ISIS TS1 Project target – design for manufacture

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Abstract. The planned upgrade for the ISIS Spallation Neutron Source First Target Station requires a complete redesign of the Target, Reflector and Moderator (TRaM) system whilst working within the constraints set by the existing Void Vessel and target station infrastructure. This talk focusses on converting the optimised simulated design for the TS1 project target into a physical reality that will be robust and give a reliable service life equal to or greater than the existing TS1 Target (>5 yrs). ISIS has the advantage of having its own ‘Target Manufacturing Facility’ (TMF). The experience it has gained from manufacturing ISIS current TS1 & TS2 targets has been invaluable in identifying potential manufacturing challenges that must be overcome at the design stage. The Target Design Group (TDG) has worked very closely with the TMF to test design ideas and develop techniques. This has culminated in a target design suitable for manufacture. The target design presented here is a work in progress that has now reached the prototype stage and closely resembles the final product. It is the result of a close collaboration between the Neutronics, Engineering Simulation, Engineering Design and Target Manufacturing Groups. The aim is to deliver a target that can be readily manufactured and is reliable in operation without compromising neutronic efficiency.

1. Background
The ISIS spallation neutron source was officially opened in 1985, operating with one target station (TS1). Whilst the target material has changed from the original depleted uranium to tantalum, in the early 1990’s, and to tungsten clad with tantalum from 2001 to present the overall design of the target has remained unchanged. The addition of a second target station, which opened in 2008, was an opportunity to design a target that was optimised for tungsten clad in tantalum and therefore neutronically more efficient. Other features were incorporated in the Target, Reflector and Moderator (TRaM) design to reduce time needed for regular maintenance tasks and improve remote handling operations.

With ISIS TS1 having been in service for 32 years and TS2 for almost 9 years, the time is right to develop a new Target, Reflector and Moderator for TS1 using modern software and analysis techniques to increase useful neutron output without the need to increase beam power. The proton beam will remain at 200µA, 800MeV energy.

ISIS has a well-established user community and continues to operate reliably so it is critical that any changes to the TRaM don’t compromise the high level of reliability that it currently achieves.
To arrive at a design that is optimised for neutronic performance, whilst being practical to manufacture and will be reliable in operation, has called for a careful balance between the needs of the various stakeholders. As the TS1 Project is restricted to changing the TRaM components only, it is imperative that the new TRaM assembly integrates well with the existing accelerator system and instruments. ISIS Neutronic Group and Engineering Simulation have co-operated to define the physical attributes for the target, such as size and number of target and position within the reflector and moderator. On the practical side the Target Design Group and Target Manufacturing Facility have worked closely to design the components and develop the special techniques and procedures required for manufacture of the target assembly.

**Figure 1.** TS1 Project Target compared to TS1 current design (not to scale)

| Material      | Current TS1 target | TS1 Project target | Reduction |
|---------------|---------------------|--------------------|-----------|
| Stainless Steel | 73.8                | 8.1                | 89.0%     |
| Tantalum      | 32.7                | 6.9                | 79.0%     |
| Tungsten      | 47.3                | 46.0               | 2.8%      |
| Total         | 153.8               | 61.0               | 60.3%     |

2. **Overview of TS1 Project target**

The current target designs in use on TS1 and TS2 are very different from each other. The older TS1 target was originally designed and optimised for depleted uranium. It included a secondary cooling circuit and thick walled stainless steel vessel to satisfy stringent safety requirements. In the 32 years of service history the only major changes to the design have been to replace the target material for tantalum and later to tungsten clad in tantalum. The newer TS2 target design used only tungsten and tantalum which produced a very efficient neutron source. In the case of the TS2 target this was the obvious choice as there is, effectively, only one target plate. As the TS1 Project target will have a stack of 10 target plates things are not so straight forward, so two options were put forward for consideration. Option 1 was for a TS2 style target with only neutron producing materials used in the construction of the target assembly. Water cooling manifolds were tantalum and EB welded to the target stack. Option 2 proposed that the stack of 10 target plates would be contained within a thin walled stainless steel vessel incorporating the cooling water manifolds in the design.

When weighing up the two options (see Figure 2 below) it was concluded that Option 2 was the most viable as it would reduce the time to manufacture whilst eliminating the risks posed from EB welding the tantalum manifolds onto the finished stack of target plates. EB welded joints have proved troublesome in the construction of TS2 targets on a couple of occasions, and although these problems
have been overcome by improvements in weld design and weld procedures a design that minimises the amount of exposed weld is likely to be more robust.

Option 1
- Tungsten/Tantalum (only)

Option 2
- Stainless Steel Outer Vessel

| Option 1 – Tungsten/Tantalum (only) | Option 2 – Stainless Steel Outer Vessel |
|-------------------------------------|----------------------------------------|
| Maximum neutron output              | <5% fewer neutrons                     |
| Higher material costs               | Lower material costs (£50K)            |
| EB welds in tantalum - challenging  | Standard material for EB welding       |
| Risk of water leaks from external EB welds | Less external weld length – less risk |
| Risk to target stack when EB welding manifolds | Target Stack protected in vessel |
| No stainless steel                  | 8 Kg stainless steel only (89% < TS1)  |
| Longer to manufacture               | Stain.St. Vessel mfr in parallel with target plates |

Figure 2. Target option merit chart

3. Design for Manufacture

3.1. Target Core
The Target Core comprises a stack of 10 tungsten plates of varying thickness from 11mm to 143mm, each encased in a protective layer of tantalum cladding. The cladding thickness is 1.5mm. This is 0.5mm thinner than the present TS1 target and 0.5mm thicker than TS2. Decay heat calculations and decay heat temperature measurements from our TS1 target suggest this is an acceptable amount of tantalum and will give a good level of protection to the tungsten core whilst providing a practical thickness for EB welding.

Figure 3. Target plate construction
Moving to a circular profile, from the rectangular profile of the present TS1 target plates has reduced the number of EB welds from 13 to 3. This is seen as a positive step, as it reduces the number of set-ups, but in practice it has been observed that a lot more heat is deposited into the plates during welding due to the length of weld when completing a $360^\circ +$ overlap weld @ 3mm/sec. This can lead to distortion of the plates making it more difficult to align for the next welding stage. To help overcome this problem the material thickness at the weld joint is reduced to 1.2mm ensuring full penetration with a less intense beam.

After HIP and NDT each target plate has location features machined to ensure correct orientation of the plates and positioning of the thermocouple holes. The 10 plates are EB welded together to form a connected stack. The reason for this is to ensure that the plates don’t vibrate against each other in the fast moving cooling water allowing small particles of tantalum to be rubbed off and travel around the cooling system leading to radioactive contamination in the circuit.

The number 10 plate is located and bolted to the ‘Target Spacer Plate’ so that the stainless steel vessel does not have to support the weight of the Target Core. This has the added benefit of simplifying the assembly process, because the vessel remains independent, and will make it possible to remove at end of life for PIE or separation of materials for waste disposal. A thermocouple will be inserted into each target plate to monitor the core temperatures. This is similar to the arrangement for TS1 target, except the thermocouples exit through the vessel. Compression fittings will seal onto the thermocouples, which are a swaged design allowing 3mm diameter to seal onto and reducing to 2mm for insertion into the plates. A similar arrangement has been in operation on TS2 manifold since start-up in 2008 with no leakages.

3.2. Pressure Vessel

Material for the Pressure Vessel will be 316L due to the many years of experience with this grade of stainless steel at ISIS and other synchrotrons plus the abundance of experimental data confirming suitability for use in similar radioactive environments. To reduce the number of external welds it is proposed that the Flange will be machined as an integral part of the vessel with only the Window and thermocouples compression fittings being welded on. The Pressure Vessel cross section is an oval shape which does not lend itself readily to a single pass radial EB weld because of the changing focal point. However, successful development trials at The Welding Institute (TWI) have shown that this is possible and will be our preferred method of construction. The rest of the vessel will be machined using a combination of conventional milling (external profile), Wire EDM (integral water manifolds) & Die sinking (internal water cooling slots).
3.3. Thermocouple Protection

As the thermocouples exit through the Pressure Vessel before being routed along to the Flange, where they are fixed, they are exposed and liable to damage when the Reflector is open and the Moderators are being worked on with the remote manipulators. A simple guarding system has been designed to cover them whilst allowing a partial view of the compression fittings in case a water leak develops. They are also designed to be easily removed, with the target still in position, should any access to the thermocouples be required.
4. Conclusions
The TS1 Project Target has many similarities to the current TS1 Target. It consists of multiple tungsten plates clad in tantalum and housed in a stainless steel vessel. However, all the redundant features that were designed for the original uranium target and not required for a W/Ta target have been removed. This has resulted in a compact target that will integrate into the new TRaM, maximising the amount of Beryllium in the reflector and minimising the amount of stainless steel.

Progress with prototyping the target plates and vessel have shown this to be a practical design that can be manufactured within the project timescale.

References
[1] ISIS TS1 Project – Design Philosophy ver 3.
[2] S.Lilley, G.Skoro - MCNPX model 7B
[3] D.Wilcox – Engineering Simulation