Bulletin ISIS Special
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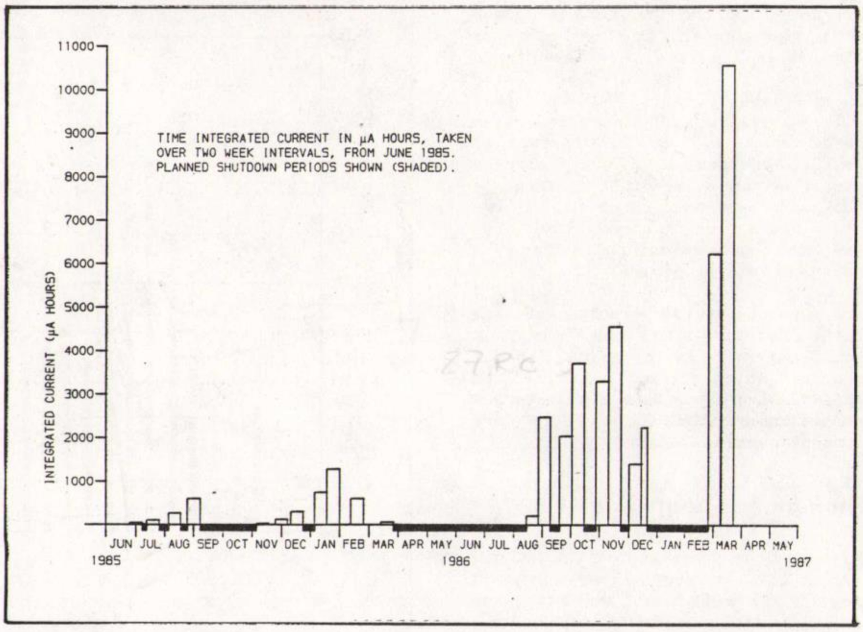
ISIS GOES FROM STRENGTH TO STRENGTH

ISIS has had a wonderful start to its running programme this year. A current of greater than 50 μA has been reached several times. This is 25% of the design current. During the 4 weeks of running for users during March a total of some 17,000 μA-hr of 550 MeV protons were transported to a fully-working target station. During the last 4 days of the run the average current was 42 μA. This performance means that ISIS is already twice as powerful as any other pulsed neutron facility in the world. During March a large number of user experiments were carried out over a wide range of science. Notable experiments were on the determination of the structure of several of the new superconducting materials which have excited world-wide interest.

During the machine development period following the users run on Monday 23 March the muon beam was run for the first time and successfully commissioned. On the Tuesday the accelerator was successfully run at low repetition rate to give 750 MeV protons. This will give 50% increase in the neutron yield.



Up and Up!! Fig.1 shows how the performance of ISIS has developed in the form of the number of μA-hrs of protons delivered to the target during two-weekly periods of scheduled time for users.

Shutdown (Jan-Feb)

Since the good user running period between August and December last year, when some 18,500 μA-hr of protons were delivered to the target station, there has been a shutdown lasting two months. Work in this shutdown has aimed at improving the reliability of the accelerator system, removing the bottleneck on the achievable proton current in the synchrotron, improving the operation of the target station, carrying out tests on subsystems of the accelerator system aimed at getting towards the design proton energy of 800 MeV and installation of the beam for producing muons for condensed matter and other research.

The limit on the number of protons per pulse which could be accelerated was that the voltage induced in the accelerating RF cavities by the intense bunches of protons in the synchrotron was of the same sort of magnitude as the voltage needed to produce the bunches. A feed-forward system was already in operation which measured the first harmonic component of the bunch amplitude, amplified this and fed a signal proportional to it through the high power amplifier chain to the cavity such as to cancel out the voltage induced in the cavity by the two intense bunches of protons. This was successful up to about 4×10^{12} protons per pulse. At this level the cancellation became imperfect. To get beyond this intensity level a scheme was devised to reduce the impedance of the cavity and hence the induced voltage by reducing the impedance of the cavity by having a resistive load across the cavity. This was achieved by the provision of a ring main of copper sulphate solution feeding a liquid resistor across each accelerating gap (2 per cavity). This has the advantage that the load can be relatively easily cooled and by varying the concentration of copper sulphate the impedance of the cavity

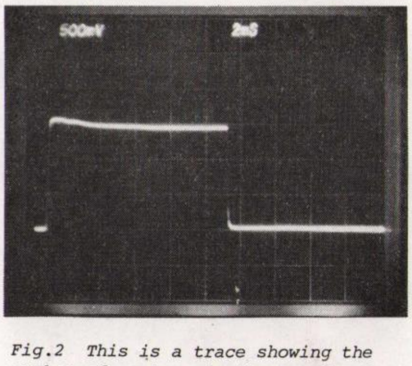


Fig.2 This is a trace showing the number of protons in the accelerator during the 10 ms acceleration time, with the average current about 45 μA. Note how little beam is lost.

can be changed (under computer control, of course) as the intensity increases. This successfully got rid of the intensity limit and more than 6.25 x 10^{12} protons per pulse at 50 Hz was achieved several times (50 μA of mean current).

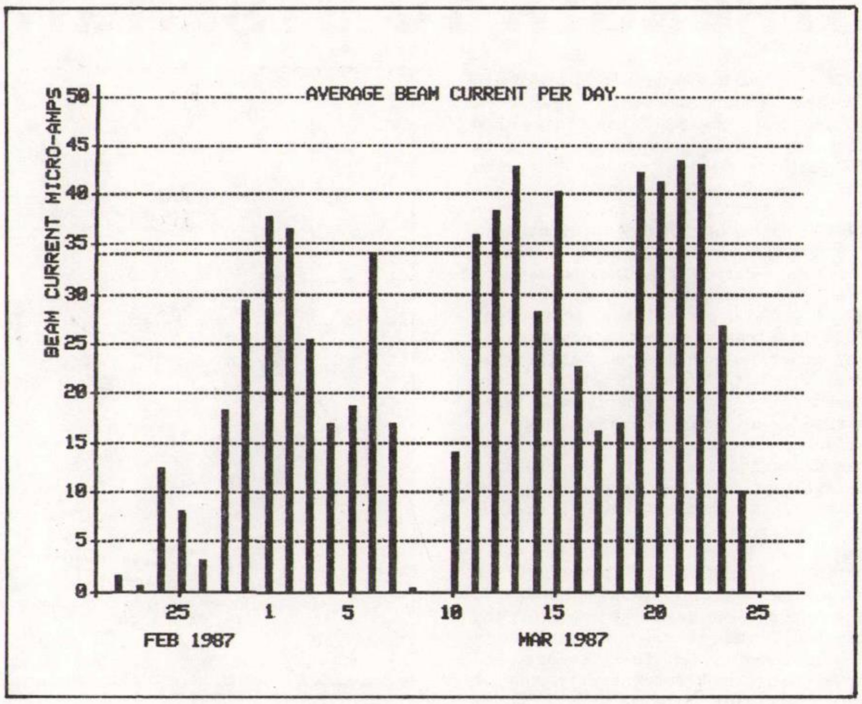
Work on the injector during the shutdown was aimed at producing more reliable and more easily maintainable operation of the 70 MeV injector system. Also, a large number of relatively minor modifications were made to the extraction kicker system which provides the first deflection of the beam from the synchrotron into the extracted proton beam. The record of running during the users run shows that this was successful. The installed extraction septum magnet, the first magnet in the extracted proton beam and whose function is to peel the proton beam off from the synchrotron into the extracted proton beam, had given cause for concern at levels higher than 550 MeV. It was replaced by a new design of magnet which was tested in the laboratory to 850 MeV level. All sub-systems of the accelerator were successfully set to operate at levels required for 750 MeV proton acceleration. The installation of the muon beam was completed to the stage where protons could be run down the extracted proton beam for the neutron users programme.

Arrangements for operation of the target station were improved. A notable feature is that most of the shutters which cut off neutrons from individual neutron beam lines are now controllable from the neutron line control cabins.

Running for neutron users

Although the start-up for the neutron users was delayed by an equipment fault, the effect of the hard work done in the shut-down very quickly became apparent. New displays of the output of the beam loss monitors along the linac, around the synchrotron and along the extracted proton beam line tunnel in R55, allowed the operators to see the early onset of mal-operation of equipment and to take corrective action. During all of this run the complex target station was working with all 4 moderators at working temperature. As the intensity from the accelerator had increased, the trip levels on the target temperatures were set up. The whole system behaved as expected. The record of average current achieved each day during the run is shown in Fig.3. The accumulated number of μA-hrs delivered to the target was about 17,000. The average current for the whole scheduled 4 weeks, even with the late start-up, was 25 μA. For the last 2 weeks it was nearly 33 μA and for the last 4 days 42 μA. This already makes ISIS more than twice as powerful as the previously best pulsed neutron source in regular operation which is at the Argonne National Laboratory in the USA which has 14 μA with 500 MeV protons.

Fig.3 The average daily current delivered to the target station. The average during the one shift for users on 24 March was also greater than 40 μA.



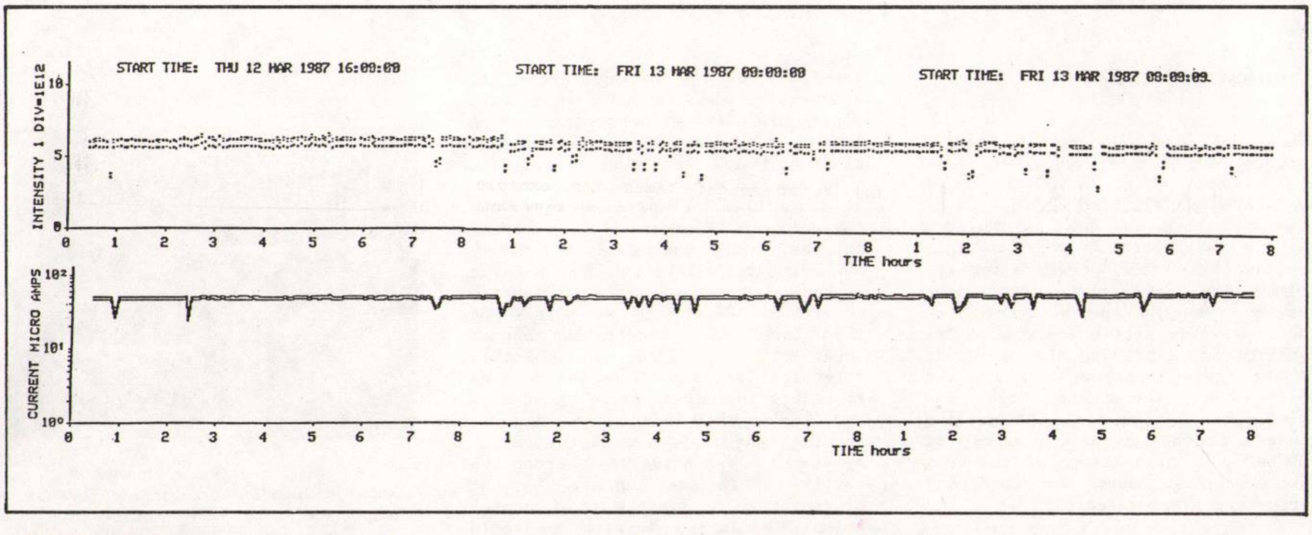


Fig.4 Beam intensity read-out for the first 24-hr period during which the beam was off for no longer than 4 minutes. The top traces are read-outs of the number of protons per pulse at various locations. The bottom shows the current in the injection line and at the neutron target.

Other notable features were that there were several 24-hr periods during which the beam was not off for more than 4 minutes. (There is competition between operating crews to see which can achieve most frequently a shift without hitting 'base-line'). Fig.4 shows the first such 24-hr period – achieved during Friday 13 March.

Another broken record was the lifetime of the stripping foil which converts H^- ions from the injector into protons in the synchrotron. This deliberately modified foil lasted from 5 March and was still unbroken at the end of the run. It had lasted for about 13,200 μA-hr of injected beam compared with a norm of about 1,600 μA-hr. The fragility of the foil is such that it can be broken by a too rapid pump-down of the ISIS vacuum chamber.

A key feature of the design of ISIS is that uncontrolled beam loss must be kept to a minimum. Beam lost during the injection and trapping process falls upon specially designed collectors which are made of materials, like graphite, which do not become very radioactive. The amount of beam lost after trapping must be kept to less than 1% of full intensity otherwise the machine components will become too radioactive. On average during the run more than 90% of the current from the injector was injected, trapped, accelerated, extracted and transported to the target (see Fig.6).

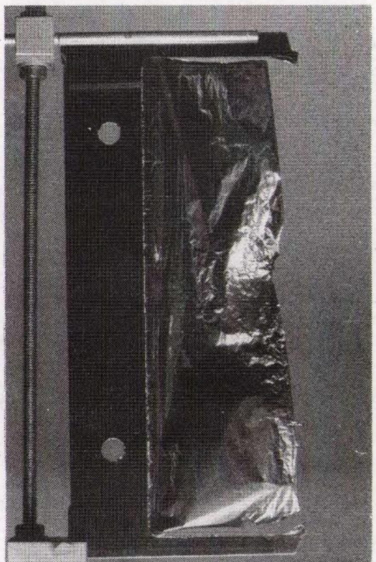


Fig.5 The record breaking foil after retrieval from the synchrotron. The tear at the top happaned as the foil was being removed from the synchrotron. The tear at the bottom was deliberate and is thought to be the reason why the foil lasted so long.

The induced activity level at the 'collectors' after the run was at the maximum point 50 mSv/hr (5 rem/hr), elsewhere in the machine it was at only a few mSv/hr. This is a perfectly manageable level.

During the operation, radiation levels in R55 were generally at a level consistent with occupancy by the general public.

First muons

The 3-day development period from Monday 23 March was also extremely productive. On Monday the muon beam was successfully set up. The 2.5 mm thick carbon target in which the muons are produced is in the extracted proton beam about 20 m before the neutron target. The extracted proton beam line was tuned to produce a 'waist' of 30 mm diameter at the target position. A small proportion of the protons interact in the target to produce the muons. The rest carry on to the neutron target. The beam line was then tuned and operated at full duty cycle (40 μA of protons in the epb). Measurements of neutron background at the neutron instruments were made. There was some increase but at a completely acceptable level.

First 750MeV protons

Following this the accelerator was run for the first time at 750 MeV. The synchrotron magnet AC and DC power supplies were set up to give the correct magnetic fields at injection (70 MeV) and extraction levels. All 6 RF cavities were used together for the first time to accelerate beam. The extraction system of powerful pulsed kicker magnets and the newly installed septum magnet were set to 750 MeV levels. The first part of the extracted beam line was set to steer the 750 MeV protons on to the beam dump in the synchrotron. The need to keep the peak electricity demand down before the cheaper tariff on 1 April, precluded the use of the epb to take protons to the target. A period of about 24 hrs of tuning resulted in 5×10^{12} protons per pulse being extracted at low repetition rate (50/32 Hz). This was a very successful outcome and gave confidence to the plan to run at 750 MeV for the user cycle starting on 6 April. At 750 MeV the number of neutrons will be increased by 50%.

Running plans

ISIS has been scheduled to run on a cycle of 4 weeks for users and 2 weeks for development/maintenance until the end of September. As things stand at present there are insufficient funds available to run beyond that although strenuous efforts are being made to rectify this. No fundamental limitation on the proton intensity has been detected and it is expected that by development of the equipment already available that 100 μA of mean current will be reached by September.

STOP PRESS

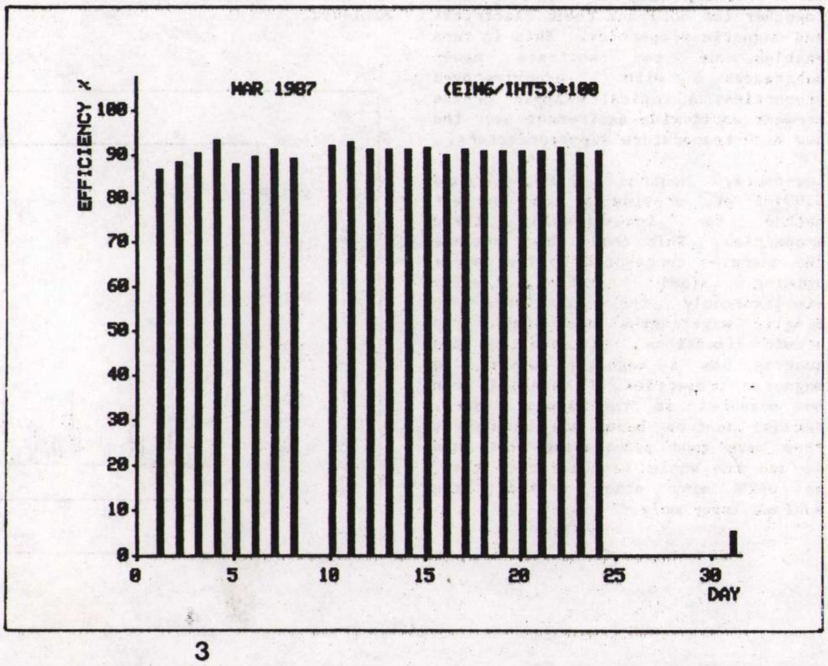
Wednesday 8 April

ISIS now running with 750 MeV protons on to target at 50 Hz.

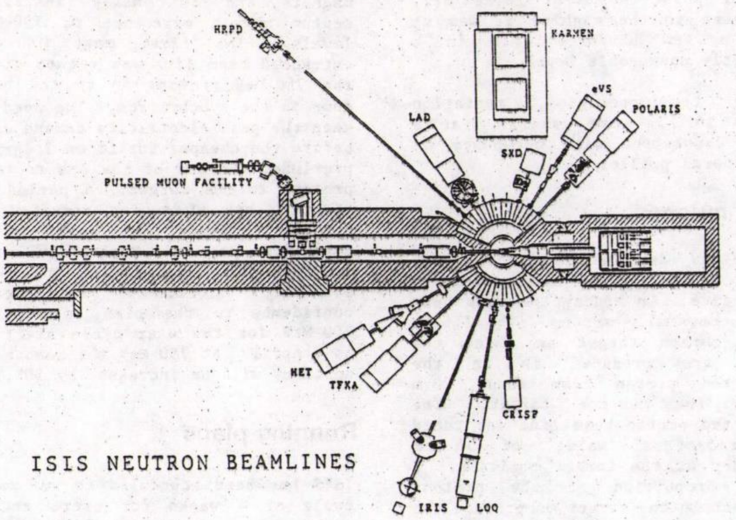
Neutron yield per proton increased by more than 50%.

Muon beam running and giving 1000 μ stops per pulse at 50 Hz. About 8 times more intense than any other pulsed source.

Fig.6 The average daily efficiency of transfer of beam from the injection line to the target.



The Experimental Programme



Layout of the Experimental Hall indicating neutron-scattering instruments, the pulsed muon facility (a joint collaboration between France, Germany, Italy, Japan, Sweden and the UK) and KARMEN the neutrino facility (Germany and the UK).

The function of ISIS is to produce particle beams for the study of condensed matter at the atomic and molecular level. By condensed matter we mean the materials of our everyday life: solids, which include biological materials, polymers and plastics, chemical compounds, metals, alloys, magnetic systems and so on, and liquids, such as water and aqueous solutions, molten materials, even quantum fluids. The behaviour of all these materials is crucially dependent on the atomic structure, i.e. the relative positions of atoms, and the interactions between them. If we can measure these properties, we gain a deeper understanding of the behaviour of materials, such as why they hold together (or not) and their electrical and magnetic properties. This in turn enables us to fabricate newer substances with ever-improved properties; a topical example is the present world-wide excitement over the new high-temperature superconductors.

Low-energy neutron beams, around 0.001-1 eV, provide a near perfect method for investigating these properties. This comes about because the energies correspond to the forces holding atoms together, while simultaneously the associated de Broglie wavelengths are similar to atomic dimensions. In addition the neutron has a magnetic moment, so magnetic properties of materials can be measured at the atomic level. Because neutron beams are uncharged, they have good penetrating power and so see the whole sample rather than, as with many other methods, the surface layer only.

To cover this wide, and unique, range of capabilities, ISIS provides a corresponding range of neutron-scattering instrumentation, shown in the layout. There are two main classes - **elastic** spectrometers used for determining the structure of materials by neutron diffraction, and **inelastic** spectrometers, which measure changes in the scattered neutron energy, giving information on atomic motions. In addition there are facilities for providing polarised neutrons, important in magnetic studies, and reflection spectrometry, for investigating surfaces. In the paragraphs below we give a few illustrative examples of recent work to give a flavour of what can be achieved.

ISIS also has the capability of furnishing muon beams, and a facility has been constructed on a multinational basis for the study of solids and liquids using the μSR technique. This is an entirely different technique from neutron scattering, and provides different, but complementary, information on atomic and molecular behaviour. A report on the first measurements is given below.

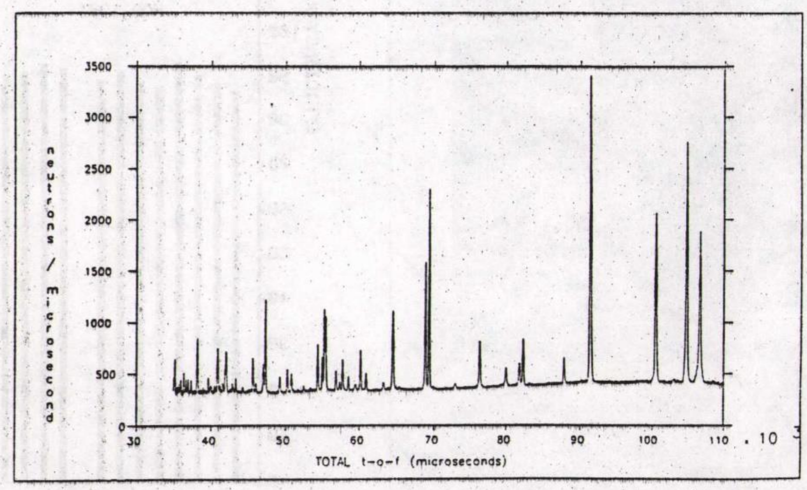
User community

Who uses ISIS? The statistics tell the story: nearly 200 Principal Investigators from over 100 UK university departments apply for experimental time ranging from periods of a day or so to some weeks. In the current application round, 175 individual proposals have been received, but because of the demand, only half the requested time can be allocated. Scientists from eight countries outside the UK are also involved in the experimental programme.

Applications of ISIS

The few reports below have been selected from the hundreds of measurements carried out to date, and give the merest flavour of the breadth of science accessible with ISIS. We highlight the recent structure measurements on the new superconductors at ISIS, which have been widely reported in the press and on television. The new spectrometer

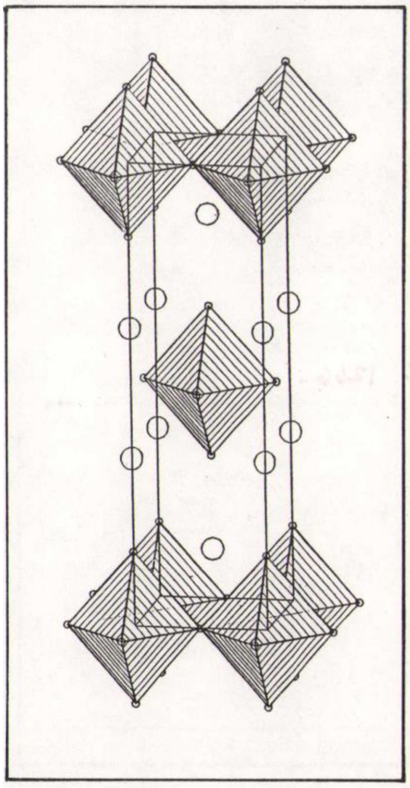
The HRPD diffraction pattern of $La_{1.85}Ba_{0.15}CuO_4$ at 10K. The large number of peaks yields an unparalleled quality of structural information. Subtle distortions of individual peaks are correlated with the onset of superconductivity.



CRISP promises to open up entirely new areas of surface and interface science from the study of multilayer electronic devices to molecular films on liquid surfaces. The hitherto unobtainable neutron intensities and resolutions available at ISIS are illustrated by measurements on the HET spectrometer. Finally we report the first measurements on the muon facility, which triumphantly started operation last month.

Studies of high temperature superconductors on HRPD

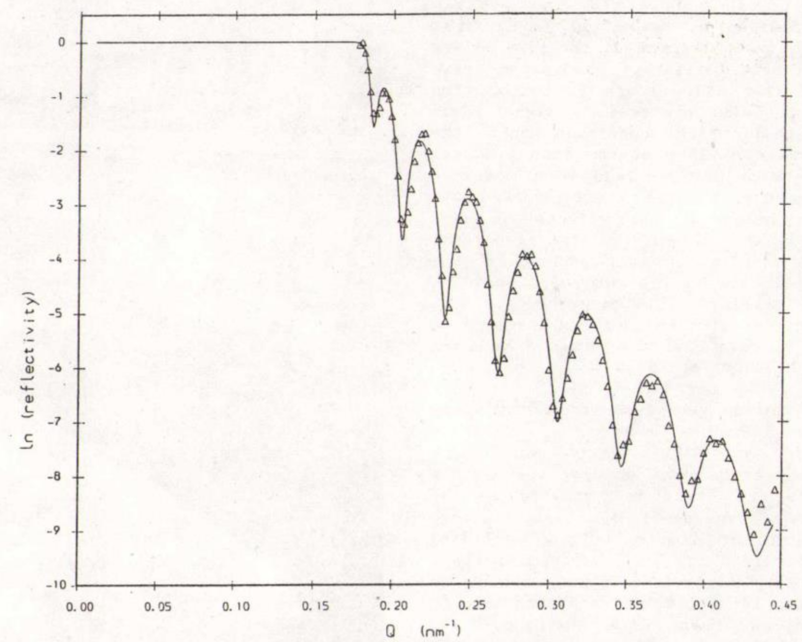
The high resolution powder diffractometer, HRPD, is the best machine of its kind in the world for the study of crystal structures. A recent example of the power of the instrument is provided by the high temperature superconductor, $La_{1.85}Ba_{0.15}CuO_4$. Structural anomalies associated with the onset of superconductivity were anticipated but not observed in an American study. Our superior results, the first of their kind, clearly indicate very unusual but subtle structure behaviour. Analysis of the data has resulted in a more fundamental understanding of high temperature superconductivity and has provided indications of how to make improved superconducting materials.



The atomic structure of $La_{1.85}Ba_{0.15}CuO_4$ containing highly distorted corner-linked layers of CuO_6 octahedra.

Superconductivity is associated with anomalous behaviour of the oxygen atoms.

Studies of low dimentional structures on CRISP



Reflectivity profile for a 30 bilayer Pt-c film measured on CRISP. Each layer is 37Å thick. The solid line is a fit with the thickness and density as variable parameters.

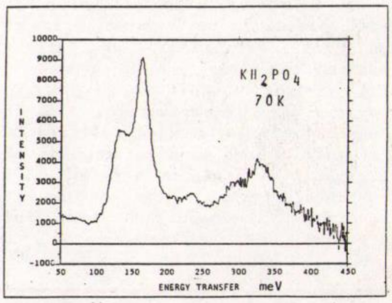
The critical reflection surface spectrometer, CRISP, was recently installed on ISIS and is designed for the study of problems in surface chemistry, surface magnetism and low-dimensional structures. These areas all have technical as well as scientific interest.

Total reflection of neutrons from layer structures enables the non-uniformity of the layers to be resolved and information about the thickness distribution and degree of homogeneity can be obtained. It is particularly important for low-dimensional structures where other techniques have little sensitivity. For example a series of experiments has been carried out to measure the total reflection of neutrons from platinum-carbon multilayers. (These structures are used in mirrors on x-ray satellites). The reflectivity profile from a 30 bilayer film is shown in the Figure. These data are of a far superior quality than those obtained using spectrometers at other facilities, giving detailed information about the nature of the layers. The data are particularly sensitive to the density of the carbon layer for example, and the fit enables estimation of the deviation of the density below the ideal, some 20% in the sample studied.

Molecular spectroscopy

Ferroelectric materials have had a long history in device applications and at different times for example have been used in audio pickups and microphones, computer memory elements, piezoelectric devices, optical memories, pyroelectric detectors. There has been an equally long interest in the scientific properties of these materials, both experimental and theoretical, and neutron scattering has played a crucial role in these investigations.

New information on the ferroelectric KH_2PO_4 has been obtained using the HET spectrometer on ISIS. The main aim of the work is to study the dynamics of the protons in the crystal above and below the 123K ferroelectric phase transition; above this temperature the hydrogen atoms are known to be orientationally disordered on their sites, and below it the hydrogens become ordered. The Figure shows a spectrum measured at 70K, giving information on the "molecular-solid-like" behaviour at this temperature.



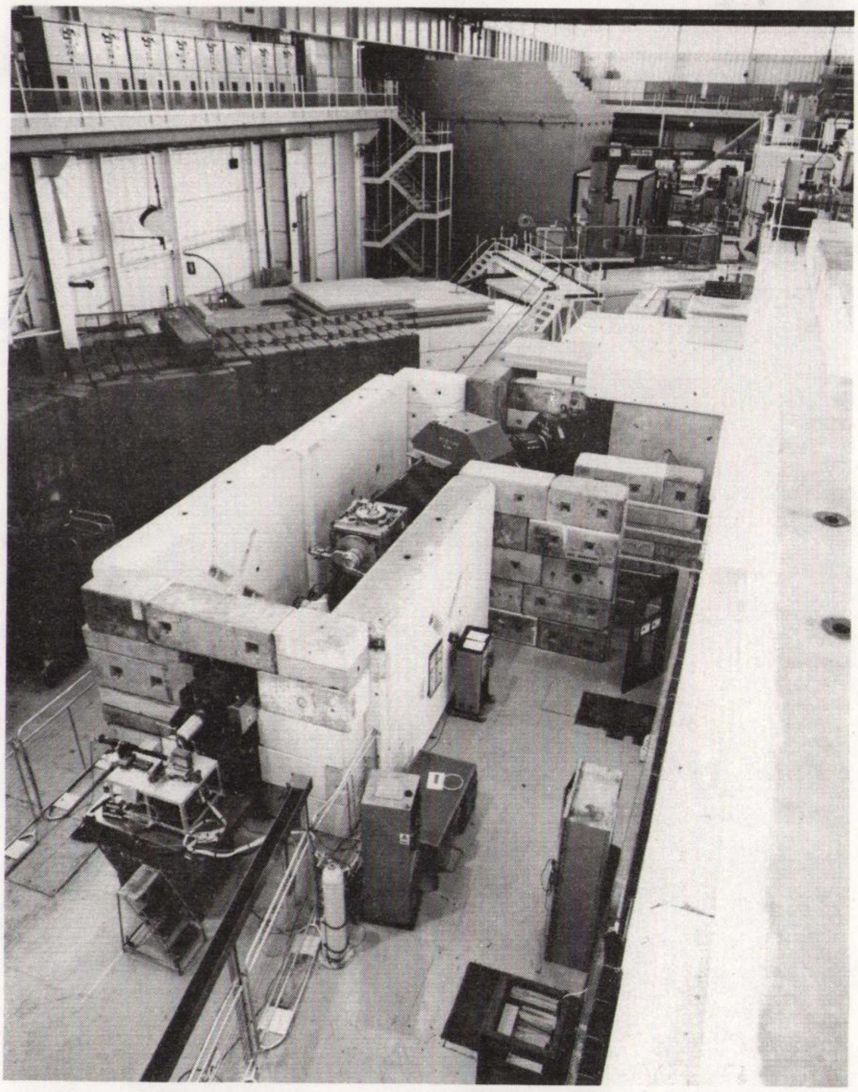
Spectrum of KH_2PO_4 at 70K measured on HET. The peaks reflect the motions of the hydrogen atoms in the crystal which, in turn, determine the ferroelectric behaviour.

First pulsed muons at RAL

At mid-day on Monday 23 March first muons were observed at the ISIS pulsed muon beam facility. Soon after this, following a few hours of tuning, the first μSR precession signal was obtained which confirmed both the expected quality of the beam line and the prospects for the muon research programme. These events marked the culmination of the efforts of many people at RAL over the last five years in procuring European funding for the project and in designing and building the facility. This happy event at RAL coincides with the 50th anniversary of the discovery of the muon by Anderson and Neddermeyer in 1937.

The muons generated from the ISIS channel are of course not the only muons at RAL, since muons are continuously showered upon the earth's surface. These are created in the upper atmosphere by light energy protons of cosmic origin colliding with light nuclei such as carbon. These interactions give birth to pions, each of which decays rapidly to produce a muon and a neutrino. The 'new' muons at RAL are produced in exactly the same way as this by using the high intensity ISIS proton beam and a thin graphite target. Interactions within the carbon target produce profuse numbers of pions and subsequently upon decay to intense pulses of muons, all of which are polarised in the same longitudinal direction.

The muon is an unstable particle, with a mass some 207 times that of the electron (and one ninth that of the proton) and a lifetime at rest of 2.2 μs. The fact that a muon can be considered as a heavy electron or light proton, together with its special decay characteristics, is the key to its use as a probe of the internal properties of solid state materials. Because the muon decays via the nuclear weak force into a positron and two neutrinos, and since this force violates mirror symmetry (or parity), then the decay positron prefers to be emitted in the direction of the magnetic moment of the parent muon. When a polarised beam of muons is stopped in a sample of interest, the whole ensemble of muons will, because of their magnetic moment, precess in the internal magnetic field at a frequency dependent upon the local field. The asymmetry in the decay is revealed in an external positron detector as a series of wiggles superimposed on the 2.2 μs muon decay distribution. The frequency of the wiggles reflects the frequency of the muon rotation in the sample, in turn giving information on its local environment, and so the technique is known as Muon Spin Rotation, μSR. Damping of the amplitude of these oscillations can reveal further information on diffusion of the muons in the sample, time dependent variations of the internal field, and relaxation phenomena. When the muon interacts in the sample to form muonium μ^+e^-, a light isotope of hydrogen, new areas of physics, and particularly chemistry, may be explored. The first μSR spectrum to be measured in the UK is shown in the Figure.



South side of the Experimental Hall showing the muon beam line and μSR equipment. The main ISIS target station is to the top right; the HRPD beam exits the hall to the left. Top centre is the massive KARMEN neutrino facility.

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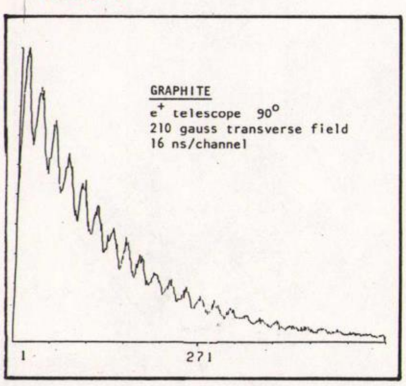

First spectrum measured at RAL showing the μSR oscillations superimposed on the muon decay curve.

Bulletin

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