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The ISIS Second Target Station Target, Reflector and Moderator Design and Operation

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ABSTRACT

The ISIS Second Target Station has been operational now since August 2008 and this paper reviews the final design and current operation of the Target, Reflector and Moderator system.

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The primary aim of the ISIS Second Target Station Project was to provide an optimised source of ‘cold’ long wave length neutrons for condensed matter studies.

However, there was also a secondary but equally important aim of optimising the operation of the new target station. The operational experience of the ISIS first Target Station was examined and those features which had worked well were retained and those that had not were changed where possible.

The overall layout of the First Target Station has worked well and this layout has been retained in the Second Target Station.

Fig 1. The ISIS Second Target Station

There are however some subtle differences. For example, experience has shown that it is important to have quick and easy access to the target and cryogenic moderators for efficient maintenance purposes and also to have the ability to change moderators without removing the target. This facility has been engineered into the Second Target Station where the reflector can be split and moved away from the target and moderators very quickly and without having to disconnect the water cooling services.

In addition, there has always been concern about our ability to change the proton beam window and neutron beam port windows in the First Target Station target containment vessel. The Second Target Station vessel can be withdrawn into the remote handling cell for maintenance of these windows.

Other changes include:

- Simplified water cooling services for the target. Those for the First Target Station are complicated by the original need to provide for the fail safe operation of Uranium targets.
- Access to the remote handling cell is at ground floor level for hands-on maintenance operations. On the First Target Station this is done via the service tunnel and trap door of the cell and this is not ideal for the operations staff wearing cumbersome suits and respirators.

Design of the ISIS Second Target Station: Target, Reflector and Moderator system

Design criteria:

- Safety - To be compliant with the latest legislation and best practice.
- Neutronics - To meet the current instrument requirement and be capable of future upgrade.
- Engineering - To deliver the neutronic requirement whilst being safe to operate and within current legislation and codes; minimising radioactive waste production; have ease of manufacture; reduced costs and flexibility for future upgrades.
- Operation - Reduce time to carry out maintenance; reduce radiation dose to operational staff; meet the requirements of ISIS operations cycles.

Target [1]

Fig 2. The Target, Reflector and Moderator Assembly in maintenance position

The ISIS Second Target Station operates at 10Hz (one in five pulses from the ISIS accelerator) and the 60μA of 800MeV protons hitting the target create a pulse of high energy neutrons and approximately 29kW of residual heat which has to be removed from it by cooling water.

The target is a solid cylinder of tungsten 68mm in diameter and 300mm long clad in a shell of tantalum. This cylinder is cooled at its outer surface by D_2O.

Design Focus

The compact cylindrical design gives:

- Optimal neutronic performance: 95% of the flux of a pure tungsten target.
- The cooling water is contained in tantalum pressure vessel which gives large flux gains (+15% from baseline design which had a stainless steel pressure vessel). In addition, optimisation of the vessel wall thickness gains a further 24% flux.
- Reduction of coolant channel volume: the coolant channels comprise only 1.8% of the total target volume; this further reduces the target diameter while increasing average target density to 18.4g/cc (95% of pure Tungsten). Diameter reductions gain a further 36% flux.
- The coolant channels are incorporated within the pressure vessel wall reducing the target diameter. The flow guides have an aerofoil form to minimise pressure drops and thereby preventing cavitation problems.
- Removal of a water cooled proton beam entry window increases flux (5%) and simplifies the design.

Analysis and optimisation:

- Design Simplicity: It is comprised of 3 basic tantalum components and a tungsten rod, and is assembled using only 4 welds and 1 Hot Iso-statically Pressed bond.
- Extensive Computational Fluid Dynamics (CFD) analysis was performed on the preliminary target designs allowing the feasibility of design concepts to be assessed quickly and cheaply.
- The coolant channel design was optimised through an iterative process of CFD analysis and subtle design alteration. This has allowed the creation of a coolant channel geometry which will remove heat rapidly by maximising heat transfer coefficients, whilst minimise the pressure drop through the target and importantly, prevent coolant cavitation or boiling.
- Finite element analysis has also been used extensively to model thermally and mass-induced stresses too.

Reflector

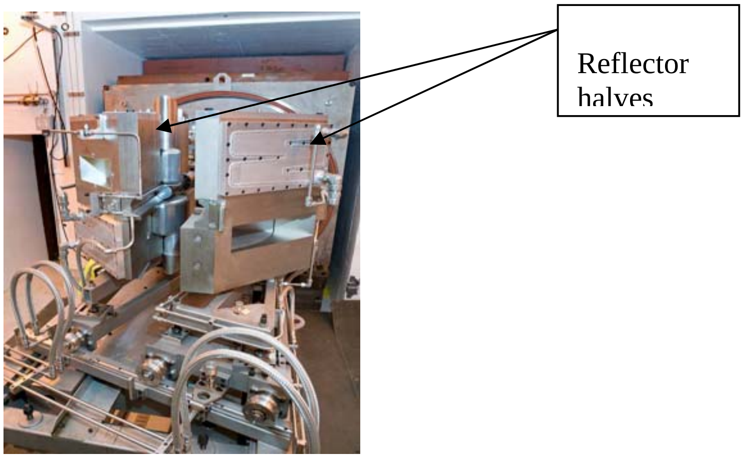

Fig 3. The reflector shown partially split apart

The reflector is comprised of six accurately machined and profiled solid beryllium blocks and has a theoretical density of 99% of solid beryllium. The surfaces of the blocks are protected by an electro-plated nickel layer, 0.05mm thick. The blocks are held together with beryllium bolts and studs and have layers of soft aluminium sheet sandwiched between them to increase the thermal conductivity between adjacent blocks.

Cooling pads are bolted to the outer surfaces of the reflector and remove the 7kW of heat deposited within it. This edge cooling removes the requirement to contain the reflector in a stainless steel casing to protect the beryllium and provide a container for the cooling water. This improves neutronic efficiency and in addition allows us to use light water cooling.

The reflector is split into two halves, with each half mounted on rails. The rails allow easy and quick access to the target and cryogenic moderator for maintenance purposes. The rails which control the splitting apart of the reflector enable the halves to move accurately and repeatably with minimal clearances between critical components of the target pre-moderators and moderators. The ambient water pre-moderators are bolted into the reflector and move with it.

The decoupled poisoned moderator which sits in the upper part of the reflector is decoupled from it by a cadmium ‘bucket’ as well as flight line decouplers of cadmium sheet, typically 1.2mm in thickness.

Thermal analysis of the reflector cooling was performed by using finite element analysis software with a heat input generated from MCNPX. The results gave an accurate heat distribution within reflector and a predicted maximum reflector temperature of 50°C.

Pre-moderators

The ambient light water pre-moderators which sit directly between the target and the two cryogenic moderators and are an integral part of the reflector and move with it.

The pre-moderator for the coupled moderator is extended to form a window frame around the hydrogen face of this moderator allowing instruments to view both ambient water as well as cold hydrogen.

Moderators [2]

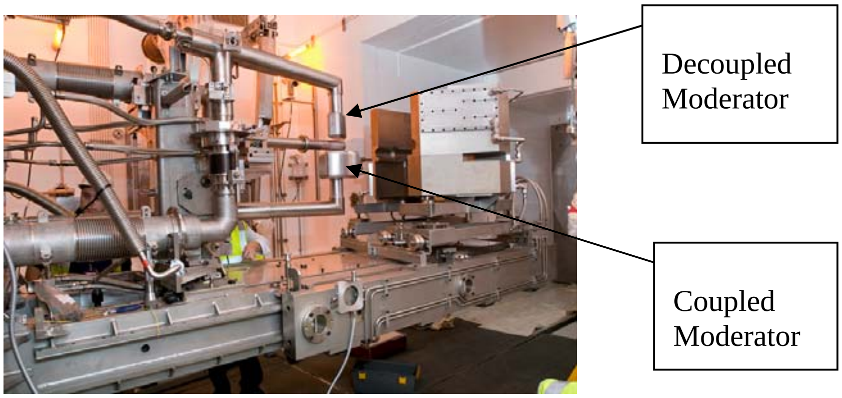

Fig 4. The target, reflector and moderator assembly in maintenance position

Initial design objectives for moderators:

Safe to operate and meeting current legislation on use for explosive gases (ATEX/DSEAR):

- Relatively low pressure system
- Low hydrogen inventory
- Protective tertiary containment with inert gas

Scientific requirements:

- Optimum neutronic performance
- Stable para hydrogen content (governed by surface area of catalyst and providing a liquid hydrogen buffer supply).
- Low moderator temperature gradient and good temperature stability (governed by fridge cooling power, moderator heat exchanger capacity and high purity aluminium foam matrix to boost thermal conductivity in solid methane).
- Quick anneal and charge change time (governed by fridge cooling power and moderator heat exchanger capacity).
- Transient modelling (e.g. anneal). (This was not straight forward and a factory test was very useful in confirming the final capability of the cryo plant).
- Reliability of operation

Engineering requirement:

- Feasibility (extensive use of Finite Element Analysis and CFD used in the design process backed up by a factory test of system before shipping to site).
- Manufacturability (governed by use of proven materials: high purity aluminium, aluminium alloy 5083 and stainless steel 304 L).
- Ease of maintenance and replacement.
- Procurement of a high thermal conductivity aluminium foam (at least 99.96% purity) to extract heat from solid methane whilst providing a low neutron absorption and an open enough structure to allow the easy flow of methane in and out of it.

Table I. Final moderator specification

	Decoupled poisoned moderator	Coupled moderator
Moderating material	Solid methane	Solid methane and liquid hydrogen
Operating temperature	26K	26K (CH_4) and 20K (H_2)
Cooling ‘fluid’	Helium gas (26g/s) direct from fridge with heat exchanger in moderator.	Liquid hydrogen (80g/s) with common wall heat exchanger in moderator. H2 cooled by helium fridge.
Heat load at base temperature	300W (includes poisoning)	290W
Temperature stability	±0.25K (in any 24 hours)	±0.75K (in any 24 hours)
Ortho-para stability	N/A	±0.5% (in any 24 hours)
Anneal	1 hour (in any 24 hours)	
Charge change	3 hour (in any 72 hours)	

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Current operation of the target reflector and moderator system

Target

Initial operation of the target has been with light water cooling. The cooling water flow characteristics, temperatures and pressure drops are very close to those predicted and the heat load at 40µA is as expected.

The temperatures at the front outer edge of the target are slightly higher than expected (200^{o}C as opposed to 140^{o}C) and we are currently investigating why this is so.

Reflector and Pre-moderator

The combined heat load from these systems at 40 µA is as expected. However, a late decision to couple the flow of the reflector in series with that of the pre-moderators did not work well with non-optimal flow characteristics for the cooling water pump. This has recently been re-plumbed to give the original parallel circuit configuration and we await the results of running tests.

The aluminium alloy shells of the pre-moderator were very thin, typically 1mm, to give optimal neutronic performance. Corrosion of the 2000 series aluminium alloy used for its high strength and the subsequent leaks on this system has caused interruptions to recent operational cycles. The leaking pre-moderator has now been replaced with a new pre-moderator with 1.5mm wall thickness and in a 5000 series alloy. The ability to split the reflector easily and quickly has helped considerably in this operation and also during our routine cryogenic moderator changes.

Moderator

The cryogenic systems have worked well and the cooling power at operating temperatures is as expected. The time to complete anneals and charge changes for both moderators are well within that originally specified. However, the decision to combine the control of the two moderators to make anneals and charge changes more efficient has not been as successful as we would like and we have worked with the fridge manufacturer to separate the control of the two moderators. This facility has helped us in recent running cycles where we have been able to run the moderators independently of one another.

Operation of the liquid hydrogen moderator (coupled moderator) has been as expected and with good temperature stability.

Operation with solid methane in both the decoupled and coupled moderator has not been as originally expected on two counts.

Firstly, the contact between the high purity aluminium foam matrix and the heat exchanger in both moderators was made by a press fit and this has not given us the best thermal contact. We have observed higher than expected temperatures at the methane face of both moderators typically, 40K to 60K. We now have the foam brazed to the heat exchangers and expect to confirm lower temperatures at the face of the decoupled moderator in tests to be run shortly.

Secondly, at an early stage in the operation of the moderators using solid methane we experienced breaching of the cold moderator can walls which spoiled the insulation vacuum on two consecutive coupled moderators and one decoupled moderator. The breaches occurred during warming up of the solid methane to allow a charge change or anneal to take place and we suspected that they were made by excessive strain in the cold moderator cans. We were subsequently, able to operate with solid methane in the coupled moderator but with much reduced time intervals between anneals and charge changes: typically eight hours between anneals as opposed to the specified once every 24 hours. Subsequent investigations with strain gauged decoupled moderators have shown much higher strains within the cold moderator can walls than we had originally expected. These investigations are ongoing.

In between cycles of testing with solid methane we have also successfully run the decoupled moderator with liquid methane.

Acknowledgements

I would like to take this opportunity to acknowledge the dedication of the ISIS Target Task Group and the ISIS Target Operations Group in their work to complete the ISIS Second Target Station project.

Reference

1. R.H.H.Scott, D.M.Jenkins, J Butterworth, S Ansell, *Isis Second Target Station: Target Design, Analysis, Optimisation & Manufacture*, ICANS-XVII April 25-29, 2005 Santa Fe, New Mexico.

2. S Ansell, S.D.Higgins, D.M.Jenkins, M.F.D Simon, *Thermal design for the ISIS Second Target Station moderators,* ICANS-XVII April 25-29, 2005 Santa Fe, New Mexico.