring binnings are shown: 5x5x5 cm for fluences plot, 5x10x10 cm for dose.

CONCLUSIONS

The results presented in this paper don't take into account the effect of the magnetic field in every DTL second drift tube on primary and secondary charged particles. Moreover, the possible contribution coming from the RFQ upstream is not evaluated in the study. However, these effects are expected not to be important. On the other hand, the conservative approach for the loss amount can help in reducing risks of downtime during beam commissioning and operation.

In particular, optimising the electronics installation and minimising the loss rate are two key factors to have a successful DTL beam commissioning and to achieve the June 2019 milestone of first ESS beam on target.

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