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Bungau, Cristian, Bungau, Adriana, Cywinski, R., Edgecock, Thomas R., Booth, Christopher N. and Zang, Lei

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5MW POWER UPGRADE STUDIES OF THE ISIS TS1 TARGET

Cristian Bungau, Adriana Bungau, Robert Cywinski, Thomas Robert Edgecock,
University of Huddersfield, Huddersfield, UK
Christopher Neal Booth, Lei Zang, Sheffield University, Sheffield, UK

Abstract

The increasing demand for neutron production at the ISIS neutron spallation source has motivated a study of an upgrade of the production target TS1. This study focuses on a 5 MW power upgrade and complete redesign of the ISIS TS1 spallation target, reflector and neutron moderators. The optimisation of the target-moderator arrangement was done in order to obtain the maximum neutron output per unit input power. In addition, at each step of this optimisation study, the heat load and thermal stresses were calculated to ensure the target can sustain the increase in the beam power.

INTRODUCTION

ISIS [1] is currently the world's most productive spallation neutron source hosting two target stations TS1 and TS2. The TS1 target station operates at proton beam powers of up to 200 kW. The goal of this study is to find the maximum beam power the TS1 target can sustain without changing the existing design concept of using fixed solid W plates. There are many factors that could limit the performance of a high power target therefore the design of such a target presents a major technical challenge in terms of the engineering constraints of heat removal and structural radiation damage while optimising the neutron yield. The ISIS accelerator has been upgraded to achieve the increased beam intensity necessary to provide a 10 pulses per second (pps) proton beam to TS2 at the same time as maintaining present intensity to TS1 where the repetition rate is reduced from 50 pps to 40 pps. The ISIS TS1 target is driven by an 800 MeV, 200 μ A proton beam equivalent to almost 0.2 MW beam power.

THE TS1 TARGET

A schematic diagram of the ISIS target is shown in Fig. 1. It consists of a stack of 12 solid tungsten plates (105×80 mm) of different thicknesses (from 15 to 50 mm) enclosed in a stainless steel pressure vessel which contains heavy water for cooling the plates. Each tungsten plate is cladded in a 2 mm thick tantalum layer in order to avoid water corrosion of bare tungsten. The Ta/W interface must remain in close contact as developing gaps would restrict the coolant flow and create resistance to the heat evacuation generated by the target. The gaps between the plates is 2 mm and is used for cooling the plates with heavy water. The flow of heavy water is redistributed using stainless steel manifolds.

Four moderators are used to slow down fast neutrons escaping from the target to the lower speeds required for neu-

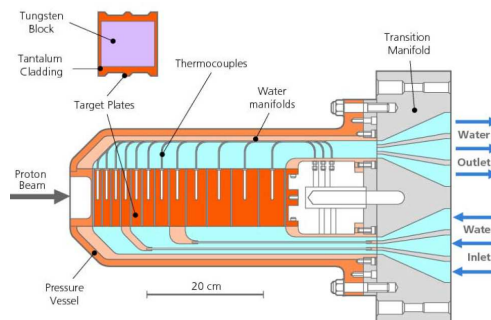


Figure 1: Layout of the ISIS-TS1 spallation target.

tron scattering experiments. Two use water at room temperature, one uses liquid methane at 100 K and the fourth consists of liquid hydrogen at 20 K. The different temperatures result in different energy neutron beams. The moderators are small, about 0.5 l, and are surrounded by a water-cooled beryllium reflector which scatters neutrons back into the moderators and doubles the useful flux of neutrons. Surrounding radially the reflector are the neutron channels which conduct the neutrons to the instruments for neutron scattering applications.

The ISIS TS1 target geometry was implemented into the Geant4 Monte Carlo code [2], and Fig. 2 shows the modelling of the target and the surrounding components. In this figure, the four neutron moderators that are used to thermalise the neutrons are shown in different colours: the two water moderators (blue), the liquid methane moderator (green) and the liquid hydrogen (yellow). 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 liquid methane moderator has curved surfaces unlike the others. The target and the moderators are embedded in a beryllium reflector shown here in grey. Also the neutron beamlines are shown (lower right) which lead the neutrons to the experimental stations.

GEANT4 Versus MCNPX Simulations

The neutron yields energy spectra measured at various instruments pointing to the neutron moderators are shown in Fig. 3. Because the neutron moderators operate at different temperatures 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. This validation study shows an excellent agreement between the GEANT4 and MCNPX predictions for

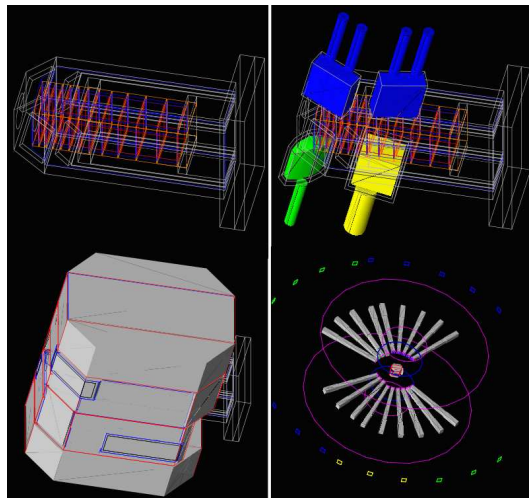


Figure 2: GEANT4 modelling of the ISIS TS1 target (upper left), neutron moderators (upper right), reflector (lower left), shielding and instruments channels (lower right).

the neutron yields measured from the three different types of moderators. The neutrons were recorded at the beamlines entrance since neither GEANT4 nor MCNPX can accurately transport the neutrons through the neutron guides to the instruments situated approximately 10 metres away from the ISIS target.

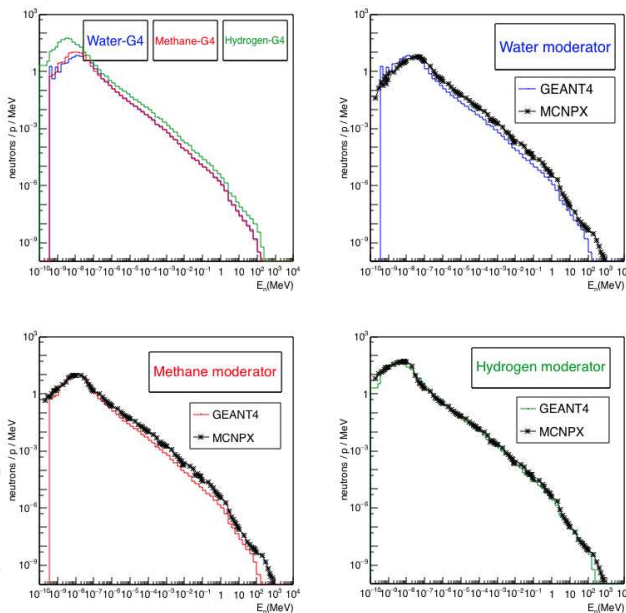


Figure 3: ISIS TS1 neutron yields for the current target plates design and a proton beam intensity of 200 μ A (GEANT4 vs MCNPX).

In a previous study [3] the authors proposed a new design for the TS1 target consisting of 31 tungsten plates (instead of 12), these being much thinner in order to cope with the increased beam power. The dimensions were reduced as

much as it was possible being given the actual plates manufacturing limitations.

Once this new target plates set up was established which, for this fixed solid tungsten plates design, is the one which will allow the target to sustain the maximum proton beam power, the next question was to establish the exact value of this maximum beam power. The criteria was that the thermal stress in these much thinner plates should not exceed the current peak thermal stress values in the current TS1 target plates. For this study the energy deposition output files from the GEANT4 simulations were input into the ANSYS code in order to calculate the temperature rise and the thermal stress values.

ANSYS Analysis of the Thermal Stress

Figures 4 and 5 show the temperature distribution for 12 plates design under a beam power of 0.2 MW and 31 plates design under 1 MW respectively.

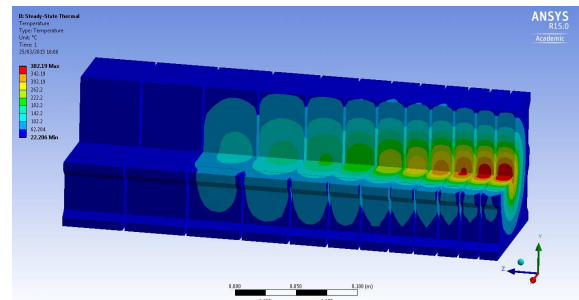


Figure 4: Temperature distribution for the ISIS TS1 12 plates design under a beam power of 0.2 MW.

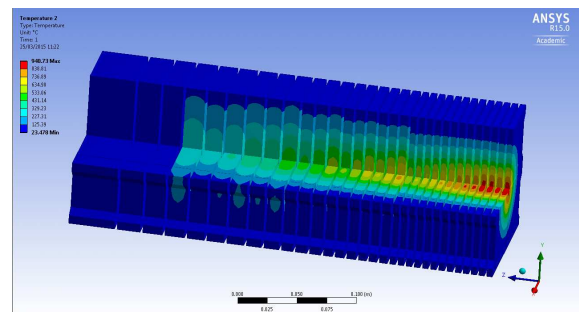


Figure 5: Temperature distribution for the proposed 31 thinner plates design under a beam power of 1.0 MW.

In these calculations the cooling water was assumed to be constantly at 22 degrees Celsius and the heat transfer coefficient between the target and the cooling water to be 6000 W/m²/C, which could be considered as turbulent.

Figures 6 and 7 show the equivalent (von-Mises) stress at the centre of the target as a function of z (longitudinal direction) under the same cooling condition of 6000 W/m²/C. As before the beam power is 0.2 MW for the 12 plates design and 1 MW for the new 31 plates design.

In Fig. 8 the data for the film coefficient scan and beam power scan has been included. From these studies one can

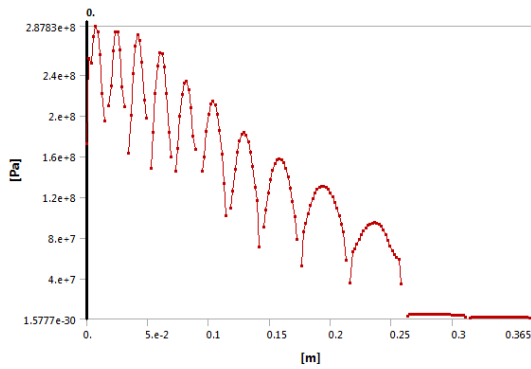


Figure 6: Thermal stress (Von Mises) at the centre of the target as a function of z (beam direction) for the 12 plates design.

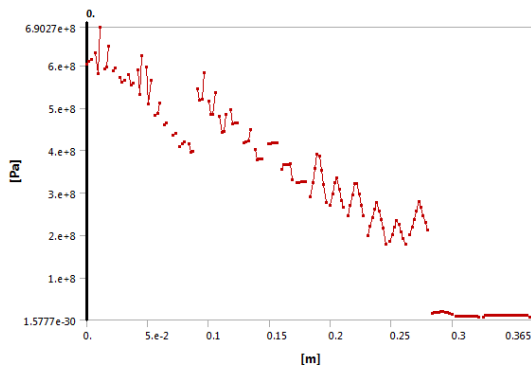


Figure 7: Thermal stress (Von Mises) at the centre of the target as a function of z (beam direction) for the new 31 plates design.

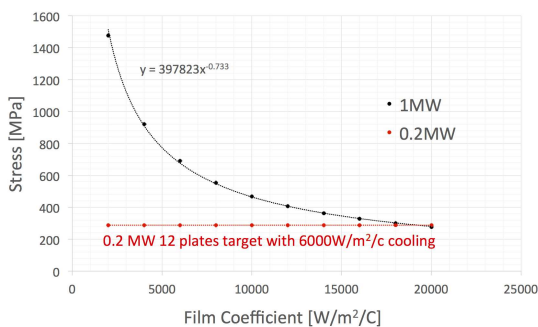


Figure 8: Thermal stress at the centre of the target as a function of the film coefficient.

conclude that the 31 plates target could only cope with 0.4 MW beam without modifying the cooling system. Alternatively the cooling efficiency should be increased to more than 3 times the current design value (from 6000 W/m²/C to 20,000 W/m²/C) in order to sustain a 1 MW beam power.

A preselection cut was applied to select only those neutrons which enter the beamlines and which had their final

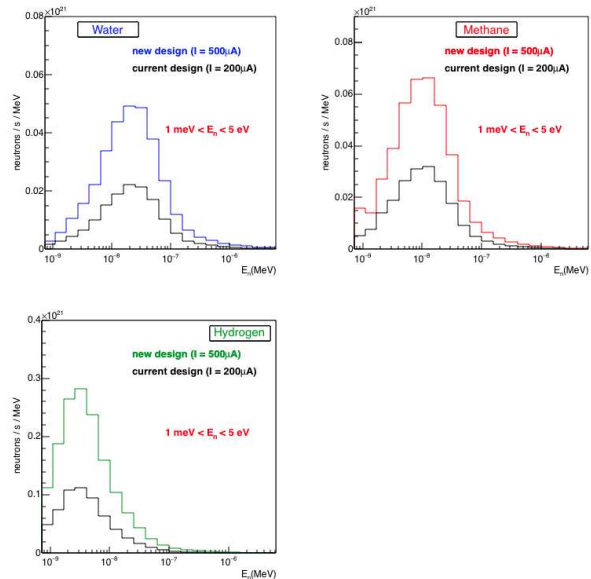


Figure 9: ISIS-TS1 neutron yields comparison between the current design and the new thinner target plates design for the neutron energy range of interest.

interaction inside one of the neutron moderators in order to eliminate the neutron background. For a direct comparison between the new target design (0.4 MW) and the current TS1 target (0.16 MW), the neutron yields were plotted for each moderator type in the energy range of interest for the neutron instruments. The direct comparison is shown in Fig. 9 and shows that with the new target plates design the neutron yield is almost three times higher than with the current target design.

CONCLUSION

This study has shown that using the thinnest possible tungsten plates that can be manufactured for the fixed solid target plates design, it is not possible to exceed a beam power of 0.4 MW with the current water cooling efficiency. A new target design corresponding to 31 thinner tungsten plates was proposed and, for a beam power of 0.4 MW, this resulted in an increase by almost a factor of 3 in the neutron yields whilst not exceeding the thermal stress values in the current TS1 target. Any beam power above 0.4 MW will require either a molten heavy metal target, or a rotating solid target, all these options being considered at present.

REFERENCES

- [1] ISIS neutron spallation source, UK: <http://www.isis.stfc.ac.uk>
- [2] GEANT4 Monte Carlo code (version geant4.10.0): <http://geant4.cern.ch>
- [3] C. Bungau et al., “Power Upgrade Studies for the ISIS TS1 Spallation Target”, THPRI082, *Proceedings of IPAC 2014*, Dresden, Germany (2014).