A tale of two foils: ISIS TS-1 water moderators

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Abstract. Currently there are two, decoupled and poisoned, water moderators at the ISIS Target Station 1 (TS-1), located above the target, operating at room temperature and providing neutrons for the experiments in the fields of spectroscopy, diffraction, etc. In this paper, the details about neutronics model of ISIS Target Station 1, simulation results related to TS-1 water moderators and comparison with corresponding measurement results are presented. The importance of the quality neutronics calculations for planning the upgrade/changes in the target station (as in removal of the poisoning foil in upstream water moderator) and locating the operational issues (disappearance of poisoning foil in downstream water moderator) is discussed.

1. Introduction

The cross-sections of MCNPX [1] model of current ISIS [2] Target Station 1 (TS-1) target, reflector and moderators (TRAM) assembly are shown in Figure 1. The target consists of tantalum cladded tungsten rectangular plates. The target pressure vessel is made of stainless steel and the target coolant is a mixture of heavy water (82%) and light water (18%) [3]. Proton (800 MeV) beam orientation is from the left to right (vertical cut plot), from the bottom upwards (horizontal cut plots). The reflector is made of water-cooled beryllium rods (packing fraction by volume = 90% beryllium : 10% coolant). The reflector coolant is a mixture of heavy water (82%) and light water (18%) [3].

Currently there are four moderators at the TS-1. Below the target there are: coupled liquid hydrogen moderator and poisoned, decoupled liquid methane moderator. Two, identical in size, decoupled and poisoned water moderators operating at room temperature are located above the target (see Figure 1). The upstream water moderator has, asymmetrically positioned, poison layer (foil). The 'active' poison (gadolinium) layer, with thickness of 0.005 cm, is sandwiched between two aluminium layers (total thickness of aluminium layers is 1 mm). The downstream moderator (so-called Merlin) is centrally poisoned with a single gadolinium foil (layer). These two moderators (the main actors in the following story) serve 8 instruments at ISIS Target Station 1 (see Figure 2) and provide neutrons for the experiments in the fields of spectroscopy (MAPS, MERLIN, TOSCA, VESUVIO), diffraction (SXD, POLARIS), etc.

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2. The upstream water moderator
At the beginning of 2016, the design of the upstream water moderator has been changed to what we have now (see Figure 1). The previous ("old") upstream water moderator had two gadolinium poisoning foils, which partitioned the moderator into three approximately equal volumes. Then, the decision has been made to install a new moderator where one (the South side) gadolinium foil is removed to give the corresponding instruments an increase in neutrons flux.

The planned change of design of the TS-1 upstream water moderator was successfully completed in February 2016. The neutronics simulations performed beforehand predicted a factor of 2 increase in neutron intensity for the South side instruments (see Figure 3) and no changes for the North side instruments. The measurements performed in November/December 2015 with old moderator and in April/May 2016 with new moderator confirmed that there are no changes in intensity and pulse time profiles for the North side instruments (POLARIS, TOSCA). All South side instruments, however, measured the gain which is significantly (10 – 20%) higher than expected (see Figure 3).

The reason for such an unusually big difference between experimental and simulation results was not hard to find. Calculations of expected gain factors have been performed assuming two
"perfect" moderators. However, old moderator was not "perfect". It was installed in 2004 and after a first cycle its performance started to deteriorate. Figure 4 shows the sample of the history of neutron flux measurements at MAPS instrument. The loss of neutrons, at the level of 10 – 20%, coming from the (old) water moderator in period between 2004 and 2011 is clearly visible. If we take this into account, the agreement between predicted and measured flux gain is very good. However, the question about the reason(s) for such a change of old water moderator performance is still without the answer. Several possible scenarios have been proposed: from simple one (displacement of the south side poison foil) to very unusual (extraordinarily high production rate of $^{22}\text{Na}$ in moderator can). None of them has been convincing enough so the "mystery" of old water moderator flux loss is still under investigation. In the meantime, it is important to regularly monitor current (new) upstream moderator to see if there is any sign of such a strange behaviour.

3. The downstream water moderator (Merlin)

According to engineering drawings, downstream water moderator (so-called Merlin) is centrally poisoned with a single gadolinium layer (its thickness is 0.005 cm). The ‘active’ poison layer is sandwiched between two aluminium layers. The moderator is surrounded (except the viewing side and top side) with, 0.65 cm thick, boral layers. The original (old) Merlin moderator has been installed in, approximately, same period as the old upstream moderator (in 2004). Before installation, different tests were performed that confirmed that there is a strong neutron absorbing material (gadolinium) inside. Merlin moderator was in the TS-1 TRAM for almost 2 years before the MERLIN instrument [4] was ready for operation. Once the measurements started it was found that time resolution of MERLIN instrument was much broader than originally planned.

Current, very detailed, neutronics model [5, 6] of ISIS Target Station 1 provided the opportunity to investigate this issue. If the poison layer is removed from the model there is an excellent agreement (see Figure 5) between experimental and calculated time resolution$^2$ values [7]. This result was a strong indication that an effective poison layer is not in the moderator.

$^2$ In Figure 5 (and 6) apparently the tail of the pulse of 29 meV neutrons arrives before the ‘main’ pulse. This, at the first sight, ‘unusual’ behaviour can be explained if we keep in mind that the last chopper within the MERLIN instrument acts like a pinhole camera giving ‘inverted’ time-of-flight image.
This assumption has been confirmed in September 2016. New Merlin moderator (where presence of poison foil was experimentally confirmed beforehand) has been installed and measured flux and time profiles clearly show excellent agreement with simulation scenario with poison foil in (see Figure 6). This means that, for whatever reason, there was no poisoning in the old Merlin moderator [8]. On the positive side the MERLIN instrument will now have better line shapes and resolution though the disappearance of the gadolinium needs further investigation. One of possible scenarios is that gadolinium dissolved in water (because of potential issues with welding of the aluminium sandwich around) in the years before MERLIN instrument started up. If this is true it could have serious implications for the design of the water moderators within ISIS TS-1 project.

Figure 5. Simulated and measured time profile of 29 meV neutrons at MERLIN instrument with old (original) moderator.

Figure 6. Simulated and measured time profile of 29 meV neutrons at MERLIN instrument with new moderator.

4. Conclusions
This tale of strange behaviour of ISIS TS-1 water moderators clearly shows the importance of the quality neutronics calculations for planning the upgrade/changes in the target station (as in removal of the poisoning foil in upstream water moderator) and locating the operational issues (disappearance of poisoning foil in downstream water moderator).

References
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