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ISIS TS2 Phase II Instruments

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ABSTRACT

Recently ISIS has expanded its capacity by building a new target station (TS2). Seven instruments already populate this target station leaving eleven as yet unused beamports. The scope of the Phase II project is the design/construction of the next set of instruments. Five instruments are being designed and this poster will show the current state of the designs for these instruments. It will present any significant challenges that we are facing or have faced in the design of these instruments.

CHIPIR	Irradiation of electronic devices with a neutron energy spectrum corresponding to the cosmic ray background, for single event upset testing.
ZOOM	Focussing small angle neutron scattering for the study of nanostructures.
LARMOR	Multi-purpose instrument which extends the length scale of SANS2D (Phase 1 instrument) and ZOOM and enables dynamics measurements on the corresponding time scale.
IMAT	A unique design combining neutron imaging and diffraction with applications in engineering, materials science and cultural heritage research.
LMX	Single crystal neutron diffraction for supramolecular chemistry and biological structure.

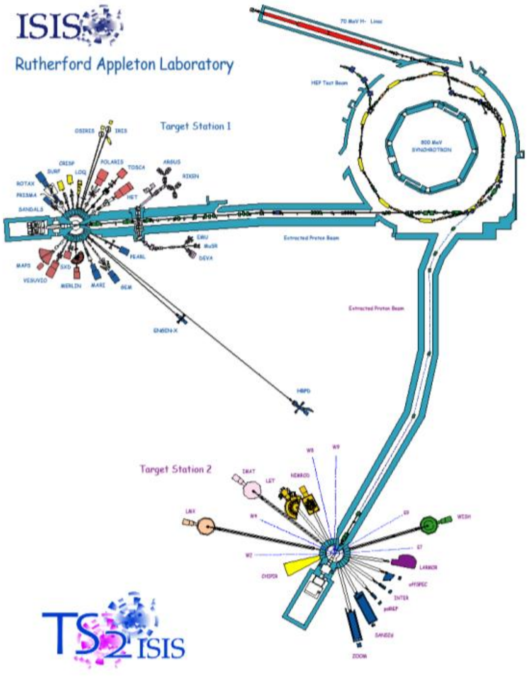

Fig 1: Layout of ISIS and instruments

1. Introduction

Recently ISIS has expanded its capacity by building a new target station (TS2). Seven instruments already populate this target station leaving eleven as yet unused beamports. The scope of the Phase II project is the design/construction of the next set of instruments.

2. New instruments

2.1. Imat

A Neutron imaging and diffraction instrument for materials processing and engineering.

Science

The penetration power of neutrons is the basis of a materials science instrument for engineering, geology, and archaeological sciences. Imat will allow study of novel alloys and composite materials, phase transformations, creep and fatigue, corrosion, and ancient fabrication techniques.

Applications

- Aerospace and transportation
- Civil engineering
- Power generation
- Fuel and fluid cell technology
- Cultural heritage
- Agriculture
- Earth sciences

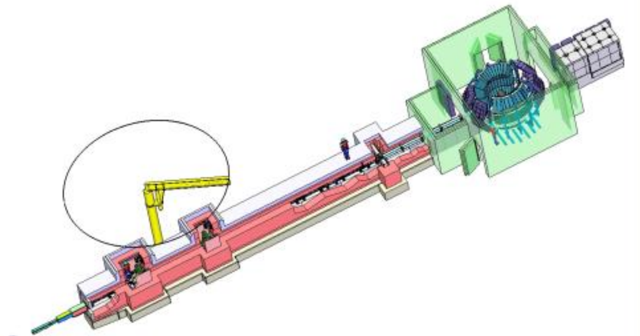

Fig 2: Imat layout

Techniques

Imat will provide advanced non-destructive energy-resolved imaging and diffraction techniques:

- Neutron radiography and neutron tomography.
- Diffraction-enhanced imaging, and contrast variation.
- Neutron strain scanning
- Rapid texture analysis

2.2. Larmor

Multi-Purpose Instrument for SANS, Diffraction and Spectroscopy utilising the Larmor precession of polarised neutrons. Larmor will provide a suite of techniques not currently possible at ISIS and will also expand the range of spatial and temporal length scales to new areas.

Science

Many of the soft matter themes relevant to Loq and Sans2d today will be extended to significantly longer length scales by SESANS, but retaining good count rates and the advantages of neutron contrast variation. SESANS will allow detailed studies of long-range structure and inter-particle interactions in colloidal dispersions, foams, lamellar fragments, supramolecular conjugates, complex mixtures, composites, ‘templated’ and phase segregated systems.

Applications

- Soft Matter and Complex Fluids
- Food Science
- Bio-materials and Pharmacy

Techniques

- SESANS (Spin-Echo Small Angle Neutron Scattering)
- MIEZE (Modulated Intensity Experiment with Zero Effort)
- MISANS (Hybrid instrument combining the MIEZE technique and conventional SANS)
- Larmor Diffraction
- NRSE (Neutron Resonant Spin-Echo) Spectroscopy.

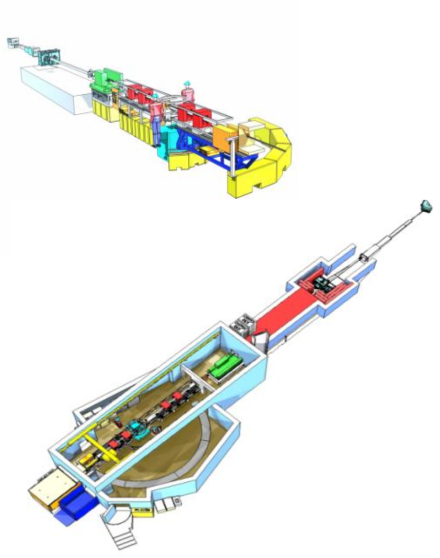

Fig 3: Larmor Layout

2.3. Lmx

An innovative single crystal neutron diffractometer which will provide a high flux cold neutron solution for problems in supramolcular chemistry and biological structure.

Science

The instrument will be a world-leading single crystal diffractometer, ideally suited to ISIS TS2, and will access the large structures that play a crucial role at the forefront of modern molecule-based materials and molecular biology.

Lmx will contribute substantially to two of the TS2 science themes, namely advance materials and biomolecular sciences, with a significant but smaller contribution in the third area of soft condensed matter.

Thus, an outstanding opportunity is presented which tackles some of the exciting and leading areas in chemistry and structural biology which are currently not within the scope of existing ISIS instrumentation and not yet well catered for at neutron facilities internationally.

Techniques

- Neutron diffraction

Applications

- Biomolecular science
- Partially ordered systems
- Zeolites and other framework materials

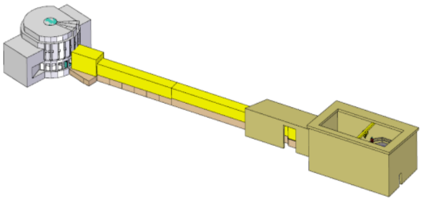

Fig 4: Lmx Layout

Technical

The Lmx design includes a long incident beam path and novel neutron optics, allowing the diffractometer to be highly optimised to deliver a high flux of cold neutrons and to resolve low d-spacing Bragg reflections from very large unit cell crystals.

2.4. Chipir

Accelerating the capability of the micro-electronics industry in cosmic ray neutron testing

Science

Whilst we take for granted the life sustaining atmosphere that we breathe we are not always aware of the radiation protection it provides us from the constant bombardment by the earth from cosmic rays. This protection is however not quite complete; a very small amount of very high energy neutrons are present at ground level as a result of this cosmic ray bombardment.

Fortunately for us life has had 3.5 billion years to adapt but the electronic systems that we are becoming increasing reliant on over the last few decades have not and so cosmic ray neutrons are playing havoc with these devices – effectively reprogramming them, making them crash or burning them out completely. These effects were first noticed in aircraft's electronic systems during flight where, due to the higher altitude, the atmosphere does not give quite such good protection, about 1/300 less at 35,000 feet.

Recently, as chips have become smaller and more sophisticated the problems seen in the aerospace industry has spread to more terrestrial ones like transport, communications, medical, control systems and computing systems.

At ISIS we are able to simulate these effects but at an accelerated rate so that one hour in our beamtime will be equivalent to a hundred years in the air.

Technical

We will be able to operate in two modes; A collimated 'pencil' neutron beam for individual component testing and a beamline which will provide a reasonably isotropic flood of neutrons which will allow very large integrated systems to be tested.

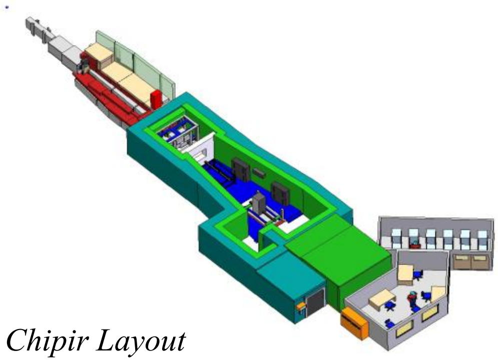

Fig 5: Chipir Layout

1.1. Zoom

Zoom will be a flexible, high count rate small-angle scattering instrument. It will use novel focussing devices and high resolution detectors to reach very small Q (VSANS).

Science

One goal of Zoom is to study much larger length scales (2-1000nm) than Sans2d by using a neutron lens to focus a 50mm beam to a 2mm spot at up to 10m from the sample. For large samples this gains over conventional pinhole collimation without the need for a very long beam line. Zoom will also have an option to polarise neutrons for studies of magnetic materials. A large, high precision sample stage will allow grazing incidence techniques to study surface structures.

Applications

- Advanced Materials – multicomponent polymers, self assembled systems, functional surfaces.

- Environmental Science – nanoparticle aggregates and naturally fractal materials.
- Pharmacy – multi-scale drug delivery systems.
- Magnetism – patterned surfaces and novel memory devices.

Techniques

- Small-Angle Neutron Scattering (SANS)
- Grazing-incidence SANS (GSANS)
- Very Small-Angle Neutron Scattering (VSANS)

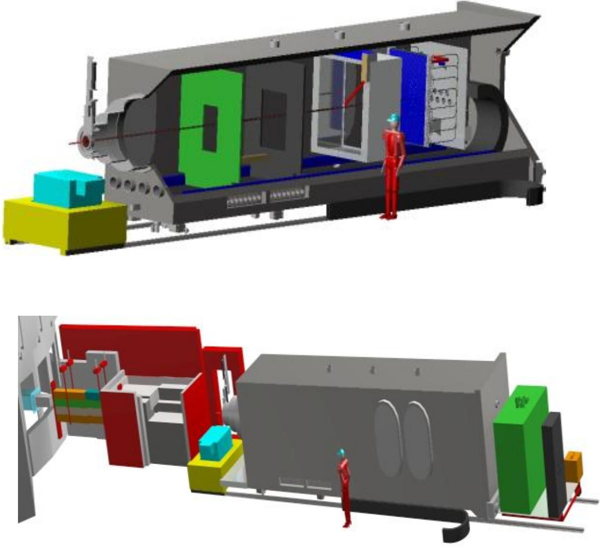

Fig 6: Zoom Layout

Technical

An array of 8mm diameter, 1m long ^{3}He gas tubes, with electronics in an airbox, will move inside the 10m long vacuum tank.

The vacuum tank itself will move on rails to accommodate large sample environment equipment.

Adjustable incident collimation includes a choice of neutron polarisers.

2. Challenges

There have been many challenges in the design of the instruments, given the position we are in at the moment, most of these challenges have been about the balance between science, engineering and operation of the instruments. There are three examples of challenges and how we have approached them.

2.1. Layout for instruments

The challenge was to fit the Larmor instrument into its allocated 13 degree segment of the experiment hall without significantly intruding into the adjacent segment and thereby rendering the adjacent neutron beam port unusable. The instrument layout was driven by the 5m long detector bench that rotates about the sample position through 135˚. When positioned in its 90˚ position the detector bench with a 600mm walkway between it and the instruments 300mm thick radiation shielding wall (borated wax), put the instruments external wall over the nominal beam centre of the adjacent beam port.

To improve this we rotated the Larmor neutron beam trajectory away from the interference as for as physically possible within the limits of the target stations shielding while maintaining a straight flight path and the view of the moderator required. While improving the situation this change did not give us the minimum clearance to the adjacent nominal beam position of 600mm. To achieve this we pushed the sample point out further away from the target station with the result that the instrument blocked the walkway at its rear. By moving the offending wall and taking a lump out of the Chemistry lab located at the rear of the instrument the walkway could be re-established and we had our first acceptable instrument layout.

This layout was further improved by removing the walkway between the end of the rotating detector bench and the radiation shielding wall. This change required the addition of a second access door through the shielding wall to enable access to the far side of the beamline. Also when in the rotated 90˚ position the detector bench creates an inaccessible floor area within the instrument.

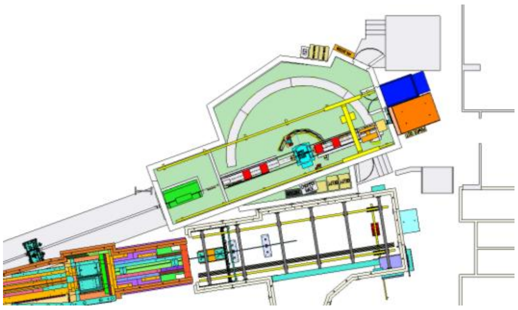

Fig 7: Larmor Layout

Under beam (beam height 1.1m) crawl through access was added although there is no planned access to this area with the bench in this position. This layout enabled us to move the sample point back towards to target station re-establishing the walkway at the rear of the instrument and removing the need to move any walls. It also increased the clearance to the adjacent beamline to a comfortable 960mm.

2.2. Vacuum Vessel Selection for Zoom

2.2.1.1. Background

The outline scientific specification for Zoom identified early on the need to position a larger sensitive detector array, 1000w x 1600h, over a range of sample to detector distances. The detector tubes were to be mounted in air outside the tank vacuum closely coupled behind a thin aluminium window. The tank would be housed in a blockhouse, adding around 600 mm width to the assembly. The location of the instrument in the ISIS Target Station 2 wall is between the SANS2d instrument and the Target stations wall. At the location of the tank the space tight and was 3m wide closest to the sample point. At the outset it was unclear if this outline requirement could be resolved within the constraints given and some thought was given to how competing concepts could be discriminated from each other with a good confidence.

2.2.1.2. Initial Concept

Telescopic tank, detector to sample range 4m to 10. Vacuum tank ~12m in length. A concept study indicated that with external columns and length adjustment systems the tank would be near to 2.7m in diameter and ~12 m long.

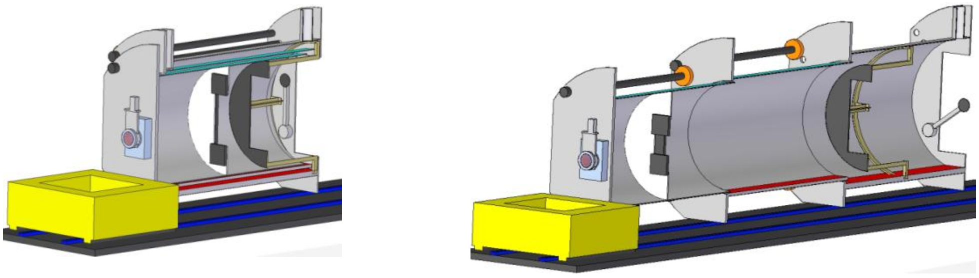

Fig 8: Zoom initial tank concept of telescoping vessel

2.2.1.3. Candidate Concepts.

Five candidate concepts were initially evaluated. These were:

- Fixed Tank with detectors on outside
- Fixed length tank with movable detectors inside
- Removable Section Tank
- Movable Piston - Fixed outer tank
- Telescopic Tank - 3 sections

A suite of Mechanical, Project Engineering and Scientific questions were each given a weighting dependent on their significance.(f:1>5), e.g. Tank Diameter = 5.

Each option was assessed and ranked (y:0>3) by a reviewed consensus of the Team. The merit index was given as M=fy.

The sum of Scientific question merit indexes was subject to a further weighting of 3 as the design should be driven by the scientific merit. There were also more engineering questions that skewed the ranking. The results of this first sift are given in table I below.

Table I Merit Indexes after First Iteration

Concept	Fixed Tank with detectors on outside	Fixed length tank with movable detectors inside	Removable Section Tank	Movable Piston, Fixed outer tank	Telescopic Tank, 3 sections
Noramlised Rank (%)	78	120	93	86	100

This changed the origional concept of the telescoping tank with detectors outside, to a layout where the tank was fixed and the detectors moved within the tank. As the individual weightings were decided in advance of the ranking some degree of independence is assured with this method of resolving a complex interactive design problem.

2.3. Shielding Design for Chipir

When designing the ChipIR beamline there have been a number of challenges that have arisen. By far the biggest has been how to biologically shield the people working within the ISIS Target Station 2 hall from the radiation generated from the ChipIR beamline.

Chipir uses a much higher integrated flux, in the order of 1×10^6 n/cm^2/s above (10MeV) than produced for other beamline on ISIS. Therefore the “standard” beamline shielding solution (600mm steel and 300mm borated wax) adopted across ISIS instruments is not sufficient. Shielding on ISIS must ensure a maximum dose rate on the external wall of the shielding of 1 micro sieverts per hour is not exceeded.

In order to solve this problem for ChipIR we have used a number of techniques.

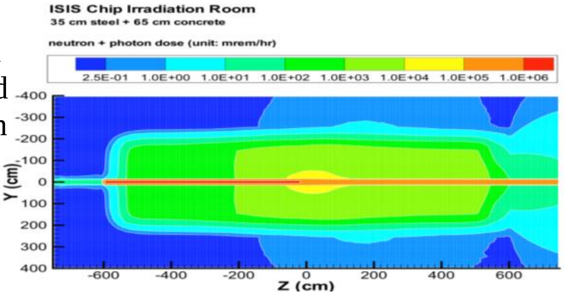

Fig 9: Neutron Flux in Chipir

1. We have looked at other facilities around the world that have similar beamlines and also areas of higher radiation at ISIS such as the target station and EPB. This has given us a “starting point” of approximately how thick the shielding should be.
2. We have preformed shielding tests at ISIS by putting “off the shelf” shielding materials in a beamline and measuring the attenuation at 3 energy regimes (thermal, fast and dose equivalent) of the beam through the materials. This has given us a good idea of which materials perform best in each area.
3. Next the available space on the beamline was considered and a number of designs for the shielding were drawn up to see what the maximum thickness of shielding that could be fitted on the beamline would be.
4. With these three pieces of information some hand calculations could be preformed to get an approximation of what materials would be most suitable and what ratio of those materials would be most effective.
5. The next stage was to construct a simple (but representative) blockhouse model in MCNPX. This allowed a simulation of the expected beam hitting a representative sample to be run showing what the dose rate around the blockhouse would be. This model could then be modified to optimise the shielding design.
6. The final step has been to construct the actual beamline model including all relevant components in MCNPX. This model is then run and optimised to ensure the initial design specification is met.
7. In addition to this process during the commissioning of the instrument we will be conducting a number of shielding tests using various samples to ensure the calculation match the reality.

All of this work has resulted in a shielding design of 350mm of steel and 650mm concrete being the optimum to create the correct balance between biological shielding and beamline cost and space. We have slightly adapted this to utilise existing ISIS steel bringing the steel thickness down to 340mm. Where possible we use a low manganese and low cobalt grade of steel. For the concrete we use an RC40 grade. When using layers of material like this it is important to consider corners and other non uniform sections of the beamline to ensure there are no areas where there is a path through the shielding that would result in a neutron travelling through less that the required distance of steel and concrete. When designing the shielding for ChipIR it has also been important to design in the option to add additional shielding in the case there is a higher level of radiation on the external blockhouse wall than anticipated. This has meant not butting any items up to the blockhouse wall and not putting services on top of the beamline. Due to the wall thickness we have also tried to stop any direct line of sight from the sample onto the blockhouse door, this will allow us to use a much thinner more user friendly door.

3. Acknowledgements

TS2 phase II is supported by a project team consisting of scientists and engineers, all of whom have contributed to the current state of the instruments.