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POWER UPGRADE STUDIES FOR THE ISIS-TS1 SPALLATION TARGET

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Abstract

ISIS is one of the world's most powerful spallation neutron sources for the study of material structures and dynamics. Currently ISIS has two spallation targets, TS1 operating at proton beam powers of up to 200 kW, and TS2 operating to 45 kW. This paper focuses upon an upgrade study of TS1 with the goal of increasing the ultimate operating power to 1 MW and beyond. During this study we have taken into consideration the necessity of maintaining the spallation neutron pulse width at current values. The increased heat deposition was monitored and the target plates dimensions were modified to take this into account.

THE ISIS-TS1 TARGET STATION

ISIS [1] is currently the world's most productive spallation neutron source. However, the increasing demand for neutron production has motivated the upgrade of the production target TS-1 as well as the built of a second target station TS-2. The ISIS accelerator has been upgraded to achieve the increased beam intensity necessary to provide a 10 pps proton beam to TS-2 at the same time as maintaining present intensity to TS-1 where the repetition rate is reduced from 50 pps to 40 pps. The ISIS TS-1 target is driven by a 50 Hz, 800 MeV, 200 µA proton beam equivalent to almost 0.2 MW beam power. It consists of 12 solid W plates (105 × 80 mm) of different thicknesses (from 11 to 46 mm) enclosed in a stainless steel pressure vessel (Fig. 1). Each W plate is cladded in a 2 mm thick Ta layer. There are 2 mm gaps between the plates used for cooling the target with heavy water. The flow of heavy water is redistributed using stainless steel manifolds.

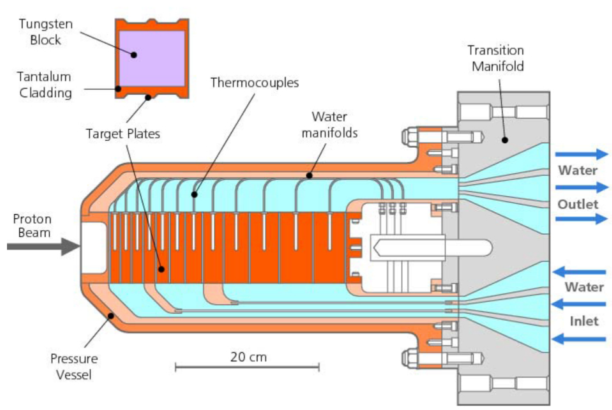

Figure 1: Layout of the ISIS-TS1 spallation target.

Based on a set of engineering drawings, the ISIS-TS1 target geometry was implemented into the Geant4 Monte Carlo code [2], and Fig. 2 shows the modelling of the target and all the surrounding components . Four neutron moderators are used to thermalize the neutrons: two water moderators (blue), one liquid methane moderator (green) and one liquid hydrogen (yellow). The liquid methane moderator has curved surfaces unlike the others. The target and the moderators are embedded in a beryllium reflector (shown in grey). Also the neutron beamlines are shown (lower right) which leads the neutrons to the experimental stations.

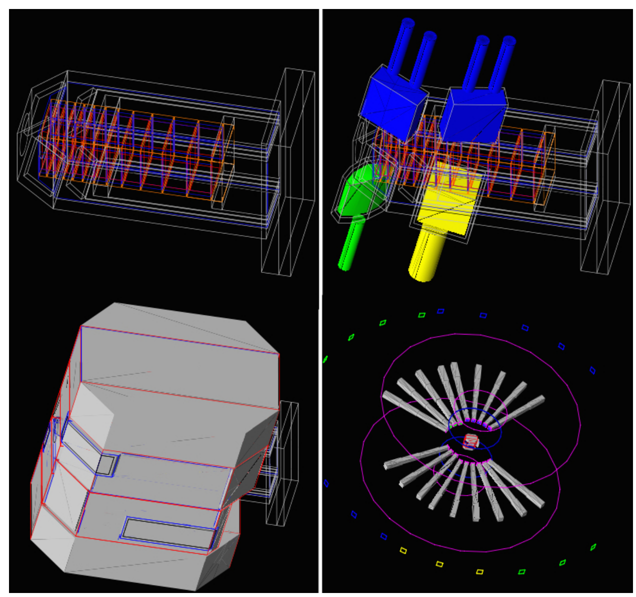

Figure 2: GEANT4 modelling of the ISIS-TS1 target (upper left), neutron moderators (upper right), reflector (lower left), shielding and instruments channels (lower right).

Heat Deposition Inside the Target

The heat deposition rates for the tungsten plates and the tantalum cladding are proportional to the beam current. Considering a beam current of 200 µA, the total heat rate deposition is shown in Fig. 3 for the inner tungsten volume and in Fig. 4 for the outer tantalum cladding. The axial distributions of the volumetric heat deposition rates on the various target plates were calculated and the results are shown in Fig. 5 for the first nine target plates.

The heat deposition rates have peaks around the centre of the target plates. The maximum value is about 0.5 W/mm^3 (the bin size is 57.6 mm^3) for a 200 µA beam. These values will be used as reference values for this power upgrade study.

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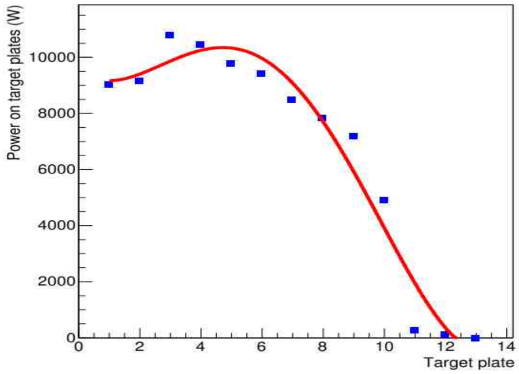

Figure 3: Total heat rate deposition onto the tungsten plates.

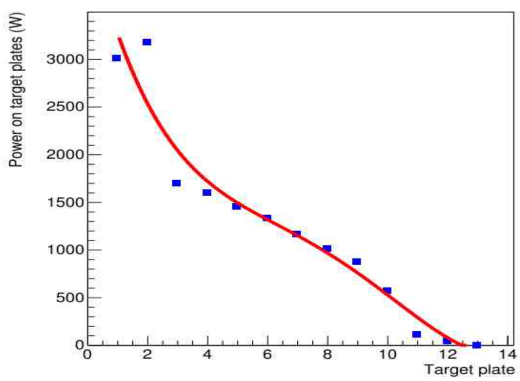

Figure 4: Total heat rate deposition inside the target plates tantalum cladding.

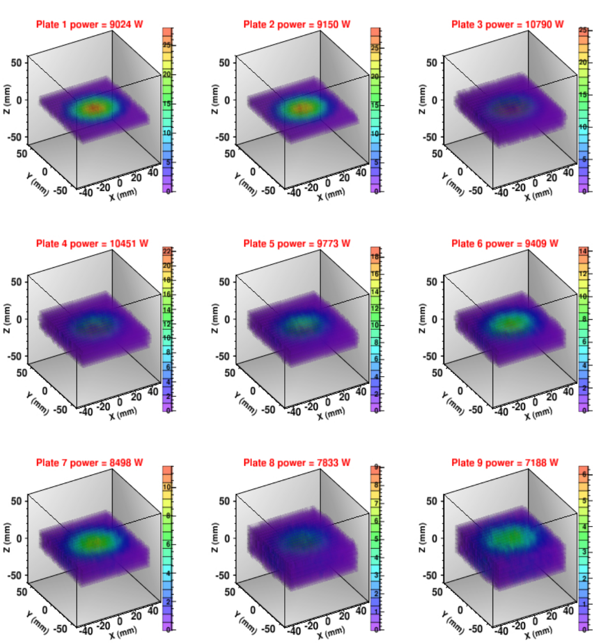

Figure 5: Power distribution inside the first nine tungsten plates.

In order to keep the fixed solid target design, more thinner plates are required to cope with the increased heat deposition due to the additional power on target. The thickness of the W plate can be reduced all the way down to 5 mm, however the existing 2 mm Ta cladding thickness can only be reduced to 1 mm. The neutron yields energy spectra measured at various instruments pointing to the neutron moderators are shown in Fig. 6. The neutron moderators operate at different temperatures: the two water moderators are at ambient room temperature (300 K), the liquid methane moderator operates at 100 K and the liquid hydrogen moderator at 20 K. The neutron spectra show a strong dependence on the moderator temperature, resulting in an increase in the number of thermal neutrons for lower operating temperatures.

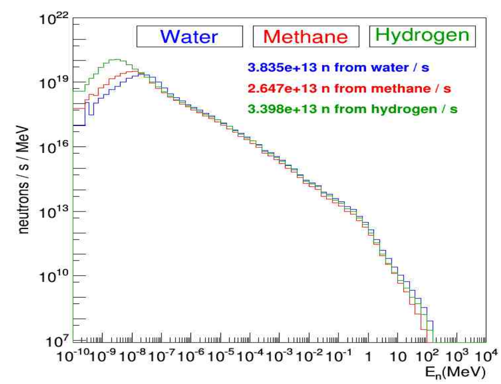

Figure 6: ISIS-TS1 neutron yields for the current target plates design and a proton beam intensity of 200 μA.

POWER UPGRADE TO 0.5 MW AND BEYOND

There are a number of things to consider when redesigning the target plates in oder to cope with the increased proton beam power. The peak values in power on each plate has to be kept at similar values to the current ones. Also the maximum temperature inside the target plates should be much lower than the melting point of the target material. The thermal stress in the target plates should be lower than the yield stress. Finally the water volume inside the target should not be increased too much in order to avoid slowing down the neutrons and altering the neutron pulse time distribution at the instruments.

Various target plates configurations have been simulated, ending up with a new design consisting of 31 plates (instead of the 12 currently present), each plate having 1 mm Ta outer cladding. The plates have an increasing thickness starting from 5 mm for the first 13 plates all the way up to 39.5 mm. Due to the fact that the Ta cladding thickness cannot be reduced to less than 1 mm, the maximum proton beam current for the new target plates configuration is 600 μA, corresponding to 0.5 MW beam power. For higher beam currents the peak heat deposition on the surface of the target plates will exceed too much the current values.

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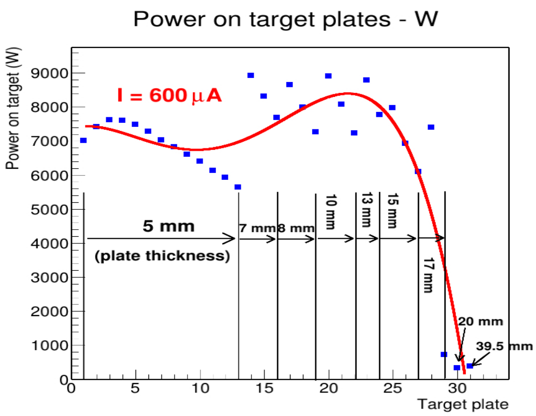

Figure 7: Total heat rate deposition inside the W plates for a proton beam intensity of 600 μA.

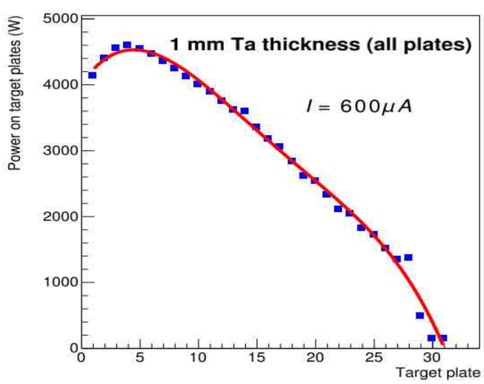

Figure 8: Total heat rate deposition inside the target plates Ta cladding for a proton beam intensity of 600 μA.

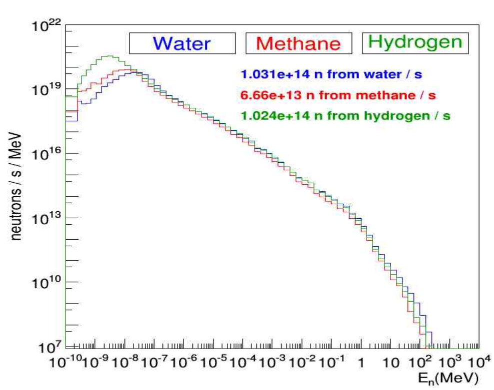

Figure 9: ISIS-TS1 neutron yields for the new thinner target plates design and a proton beam intensity of 600 μA.

The neutron spectra measured at the instruments corresponding to one of the four neutron moderators are shown in Fig. 9 for this new target design. As before, the liquid hydrogen moderator is the most efficient in thermalizing the spallation neutrons produced inside the new target. For a direct comparison between the new target design and the existing one, the neutron yields were plotted for each moderator in the energy range of interest for the neutron instruments. The direct comparison is shown in Fig. 10 and shows that with the new target plates design the neutron yield is approximately three times higher than with the current target design.

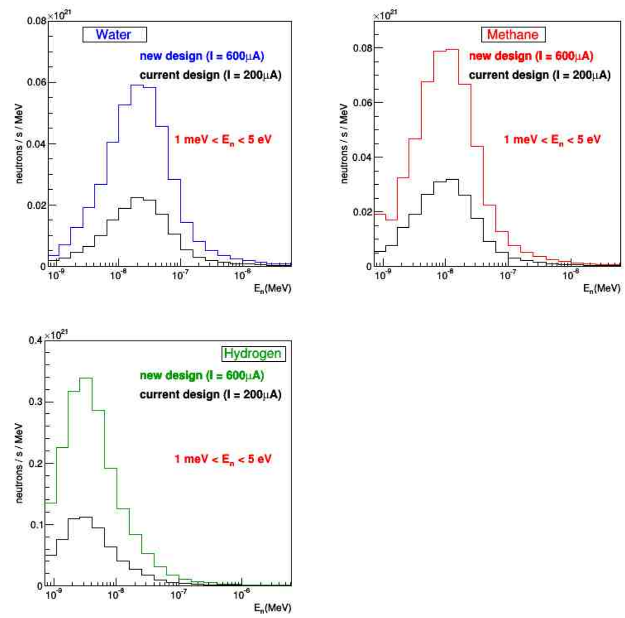

Figure 10: ISIS-TS1 neutron yields comparison between the current design and the new thinner target plates design for the neutron energy range of interest.

CONCLUSION

Increasing the proton beam current from the current value of 200 μA to 600 μA requires using much thinner target plates, which allows the target to cope with the additional proton beam power. Several target plates configurations have been simulated and an optimum design is proposed. The neutron yield increases by a factor of three compared to the current target design. Any further increase in the beam power will result in a much higher thermal stress in the Ta cladding of the target plates. A completely new design involving either a rotating solid target or a molten metal target will be required for a proton beam power above 0.5 MW.

REFERENCES

[1] ISIS neutron spallation source, UK: http://www.isis.stfc.ac.uk

[2] GEANT4 Monte Carlo code (version geant4.9.6.p03): http://geant4.cern.ch