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ESS TARGET PERFORMANCE FOR DIFFERENT BEAM PULSES

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and

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ABSTRACT

Last trends in the design of linear accelerators for high power spallation sources point to the use of ion beams of larger energies and shorter pulse lengths in order to enhance the reliability of the system. In this sense the recommendations for ESS are to increase the energy of the proton beam from 1.3GeV to 2-2.5GeV and to reduce the length of the beam pulse from 2ms to 1-1.5ms, keeping the source average power at 5MW. Different values for the repetition rate are also being discussed (16 2/3, 20, 25 Hz). ESS Bilbao is analyzing the impact of these modifications on the design of the target system. In this paper the effects of the different beam energies on the target disc thermohydraulics and the neutron performance of the source are discussed.

Initial calculations were performed for a rotating target with ESS 2002 parameters. During the development of the work –that are being performed in collaboration with SNS– the decision was made to use the SNS-STS Target-Moderator-Reflector Assembly (TMRA) –slightly modified to accommodate the target design being studied for ESS– which presents a state of the art design with a cylindrical liquid para-hydrogen moderator in wing configuration aimed to enhance cold neutron production.

1. Introduction

The 2002 ESS Project [] baseline design presented a (2x)5MW Spallation Source with a proton beam of 1.3GeV in pulses of 2ms with a 16 2/3 repetition rate. Currently its design is being updated in order to take advantage of the latest advances in the underlying technologies –in particular in linear accelerators– and the experience gained at SNS and JSNS. In this context, some parameters of the beam are being reviewed with the aim of enhancing the reliability of the accelerator. An increase in the beam energy from 1.3GeV to 2-2.5GeV is claimed because of the benefits of working with a lower average current [].

In this paper the effects of working with a higher energy proton beam on the target system are examined. Target thermohydraulic calculations and neutron performance evaluation for 1.3-2-2.5 and 3 GeV beams are presented in sections 2 and 3 respectively. The analyses were conducted on a 1.5m diameter tungsten rotating target with a cylindrical liquid para-hydrogen moderator in wing configuration. Impacts on other aspects, such as decay heat, are briefly discussed in Section 4.

2. Target Disc Thermohydraulic Design

The cooling of a 1.5m tungsten disc for a 5MW long pulse proton beam for 4 different beam energy values (1.3, 2, 2.5 and 3 GeV) has been analysed. A double Gaussian profile was considered for calculations instead of the parabolic shape defined in the ESS 2002 baseline profile, with the same 200x60mm footprint. A 30rpm rotation period has been set in order to minimize peak radiation damage, which also provides for a 2s period between two consecutive hits on the same disc location.

Power deposition along the target follows the double Gaussian shape of the beam profile, and reaches over the 60% of the proton beam energy. For 5MW source power, peak deposition values vary from 4.8kW/cm^3 to 3.5kW/cm^3 for a range of proton energies from 1.3 to 3.0 GeV (Table I).

Table I. Peak deposition for different proton beam energies (5MW total power)

Energy [GeV]	1.3	2.0	2.5	3.0
Deposition peak [kW/cm3]	4.8	3.9	3.6	3.5

The evolution along the target depth is shown in the next figure (Figure 1):

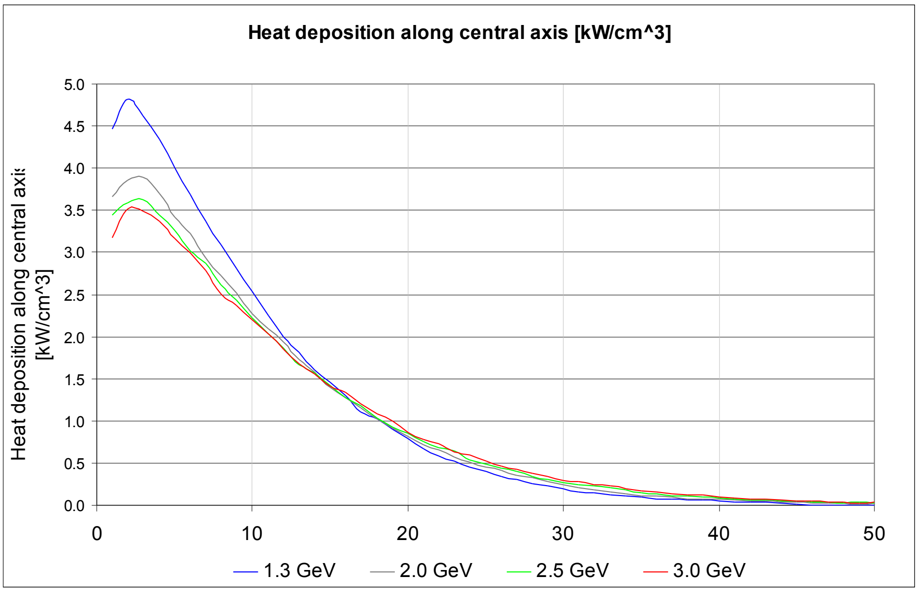

Figure 1. Heat deposition along target depth for different proton energies.

Two different scenarios for the design of the disc have been considered. One is the cold-plate configuration in which uncladded tungsten bricks are cooled at both ends through Aluminium cold plates. The main virtues of this concept are that the target material density can be maximized, the amount of irradiated cooling water is minimized and no cladding is required to prevent tungsten corrosion due to contact with water. The second one, on the opposite side, is a cross-flow cooling scheme, in which cooling efficiency is fostered over other aspects. In order to assess both cooling concepts temperatures and thermal stresses on 20mm diameter rods under normal operating conditions have been calculated, although in the case of the cold-plates configuration brick shaped tungsten elements are best fitted in order to maximize the density of the disc [3].

The general purpose Finite Element code ABAQUS [] has been used for the thermomechanical calculations. Tungsten properties evolution with temperature has been considered [].

As a consequence of the previously shown peak heat deposition reduction, peak temperatures and thermal stresses on the tungsten elements are also reduced for an increase in the proton beam energy. In the case of the cold-plate configuration with 3mm thick $AlMg_3$ plates cooled with 42l/s of water with an average sink temperature of 50ºC, maximum temperatures achieved in the central section of the target vary from 755.5ºC for 1.3GeV protons down to 547.1 for 3.0GeV. Thermal stresses reduce accordingly from 62.6 to 40.2 MPa (Table II).

Table II. Temperatures & stress in W for different proton beam energies. Coldplates.

Energy [GeV]	1.3	2.0	2.5	3.0
Maximum temperature in W [º]	755.5	606.1	563.5	547.1
Maximum stress in W [MPa]	62.6	46.2	41.9	40.2

In the cross-flow configuration the effect of larger beam energies is less significant, as the cooling power of this scheme is higher. For 20mm rods with 1.4mm separation between them and 1mm tantalum cladding thermal effect the variation in the maximum temperatures goes from about 166.4 to 135.2 ºC. Thermal stresses reduce from 48.5 to 35.3MPa, as shown in Table III:

Table III. Temperatures & stress in W for different proton beam energies. Crossflow.

Energy [GeV]	1.3	2.0	2.5	3.0
Maximum temperature in W [º]	166.4	144.2	137.7	135.2
Maximum stress in W [MPa]	48.5	39.1	36.4	35.3

The temperatures at rod surface vary from 133.5 to 111.1ºC. Coolant pressure could be adjusted accordingly in order to avoid water boiling.

3. Neutron Performance Evaluation Neutron Performance for cylidrical moderators

Final goal for target station is the production of cold neutrons on experimental lines, so this should be consider as main parameter in our optimization studies. Figure 2 shows MCNPX[] geometrical model developed for the performance calculations. Both cylindrical parahydrogen moderators based on SNS-STS design [] and ESS 2003 design-like [] box shape moderators have been studied, but only the results for the first ones is included in this document for the sake of brevity, since main conclusions are very similar for both cases.

The geometrical model reproduces all the rotating target-moderator-reflector systems, including tungsten target irself, cooling pipes (in orange), structural steel elements (light blue), bearings, seals and drive. The parahydrogen (at 20 k) moderator and the light water premoderator are enclosed in a cylindrical reflector. Both beryllium and lead have been considered for reflector material. In this paper the results for the beryllium reflector are shown. Several structural materials as moderator cladding made of $AlMg_3$ alloy have been also included in the model. Three experimental lines with 120 cm^2 of moderator surface view have been considered. In order to improve the statistics in time distribution calculations of the neutron brightness on moderator surface time-of-flight corrected point detectors have been used.

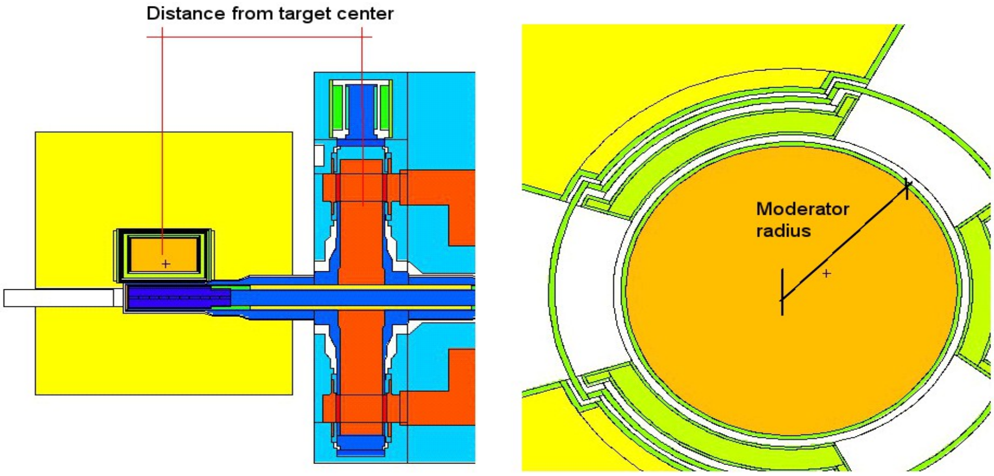

Figure 2. MCNPX model view.

For the optimization process cold neutron flux has been considered (neutrons on moderator surface below 5 meV) as the effective neutron production goal. A parametric optimization of the cylindrical moderator radius and relative position to the target edge has been performed for each proton energy in consideration.

Figure 3 shows the evolution of neutron performance resultant in the optimization procceses for the parameters mentioned above. As it can be seen, the relative position has to be adjusted when increasing proton energy. Moderator radius is less sensible to this increase.

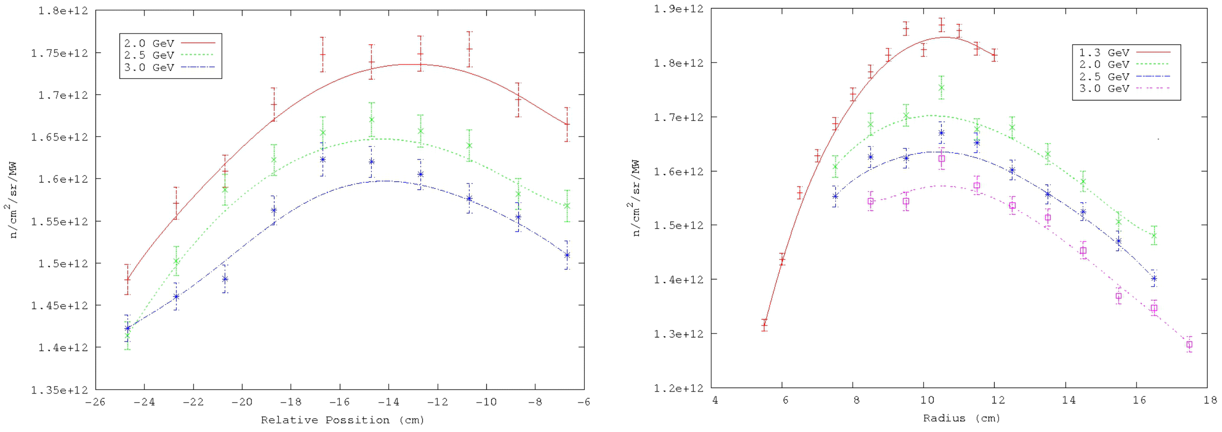

Figure 3. Cylindrical moderador geometry optimization curves for relative position and radius.

Figure 4 shows the time averaged energy espectra obtained from the simulations. Highest fluxes per MW in both cold and thermal range are obtained for 1.3 GeV given the arrangement described before.

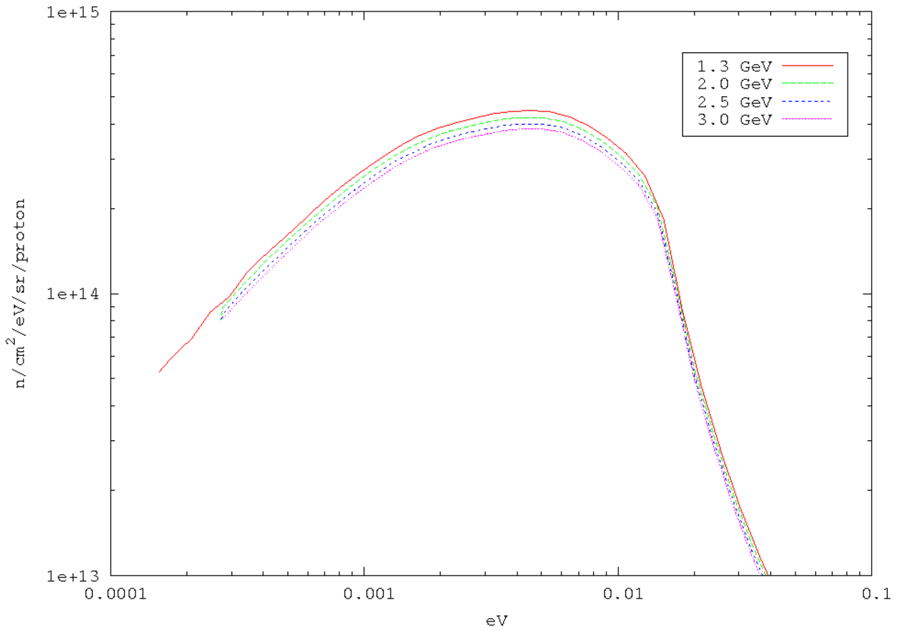

Figure 4. Neutron energy spectra on moderator surface

Figure 5 and Figure 6 show neutron time distribution for 5 and 10 meV energy bins. Increasing proton energy leads to an increase in the generation volume, in detriment of the efficiency of the moderator. This effect could be higher for other moderator materials such as methane, as in that case smaller volumes are used.

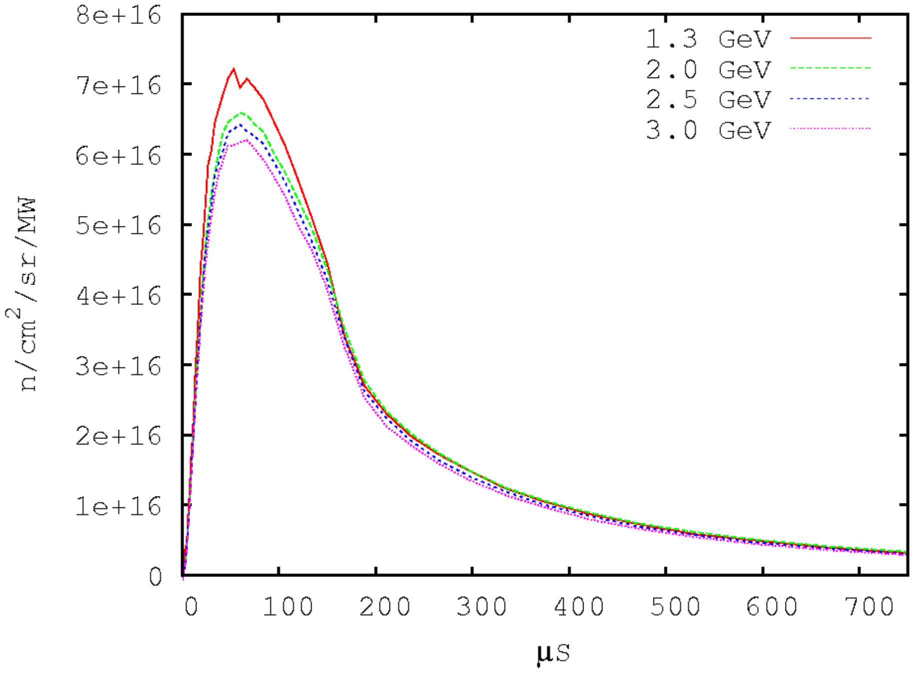

Figure 5. Pulse shape for 10meV neutrons.

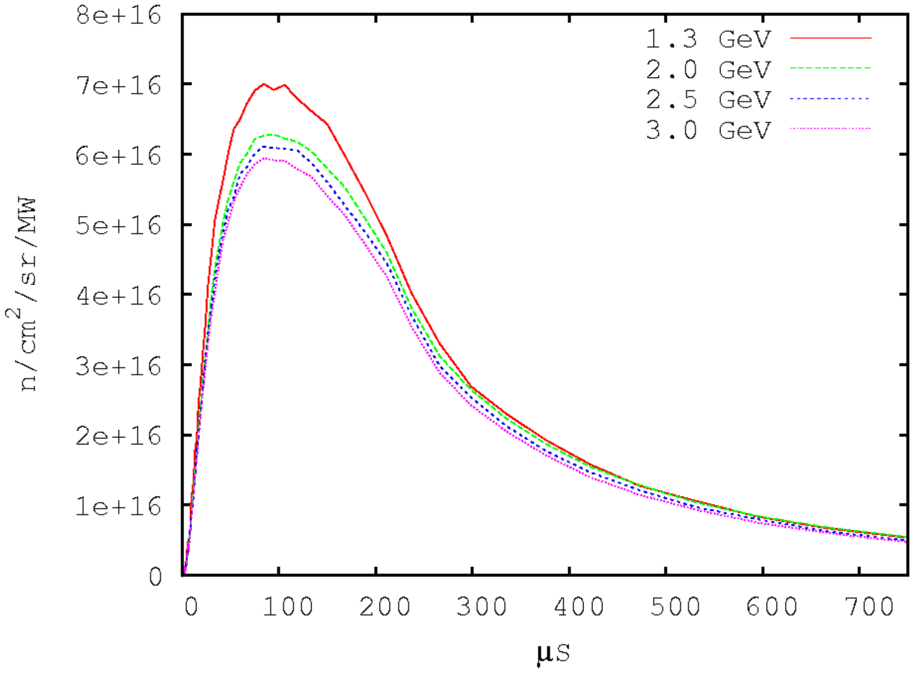

Figure 6. Pulse shape for 5meV neutrons.

These results suggest that the increase of the proton energy does not lead to an increase of the neutron source effectiveness when using cylindrical parahydrogen moderators or even smaller volume moderator materials. Table IV show the intensity values for each proton energy which would be equivalent according to several calculation criteria.

Table IV. *Beam intensity equivalent on each neutron energy consideration*

Energy [MeV]	Equivalent Beam Power [mA]	Equivalent cold neutrons source (time integrated)	Equivalent neutron peak of 10 meV enegy	Equivalent neutron peak of 5 meV energy
1300	3,75	3,75	3,75	3,75
2000	2,44	2,63	2,47	2,39
2500	1,95	2,12	2,16	2,19
3000	1,63	1,79	1,82	1,82

4. Other Expected Effects

Increasing proton energy will also affect generation of residual nuclei and therefore modify the amount of residual heat in the system. Table V shows activity and residual heat estimated by ACAB code [] considering residual nuclei generation from MCNPX nuclear models and also neutron flux bellow 55 MeV. ACAB code uses EAF-2007[] activation data librarys. Increasing proton energy residual heat will be reduced and it will produce less severe accidental conditions.

Table V. *Decay heat*

Energy [MeV]	Activity [bq/mA]	Residual heat [W/mA]	Total residual heat [kW]	Total activity [bq]
1300	9.51E+016	10117.67	37941.25	3.57+017
2000	1.38E+017	14079.79	34319.48	3.37E+017
2500	1.63E+017	16276.69	31739.55	3.17E+017
3000	1.89E+017	18821.71	30585.28	3.06E+017

Another element that could also profit from an increase on the beam energy is the proton beam window, for which a longer lifetime may be expected due to the reduction on the beam intensity.

5. Concluding Remarks

In terms of the target design an increase of the proton beam energy in the range that is being discussed has some positive effects such as a reduction on the target material and thermal stresses, as well as a reduction on activation and decay heat. These reductions are probably not so significant as to drive the general design of the system, but may turn the balance in some particular decisions. Other pros of an increase in the energy should be further assessed, such as an enhance lifetime of the proton beam window.

On the other hand, the increase of the proton energy leads to a reduction of the neutron source efficiency due to the higher volume source distribution. In a first estimation this effect will be in the range of 10-20 % for the liquid para-hydrogen cylindrical moderators, so it should be considered when going to higher proton energy spallation sources. Nevertheless, this effect is expected to be less significant for higher volume moderators such as $D_2$0. Therefore, the evolution of the performance should be analyzed for each particular configuration of moderator reflector assembly.

6. References

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