ISIS Target Development

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The ISIS neutron source at Rutherford Appleton Laboratory (RAL) operates two target stations (TS1 and TS2), both of which use solid tantalum-clad tungsten targets to produce pulsed neutron beams by spallation [1]. TS1 has proven very reliable over many years of operation, and in 2022 the ‘TS1 Project’ will be completed, improving the operational and neutronic performance and ensuring ISIS remains competitive for years to come. The second target station (TS2) was added in 2008. It has extremely high neutronic efficiency despite operating at a relatively low power (32kW, compared to 160-200kW for TS1). However, TS2 targets typically fail before reaching their design lifetime; work to improve their reliability is ongoing [2, 3].

Proposals for ISIS-II are now in development [4]. This is expected to be a MW-class short pulse facility at RAL, which will probably require a flowing or rotating target system. It may also have a second target station which pushes the limits of power deposition on a solid target. Neutronic efficiency will be a key concern for both target stations, drawing on the lessons learned from the current TS2. Ensuring reliability at these higher beam powers will require significant R+D.

A major area of interest is developing a better understanding of our material properties; existing data for tantalum and tungsten is scarce, particularly in the case of radiation damage. Fatigue testing of ISIS tantalum is currently underway [5]. In future we would like to extend this to include the combined effect of fatigue and irradiation damage, perhaps by irradiating a thin foil at the Brookhaven Linac Isotope Producer (BLIP) then carrying out small scale fatigue testing at the Materials Research Facility (MRF) [6]. A similar programme for titanium is already being carried out for the T2K neutrino experiment as part of the RaDIATE collaboration. The recent opening of the MRF at the Culham Science Centre is a significant opportunity, as it allows for more irradiated material studies to be carried out close to ISIS. Proposed improvements in their capabilities [7] would also bring benefits for ISIS material studies. Such studies can be expensive, but may be of wider interest to other facilities such as SNS and CERN’s BDF.

The best possible irradiated material data could be obtained by Post-Irradiation Examination (PIE) of spent ISIS targets, many of which are now approaching a low enough level of activity for transportation and PIE to become feasible. PIE of a spent tantalum TS1 target has already produced valuable results [8, 9]. Further PIE would allow the cause of premature TS2 target failures to be definitively identified, which has not yet been possible. The data may also be of interest to the nuclear fusion community; some regions of the target are predominantly neutron-irradiated tungsten. However, the UK has very few sites which can accept such large radioactive parts, and PIE has so far proved prohibitively expensive.

In order to accommodate higher beam powers it may be necessary to explore the use of novel materials. Possible candidates include Ta-10%W alloy as a higher strength alternative to pure tantalum, or TZM (Titanium-Zirconium-Molybdenum alloy) as a lower density material for the front section of the target. These examples have already been adopted by BDF at CERN [10]. It may be necessary to carry out material property testing (including irradiation effects), as well as manufacturing and welding process development. The majority of ISIS target manufacturing is done in-house, providing the opportunity to develop well optimised manufacturing processes.

The Hot Isostatic Press (HIP) process is used at ISIS and other facilities to bond the tantalum cladding to the tungsten core. However, HIPing is thought to introduce unfavourable residual stresses and may also affect the microstructure and properties of the materials. Some initial work on measuring residual stress [11] and fatigue testing HIPed tantalum is already underway. It may be possible to modify the HIP cycle to produce more favourable changes. Alternative methods of corrosion-proofing the target could also be investigated, such as canning it in zircalloy/stainless steel, as is currently being investigated at SNS.

A significant operational concern is the temperature rise due to radioactive after-heat (decay heat) in a loss-of-coolant accident (LOCA) scenario. In some cases this, rather than direct beam heating, may be the factor which limits achievable beam power. Work is already underway to validate simulations of decay heat production and transfer in neutron targets, via thermal measurements and activity measurement of relevant isotopes [12-14]. Recent simulations found significant differences in decay heat predictions from MCNPX and FLUKA; work to understand the reasons for this is ongoing [15].

Developing a MW-class ISIS-II will probably require a move to either a flowing or rotating target system. Required R+D for a rotating target is likely to include rotating seals, radiation-hard motors and bearings, etc. Some of this may be able to draw on experience from ESS and SNS STS. A rotating graphite muon production target may also be of interest, similar to that of JSNS. A fluidized tungsten powder target would enable extremely high power densities. Initial R+D of such a system has been carried out at RAL [16]. Further development is required, but the technology could be of general interest to other high power density applications [17]. At higher beam powers, the influence of stress waves, which has been negligible so far, will start to become significant. Simulation of these effects can be complex, and should be supported if possible with measurements on an in-beam prototype, e.g. at CERN HiRadMat.

In conclusion, ISIS has a long history of developing reliable and efficient neutron production targets. Building on the experience to enable higher power spallation targets will require a broad range of R+D from simulation and validation to materials and manufacturing studies. Many of the challenges are common to other spallation facilities, and the PIE and irradiated material issues are of mutual interest to all high power accelerator facilities.

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