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Pulsed Magnetic Fields and Pulsed Neutron Sources

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Pulsed Magnetic Fields

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Pulsed Neutron Sources

Summary of two Workshops organised by

U Steigenberger, ISIS Facility and
K A McEwen, Birkbeck College, London

August 1996

Pulsed Magnetic Fields and Pulsed Neutron Sources

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Executive summary

The combination of pulsed neutron sources and pulsed magnetic fields provide exciting possibilities for condensed matter research.

In order to achieve magnetic fields beyond 20 Tesla for neutron scattering experiments pulsed magnetic field technology has to be employed.

Two workshops have been organised by the ISIS Facility, CCLRC and Birkbeck College, London with the aim to bring together specialists in pulsed magnetic field techniques and neutron scattering and to discuss a design which could eventually be implemented at the ISIS Facility and other pulsed neutron sources.

Three concepts were put forward.

(a) A short pulse (3-4 ms), high repetition rate (2 Hz) magnet. Such a magnet based on the conceptual design study of the Los Alamos /Tallahassee group would use available materials and existing technology for the magnet and power supply, and can certainly be built. The main question is the long-term reliability of such a magnet and the need to achieve a life time of at least 10^6 pulses.

(b) A long pulse (1-5 sec) magnet, operated on a (e.g.) 1:25 duty cycle, with a cooling down period of 25-125 sec between pulses. The advantage would be a significant reduction in the number of pulses per experiment by a factor of 10^2 to 10^3. However, such a magnet would be physically larger because of the need to have a larger time constant, and it would need a larger power supply. Such a power supply could be either mains based or use a capacitor bank. Another important advantage of a long pulse magnet is that the eddy currents induced in the sample and cryogenic equipment would be very significantly less than for design (a). Such a design would be also of interest for the reactor community.

(c) A combination of a pulsed field with a steady state field providing a "platform field". Such a design would combine a wide bore superconducting magnet (say 8-10 Tesla) with a pulsed field magnet inside it. In this case the magnet would have to be a short pulse, high repetition rate design, because a long pulse magnet insert would be too large.

All three options require a significant amount of R&D in order to assess their technical feasibility. This goes clearly beyond the resources available within a single laboratory. The possibility of creating a European network between interested neutron scattering centres should be explored.

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Introduction

Neutron scattering is acknowledged as a technique of great importance in the study of magnetism. Measurements of magnetic structures by neutron diffraction and of the dynamic response by inelastic neutron spectroscopy provide us with the essential understanding of magnetic interactions on a microscopic basis over the whole range of magnetic materials based on 3d, 4f and 5f element, alloys and compounds.

Almost all materials which exhibit antiferromagnetic structures (including modulated structures, longitudinal and transverse, commensurate and incommensurate, single-q and multiple-q structures, spin density waves, as well as simple antiferromagnets) have phase transitions which are magnetic field and, of course, temperature dependent. Frequently, the (B,T) phase diagram is extremely complicated with a dozen or more phases below the Néel temperature, as in the rare-earth metal neodymium [1,2] or compounds such as CeSb [3]. Whilst bulk measurement techniques (e.g. magnetisation, magnetostriction) can normally be used to delineate the boundaries of magnetic phases, only neutron diffraction measurements in a magnetic field can determine the actual magnetic structures and order parameters of each particular magnetic phase.

Frequently, the dynamical properties of the magnetic material are magnetic field dependent. Interesting examples of recent work are the field-dependent quenching of the scattering of the magnetic excitations in the rare-earth metal praseodymium against conduction electron-hole excitations [4] and the observation of an unexpectedly large change in the spin wave energies of the field-induced ferromagnetic phase in thulium, compared with the B=0 ferrimagnetic phase [5].

Many University Physics Departments now have superconducting magnets with maximum fields of 17 - 20 Tesla for a wide variety of bulk property measurements on magnetic materials. Such measurements may be continued up to fields of 25 - 30 Tesla available with Bitter or hybrid magnets at institutes such as the SNCI/MPI High Magnetic Field Laboratory in Grenoble. Beyond that range, pulsed magnetic fields take over: fields of 40 - 50 Tesla are available in Europe, Japan and the USA. The future of this field is very exciting: for example a 60 Tesla long pulse (pulse length 0.1 - 1 s) , magnet is under construction in Amsterdam, and the EU has recently announced funding for the development of a 100 Tesla magnet.

The wealth of exciting physics discovered in high field studies of magnetic materials may be gauged from the Proceedings of recent Conferences on High Magnetic Fields, e.g. those held in Nijmegen (1994) and Tallahassee (1995).

In contrast , the magnetic fields available for neutron scattering experiments are significantly lower. The need to provide access for the incident and scattered beams with a split coil superconducting magnet design exacts a heavy penalty. The present maximum fields available are 6 Tesla (ILL), 7.5 Tesla (ISIS) and 9 Tesla (Risø). There is a 12 Tesla magnet, owned by the CENG, but this is not as flexible as the others. Oxford instruments is at the time of writing designing a 15 Tesla superconducting magnet for the HMI, Berlin. Discussions with magnet manufacturers confirm that the maximum possible field for a superconducting split pair design cannot be increased significantly beyond that limit with known materials. It is therefore clear that to reach the fields of 20 Tesla and beyond, that are available for bulk measurements, we have to consider new types of designs for magnets for neutron scattering experiments. Pulsed magnets offer the possibility to reach significantly higher magnetic fields.

Pulsed neutron facilities have clearly come of age in the last 10 years or so. This is reflected in the major projects world wide to design next generation neutron sources which will be pulsed neutron facilities: the European Spallation Source and the pulsed source projects in Japan and the US. It is widely recognised that the combination of pulsed neutron beams and pulsed magnetic fields would offer unique possibilities for condensed matter research.

Our aim was to explore the possibilities of a pulsed magnet of optimal design for ISIS. To this purpose we organised two workshops (June 1995 and January 1996) with the aim

- to bring together specialists in pulsed magnetic field techniques and neutron scattering
- to review the present technology in pulsed magnetic fields,
- to discuss a design which could eventually be implemented at the ISIS Facility and other pulsed neutron sources.

This report summarises the results from these two meetings.

Status report of pulsed magnetic fields for neutron scattering

KENS/KEK Japan

A first generation pulsed magnet capable of fields up to 20 Tesla for neutron scattering has been built for the Japanese pulsed neutron facility KENS/KEK in Tsukuba by M Motokawa (Sendai) and M Arai (KEK/KENS) [6]. This Bitter type magnet has a repetition frequency of 0.5 Hz and produces a 1 ms long half-sine wave field. The design is somewhat limited with the field in the horizontal plane and a fixed, rather small, range of scattering angle from 0° to +10°. The group of Motokawa is currently commissioning a second pulsed magnet, a split type Bitter magnet with a vertical field and a - fixed geometry - scattering angle of +30°. The maximum field of this design is 16 Tesla.

These magnets are far from optimised, but they have demonstrated that neutron diffraction experiments can be performed in 20 Tesla, revealing new magnetic structures in compounds such as $PrCo_2Si_2$ [7]

Dubna, Russia

At the IBR-2 pulsed reactor (5 Hz, half-width of fast neutron pulse : 215 μs) in Dubna, a pulsed magnet facility can be operated on the SNIM-2 instrument. The magnet can reach potentially 20 Tesla in the peak (half-sine shape) with an overall magnetic field pulse length variable between 0.45 - 2 ms. The repetition frequency of the magnet is 5 Hz. It can be operated with the magnetic field vertical and horizontal with respect to the instrumental scattering plane. The vertical configuration provides access to the neutron beam between 0 - 180°; with the magnetic field horizontal, the access is limited to an angular range between either 165° - 180° or 80° - 100° [8].

The Los Alamos design

In the expectation to go beyond the Japanese experience, the Los Alamos Neutron Scattering Centre has joined forces with the US National High Magnetic Field Laboratory, Tallahassee, Florida and put forward a conceptual design for a 30 Tesla vertical field split-pair magnet. The proposed magnet will have a 5 cm bore for sample environment equipment, a 1 cm split gap for the neutrons to illuminate the sample and through which to observe the scattering. It will run with a repetition frequency of 2 Hz and a pulse length of 3 ms. It will be a three coil design with the field vertical. The magnet can be laid on its side to do experiments with the field in the horizontal scattering plane, either parallel or perpendicular to the scattering vector.

This project has now received funding by the US Department of Energy under the "Scientific Facilities Initiative" and a test programme of the fatigue performance of conductor, insulation and reinforcement materials has been started.

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[6] M Motokawa et al. Physica B **155** (1989) 39
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[8] User Guide (1992) : Neutron Facilities at the Joint Institute for Nuclear Research
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Los Alamos Report LA-UR-95-1318

The table below provides an overview over existing and planned pulsed magnetic field facilities for neutron scattering.

	Los Alamos	**KENS #1**	**KENS #2**	**Dubna**
Maximum field	30 T	20 T	16 T	20 T
Field pulse length	3ms	1ms	1 ms	0.5 - 2 ms
Magnet repetition rate	2 Hz	0.5 Hz	0.5 Hz	5 Hz
Neutron repetition rate	20 Hz	20 Hz	20 Hz	5 or 25 Hz
Gap in split pair	1 cm	1 cm	1 cm	1 cm
Angular access within gap	4 x 80°	$2\theta = 0° - 10°$	~2° at $2\theta = 30°$	22° ??
Bore	5 cm	7 x 7 x 3 mm^3	4 cm	?
Field direction	v & h	h	v	v & h
Design	3 coil design	Bitter design	Bitter design	
Pulse shape	half-sine	half-sine	half-sine	

Pulsed Neutrons and Pulsed Magnetic Fields

Pulsed neutron beams and measuring techniques

Pulsed neutron beams are produced when a heavy metal target is bombarded with short pulses of highly energetic protons from a powerful accelerator. These protons produce neutrons by chipping nuclear fragments ("spallation") from the heavy metal nucleus. For example, for an 800 MeV proton beam, some 25 neutrons are typically produced by each proton hitting the target.

These neutrons have very high energies (~1MeV) and must be slowed down to <~1eV to be of use in condensed matter studies. This is done in hydrogenous moderators surrounding the target. The moderators are small to preserve the initial sharp neutron pulse structure and they are kept at various temperatures, enabling different spectral distributions of neutrons to be obtained for different types of instruments.

The pulsed nature of the neutron beams makes it mandatory to exploit time-of-flight techniques on white neutron beams - each detected neutron is time-stamped. If the neutron is elastically scattered by a sample, i.e. suffers no energy change, the total time of flight determines directly its velocity and hence its energy and wavelength.

Time-of-flight *powder diffractometers* exploit the ability to access an entire diffraction pattern at a single, fixed, scattering angle. Following Bragg's law, the individual diffraction peaks appear in the same detector measured at different times-of-flight corresponding to the appropriate wavelength (energy) of the scattered neutron. An example of a powder spectrum in time-of-flight is given in Fig. 1a. The typical width of a powder Bragg peak is of the order of 60 to 100 μs (see Fig. 1b).

For *single crystal diffraction* studies the white beam Laue technique is used. By making use of a position sensitive area detector, large areas of reciprocal space can be surveyed simultaneously.

For *inelastic scattering experiments* it is necessary to determine both the incident and scattered energy of a detected neutron. Two different methods are employed for both single crystal and powder studies: (i) a white incident beam followed by energy and time-of-flight analysis of the scattered beam and (ii) a monoenergetic incident beam combined with time-of-flight analysis in the detector system. An example of method (i) is the PRISMA spectrometer, which has 16 independent analyser-detector arms and is optimised for survey measurements of structural and magnetic excitations in single crystals. In a single setting of the instrument a large area of (Q,ω) space is covered simultaneously. If this measuring technique were combined with a sufficiently long magnetic field pulse, the magnetic field dependence of a magnetic excitation dispersion curve could be studied very effectively.

The ISIS Facility

The ISIS Facility, the world's most powerful pulsed spallation neutron source, provides beams of neutrons and muons that enable the structure and dynamics of condensed matter to be probed on a microscopic scale that ranges from the subatomic to the macromolecular. ISIS is a multidisciplinary international research centre that is used by a wide range of scientists from the physics, earth science, chemistry, materials science, engineering and biology communities.

The parameters of the ISIS Spallation Source are as follows :

Repetition rate :	50 Hz
Proton energy :	800 MeV
Proton current :	200 μA
Proton pulse width :	0.4 μs
Neutron pulse width :	30 μs to 100 μs.

(depending on moderator and neutron energy)

Pulsed magnetic field design considerations:

For the design of a pulsed magnetic field facility for a pulsed neutron source the following aspects appear to be of prime importance:

- *Maximum field strength:*

The present vertical field cryomagnet at the ISIS Facility has a maximum field of 7.5 Tesla. A pulsed magnetic field should provide an increase in magnetic field strength by at least a factor of 3. The highest field steady state magnet, also with a vertical field, available at a reactor is 12 Tesla (operated by a French group). In contrast many neutron users have fields of up to 20 Tesla available in their University laboratories for bulk measurements. Our objective is to have similar strength magnetic fields for neutron studies.

- *High repetition rate:*

The higher the repetition rate of the pulsed magnetic field facility, the larger the effective neutron beam intensity.

- *Uptime of maximum field:*

The longer the magnetic field stays at maximum field, the wider a Q-range (for diffraction) or (Q,ω)-area (for inelastic scattering) can be exploited and the more effective the measurement becomes.

- *Synchronisation with ISIS*

The pulsed magnetic field has to be synchronised with the ISIS masterpulse. Also incorporated in the electronic control system must be the possibility to "phase shift" the onset of the magnetic field within the ISIS time frame (20ms).

- *Minimum "magnetic, electrical and mechanical noise":*

Neutron detectors can be very sensitive to even very small magnetic stray fields. Even at a dedicated pulsed magnetic field beam line the magnetic stray field has to be minimized. Similarly, the electrical interference caused by the discharge of the power supply has to be kept minimal in order not to upset the sensitive data acquisition systems of neighbouring instruments.

- *Reliability:*

In order to build up the required statistical accuracy of the scattering experiments the pulsed field has to work reliably over a long time. A typical measuring time for Bragg scattering in a single crystal is 30 minutes, whereas the measuring time for inelastic experiments can be 12 hours or longer.

- *Magnet geometries*

A vertical field magnet should have split coils to allow access for the incident and scattered neutron beams. The magnet design should allow a window (normally of aluminium which has a low neutron absorption cross-section) for the incident neutron beam as well as for the scattered beam. A window covering 100° in the horizontal plane would be ideal as this would guarantee the required flexibility for selecting a particular scattering angle and the ability to employ a position sensitive detector. In general the scattering planes of single crystals have to be aligned with respect to the coordinate system of the spectrometer. Therefore a vertical window aperture of ±5° would be desirable.

- *Low temperature capability and space for samples:*

For most magnetic studies low temperatures are required. Therefore the magnet design has to incorporate a cryogenic insert to keep the sample at low temperatures (4 - 250K).

Uschi Steigenberger
1 May 1995

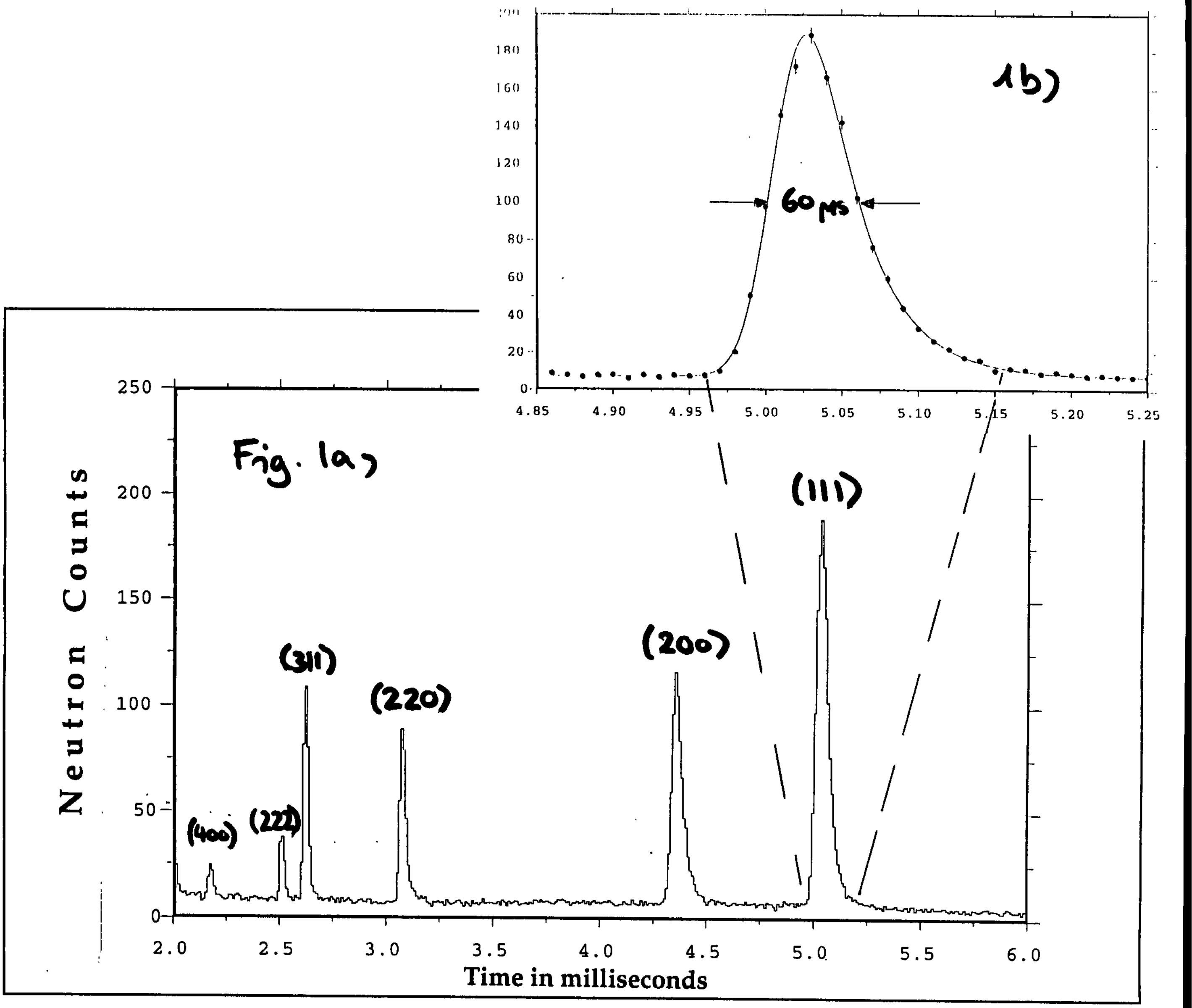


Fig. 1a:
Nickel powder spectrum in time of flight. The typical width of a powder Bragg peak is in the order 60 to 100 µs (Fig. 1b).

Pulsed Magnetic Fields and Pulsed Neutron Sources

Pulsed magnetic field design considerations

Revision 1

As a result of the discussions at the June Workshop in Abingdon, we have revised the "dream" specification for a pulsed magnet at the ISIS pulsed neutron facility. You will find that not only some of the parameters, but also the *order* in which they appear, have changed indicating a revision in the thinking of what are the most important aspects in the magnet design.

Specification

• Reliability and life time	≥ 100,000 shots
• Repetition rate (fast pulsing option (a) and (c))	2 Hz
or	
• Quasi continuous operation, e.g. 1 s "on", 24 s "off" yielding a duty cycle of 1/25	
• Pulse length (fast pulsing option (a) and (c))	3 - 4 ms
• Pulse length (for quasi continuous option (b))	1 - 2 s
• Maximum field	30 Tesla
• Pulse shape	half-sinusoidal
• Field homogeneity	1%
• Magnet bore	20 mm Ø
• Maximum vertical divergence	± 5°
• Gap	10 mm at sample
• Horizontal windows	4 x ± 45°
• Temperature range	1.5 - 300 K
• Magnetic stray fields to be kept as small as possible	

- *Long term reliability at nearly industrial standards and life time :*

In order to build up sufficient statistical accuracy in a neutron scattering experiments, we have to count typically in a diffraction measurement for 1 - 2 hours and for an inelastic experiment for typically 24 hours.

For a duty cycle of 1/25 (see below) this would require 3456 shots with the magnet per day. This compares with a fast repetition rate design as follows :

ISIS (50Hz)	**Magnet at 2 Hz rep rate (duty cycle 1 / 25)**	**Quasi-continuous (1 s on, 24 s off) (duty cycle 1 / 25)**	
Neutron pulses available	No of used neutron pulses = No of magnet pulses	No of used neutron pulses	No of magnet pulses
50 per s	2 per s		
3000 per min	120 per min	120 per min	2.4 per min
180,000 per hour	7,200 per hour	7200 per hour	144 per hour
4,320,000 per day	172,800 per day	172,800 per day	3456 per day
30,240,000 per week	1,209,600 per week	1,209,600 per week	24,192 per week

The above list demonstrates that a pulsed field operated in a quasi-continuous mode with 1 s "on", 25 s "off" has the same duty cycle as a field pulse with 2 Hz, but the total number of shots required to cover the same number of ISIS pulses is reduced by a factor of 50!

There is a school of thought which says that the coil is a "disposable" item and should be replaced after each experiment; this is in principle a valid point, as long as the coils can be produced at a reasonable price, with an acceptable amount of manpower and at a reasonable time scale.

- *Repetition rate and Duty cycle : (time of field "on" / time of field "off")*

Previously we have concentrated on the repetition rate and argued that it should be as high as possible and suggested a target value of 2 Hz. It has become clear in the discussion that there is another way of looking at it. It appears that it is technically easier to apply a quasi-continuous field for e.g. 1 second, with a subsequent down time of e.g. 24 seconds. This would be equivalent to a 2 Hz repetition rate operation at ISIS (which operates at 50 Hz). Other advantages include : heating of the sample through eddy currents is significantly cut down and less cooling capacity is required for the coil. The rise and decay times of the magnetic field could also effectively be used to study relaxation effects.

- *Maximum field strength:*

The present vertical field cryomagnet at the ISIS Facility has a maximum field of 7.5 Tesla. A pulsed magnetic field should provide an increase in magnetic field strength by at least a factor of 3. The highest field steady state magnet, also with a vertical field, available at a reactor is 12 Tesla (operated by a French group). In contrast many neutron users have fields of up to 20 Tesla available in their University laboratories for bulk measurements. Our objective is to have similar strength magnetic fields for neutron studies.

It should be considered if a staged design is possible, with operating the magnet initially at more modest fields in the range of 16 - 18 Tesla and slowly building up to the maximum field strength.

- *Pulse length and pulse shape:*

Here again the quasi-continuous mode of operation has its advantage. The longer the magnetic field stays at maximum field, the wider a Q-range (for diffraction) or (Q,ω)-area (for inelastic scattering) can be exploited and the more effective the measurement becomes. The half-sinusoidal pulse shape is very suitable because the field is above 90% of B_{max} for nearly 30% of the time. Modern data acquisition electronics allows us to separate out data taken at different fields and we will thus make use of all the recorded information. Therefore we need to know reliably what the field is at any given time.

The pulsed magnetic field has to be synchronised with the ISIS pulse. This is best done by using the ISIS "master pulse " to trigger the discharge of the capacitor bank or power supply. It has to respond within 10μs - or the response time has to be very precisely known - otherwise it is not possible to associate the time dependence of the field with the time of flight data. Also incorporated in the electronic control system must be the possibility to "phase shift" the onset of the magnetic field within the ISIS time frame (20ms).

- *Magnet geometries*

We require a vertical field magnet with split coils to allow access for the incident and scattered neutron beams. We need thin windows for the incident and scattered neutron beam. An arrangement of 4 thin windows each covering 45° in the horizontal plane would be ideal. as this would guarantee the required flexibility for selecting a particular scattering angle and the ability to employ a position sensitive detector. Good window material from a neutron point of view is aluminium as it has a very low absorption cross-section.

We also need a vertical divergence of ±5° at the sample position. This is of particular importance to determine accurately the integrated intensities. We understand that a reduction in the vertical divergence would make the magnet design significantly easier.

The bore of the magnet should be at least 20 mm Ø and at the sample position we require a vertical gap of 10 mm. Neutron scattering is an intensity limited technique and we have to use the largest samples that are available.

- *Low temperature capability:*

We require a variable temperature insert for temperatures from 1.5K - 300K.

- *Beam line requirements*

At ISIS each instrument is allocated a space corresponding to a 13° wedge around the target station. This means that instruments are very close together and that in general there is not much space available for installing equipment.

We have to assume that a pulsed magnetic field facility will have to be built on a dedicated beam line, probably at some distance from the target station. We can envisage a case for a special beam line dedicated to extreme sample environments. This could be located at the end of a neutron guide far away from other instruments. This would also minimise the disturbance in electrical, magnetic and vibrational terms.

- *European Spallation Source*

Building a pulsed magnet facility for a pulsed neutron facility provides a challenge and will open up an exciting range of new scientific opportunities. For present day neutron sources the inevitable reduction in the effective neutron flux could be a problem, and maybe only diffraction studies in high magnetic fields might be feasible. However, plans are already in hand to realise in Europe by the year 2005 a next generation neutron source, the European Spallation Source. This source will be 30 times more intense than ISIS and will certainly open up the possibility of inelastic measurements of magnetic materials in pulsed magnetic fields.

Uschi Steigenberger
July 1996

Short pulses versus long pulses

This paper is written for the participants in the Workshops on Pulsed Magnetic Fields and Pulsed Neutrons. It summarises briefly the operation principles of instruments on pulsed neutron sources and discusses their performance if measurements are to be conducted in a pulsed magnetic field. In particular different time lengths of pulsed magnetic field are considered together with their effect on the efficiency with which a neutron experiment could be performed.

Short summary of pulsed neutron scattering measuring techniques

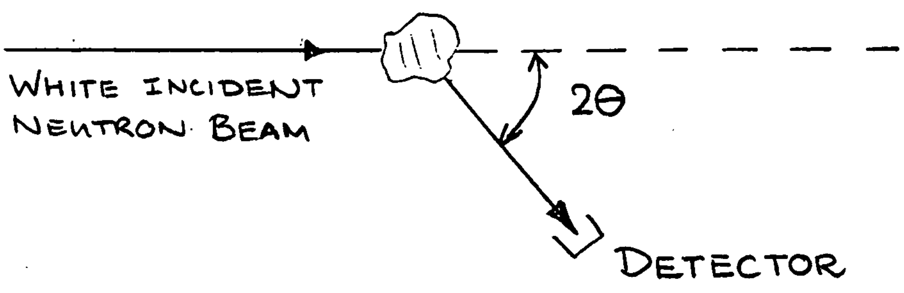
At a pulsed neutron source high energy neutrons (MeV) are created the moment the proton beam hits the target. Moderators reduce the energy of the neutrons to thermal energies (meV) within 10 μs or less. The white neutron beam travelling to the sample disperses in time - faster neutrons will reach the sample sooner than slower neutrons. The neutrons scattered by the sample are detected by a neutron detector which also registers their total time of flight from target to detector.

Elastic neutron scattering:
Elastic neutron scattering allows us to determine the time-averaged microscopic structure of materials. Neutrons have a magnetic moment and can therefore also be used to determine the arrangement of magnetic moments or the magnetic structure of magnetic materials. Neutron scattering is the only effective method which provides this latter information.

For a *powder diffractometer* the use of a white neutron beam on the sample means that each detector at a fixed scattering angle 2Θ records a *complete diffraction pattern*.

Bragg's Law : $\lambda = 2 \cdot d_{hkl} \cdot \sin 2\Theta$

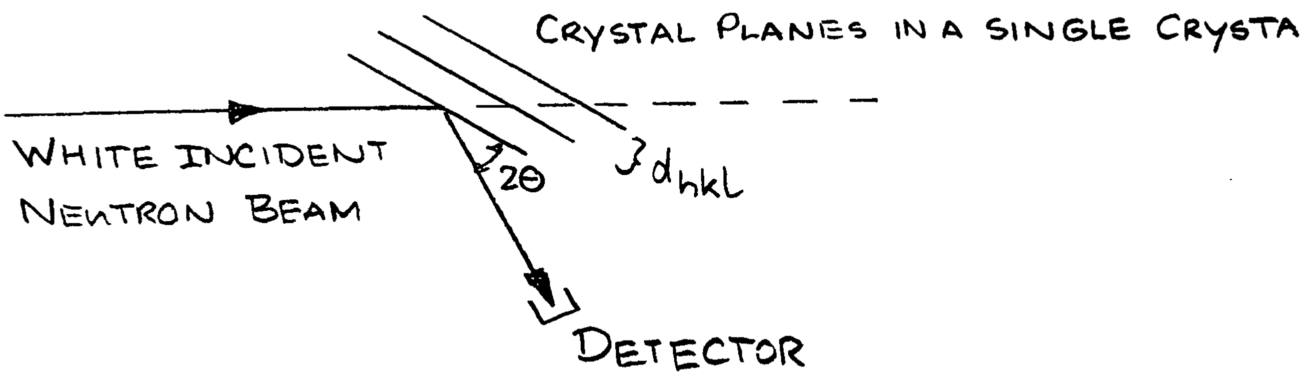
λ = neutron wave length
d_{hkl} = d- spacing of the crystallographic hkl-plane
2Θ = scattering angle



In a powder the tiny crystallites are randomly oriented and as $\lambda = \lambda(t)$ the Bragg condition will be fulfilled for each d_{hkl} at a particular time.

For a *single crystal diffractometer* this is no longer true; here a detector at a fixed position 2Θ will record only Bragg peaks from planes whose normals bisect the angle between the incident and diffracted beams

$\lambda(t) = 2 \cdot d_{(hkl)} \cdot \sin 2\Theta$, e.g. along the (1,1,0) direction



The use of two-dimensional position sensitive detectors enables us to record the equivalent of a Laue x-ray photograph of a single crystal in which, however, the orders of a single reflection nh, nk, nl are separated in time, although they are on the same position on the detector.

In many cases it is essential to study the magnetic structure using a *single crystal* since the magnetic field can then be applied along a particular crystallographic direction. This is of great importance, as the magnetic susceptibility is usually anisotropic. It is also in general easier to determine the direction of the magnetic moments from single crystal measurements.

Inelastic Neutron Scattering

We now turn to inelastic scattering measurements. In these experiments the neutron changes energy in the scattering process. This provides information about the lattice vibrations (phonons) and, in magnetic systems, on the spin dynamics (spin waves, crystal field transitions etc.).

Two different measuring techniques are used :

1) direct geometry instruments:
here a monochromating device selects from the white incident beam a very narrow wavelength band thus producing essentially a monochromatic neutron beam illuminating the sample. The time spread of such a monochromatic beam is typically in the order of 10 - 30 µs. The detector electronics records the total time-of-flight and from the knowledge of the initial time-of-flight (from target to sample) the final time-of-flight and hence the energy change of the neutron can be deduced.

2) indirect geometry:
here a white neutron beam illuminates the sample; an analyser device in the scattered beam allows only those neutrons of a particular energy to reach the detector. This, together with time-of-flight analysis, provides the information about the change in energy of the neutron during the scattering process.

Conclusion:
For white beam instruments, the neutrons illuminate the sample for a long time following each pulse (10 - 100 ms; details are given below), whereas on an instrument with a monochromatic beam the sample is illuminated by neutrons only for a few μs.

Operational parameters of some relevant ISIS instruments

The pulsed neutron source ISIS operates at 50 Hz; that means that every 20 ms a neutron pulse is created. Most ISIS instruments operate at 50 Hz, i.e. making use of each neutron pulse. Other instruments suppress one or more pulses in order to be able to measure neutrons with longer wavelengths and, hence, longer times of flight. The following table describes the mode of operation of some ISIS instruments relevant for this discussion:

Instrument	**ΔT (*)**	**operating frequency**	
White incident beam:			
POLARIS	1 - 20 ms	50 Hz	medium resolution powder diffractometer
SXD	1 - 20 ms	50 Hz	single crystal diffractometer
IRIS	0 - 40 ms	25 Hz	large d-spacing diffractometer and high resolution spectrometer
HRPD	0 - 100 ms (0 - 200 ms	10 Hz 5 Hz)	high resolution powder diffractometer
PRISMA	1 - 9 ms	50 Hz	indirect geometry crystal analyser spectrometer; also used for elastic diffuse and critical scattering studies
Monochromatic incident beam:			
HET	0.01 - 0.03 ms	50 Hz	direct geometry chopper spectrometer for inelastic studies

(*) ΔT = time for which the sample is illuminated by neutrons.

The POLARIS powder diffractometer and the SXD single crystal diffractometer both operate at 50 Hz, taking data over the time range from essentially 2 - 20 ms.

IRIS is located at the end of a neutron guide, ~ 40 m from the target. Neutrons with wavelengths larger than 0.5 Å are transmitted with very little loss over this large distance with the help of supermirrors. IRIS is operated at 25 Hz, suppressing every second pulse. Data are taken over a time window range of 40 ms.

The HRPD high resolution powder diffractometer is located 100 m away from the target. A "frame overlap" chopper between target and sample blocks 4 in 5 neutron pulses, making ISIS effectively a 10 Hz source with a neutron pulse arriving at the sample every 100 ms. Consequently, on HRPD data are typically taken in a time window of 100 ms. Occasionally a 5 Hz chopper operation is used, to allow access to long d-spacings using a 250 ms window.

On PRISMA, a background chopper blocks the beam 9 ms after the creation of the neutrons to reduce the background created by - in general unwanted - very low wavelength neutrons. For both elastic and inelastic measurements the sample is illuminated for 9 ms.

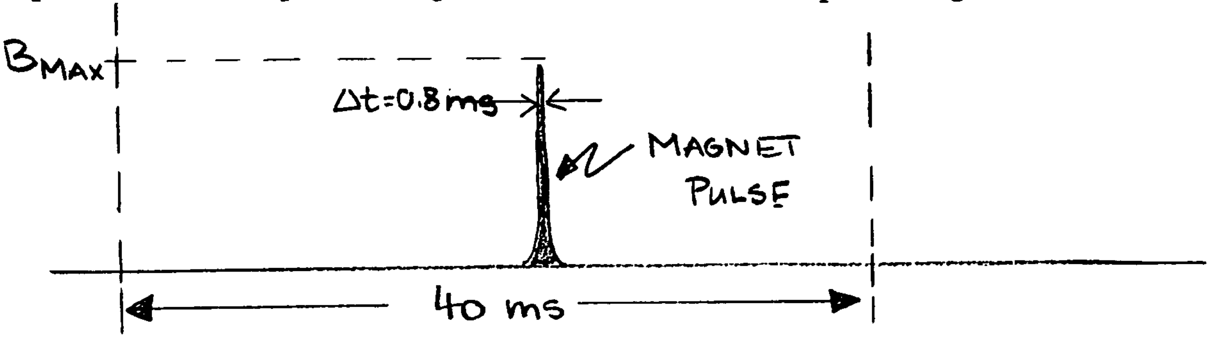
In contrast to diffractometers and white beam inelastic instruments like PRISMA, the HET chopper spectrometer has a monochromatic incident neutron beam. The sample is exposed to the neutrons for typically only 10 to 30 μs, depending on the energy of the incident neutrons.

The scattering cross-section for inelastic scattering is typically 2 - 3 orders of magnitude smaller than for elastic scattering. Typical measuring times for inelastic measurements are several days in contrast to diffraction experiments which sometimes take only a few hours. Given the fact that the repetition rate of a pulsed magnet will certainly be significantly less than 50 Hz, thus reducing the effective neutron flux considerably, this makes it a very hard task to use a pulsed magnet for inelastic studies at present pulsed neutron sources. For diffraction studies the prospects for pulsed magnetic field studies are much more promising. We will therefore focus the following discussion on the performance and efficiency for elastic scattering studies.

Choice of magnetic field pulse length

We turn now to see how the length of a pulsed magnetic field influences the efficiency with which an experiment is performed. We assume that we have available a pulsed magnetic field with a half sine wave pulse shape and with a maximum field value of B_{max} and we assume further that we require for the experiment a field of 90% of B_{max}. The relevant magnet up-time is then given by the length of time Δt for which $B \geq 0.9 \cdot B_{max}$. At this stage we do not discuss the effect of the repetition rate.

Option #1 : a short pulsed magnetic field with an overall pulse length of 3 ms

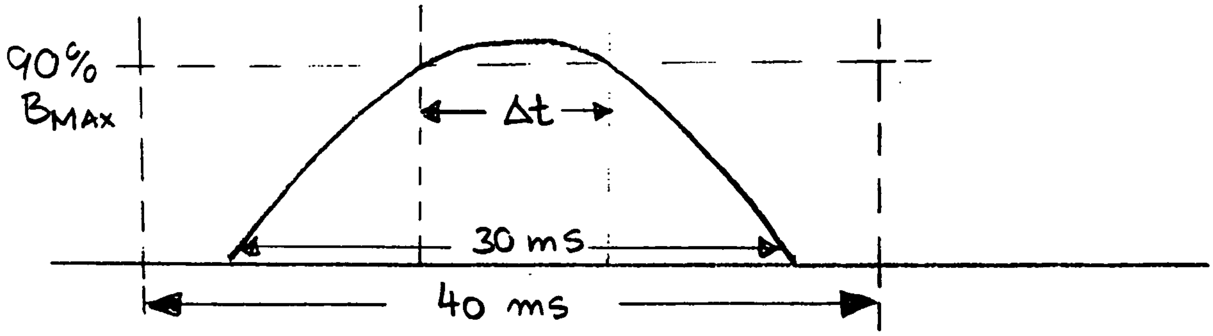


In this case Δt = 860 μs; that means that only a small part of the neutron frame is covered by the magnetic field. Because magnetic d-spacings are large, low indexed magnetic reflections (with a small scattering vector $Q=2\pi/d_{hkl}$ and therefore a strong magnetic form factor) are widely spaced apart; that means that a short pulse will probably cover only one magnetic Bragg peak at a time.

If the aim of the investigation is to detect a new magnetic phase induced by the magnetic field, a large time window might have to be "scanned" with the short magnetic field pulses before the new Bragg peaks associated with the new phase are discovered.

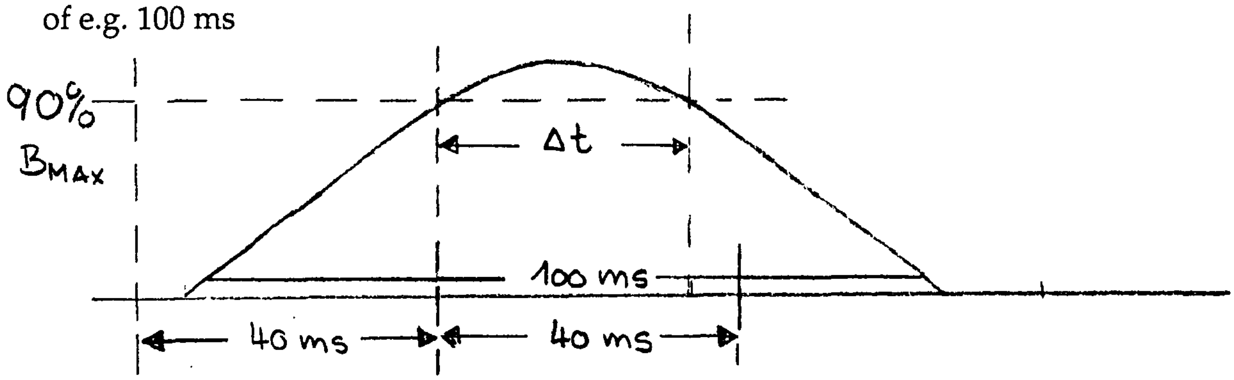
The signal recorded at times when the field is below 0.9 Bmax (1.07 ms for B increasing from zero to $B = 0.9 \cdot B_{max}$ and 1.07 ms for B decreasing to zero) might provide some information about intermediate states of the system if magnetic Bragg peaks appear during the sweep times.

Option #2 : a medium pulsed magnetic field with an overall pulse length of 30 ms



In this case Δt = 8.60 ms; that means that for a diffractometer operating at 50 Hz $B \geq 0.9 \cdot B_{max}$ for 40% of the active neutron window. The probability to detect new Bragg peaks have increased significantly. The field increases and decreases over a time period of 20 ms and therefore provides sweep information from a wide time window.

Option #3 : a long pulsed magnetic field with an overall pulse length of e.g. 100 ms



In this case Δt = 28.89 ms; for a 50 Hz instrument this would cover more than the time between two pulses and would therefore not be well matched. For an instrument operating with a reduced neutron repetition rate, the advantages of such a long pulse would be substantial.

Performance and efficiency of an elastic experiment in a pulsed magnetic field

A pulsed magnetic field facility would very probably require a dedicated beam line. It will need a significant large floor area and should be located as far away as possible from other instruments in order to avoid any interference. Therefore it is most likely that such an instrument would have to be built at the end of a guide. Such an instrument would probably also operate at less than 50 Hz in order to avoid frame overlap problems when using longer wavelengths.

We will discuss the efficiency of a particular set-up on the basis of a specific example. We have chosen for the comparison an instrument located at the end of a 40 m guide and operated at 25 Hz, i.e. suppressing one in two neutron pulses in order to avoid frame overlap and thus extending the useful neutron wavelength range to cover longer d-spacings.

Fig. 1 shows a diffraction pattern from a polycrystalline magnetic sample $Tb_{0.15}Tm_{0.85}$ at 4.2 K taken on HRPD. The magnetic reflections are indexed; the non-indexed reflections are of structural origin. If we want to measure more than one magnetic peak in the same magnetic field pulse at $B \geq 0.9 \cdot B_{max}$, Δt for which $B \geq 0.9 \cdot B_{max}$ would have to be at least 20 ms, preferably 40 - 50 ms to cover the six lowest-Q magnetic reflections. With a Δt of 100 ms, one could cover all the magnetic reflections out to Q=(0,0,4) which is about 4 $Å^{-1}$ in this case. The decrease of the signal due to the magnetic form factor means that this is about the useful limit.

The distance of HRPD from the target is 100 m in order to achieve excellent spatial resolution. For a magnetic diffraction experiment such good resolution might not necessarily be required and an IRIS type diffractometer at 40 m from the target would be more appropriate. In order to make the comparison, we scale the time-of-flight diffraction pattern of the $Tb_{0.15}Tm_{0.85}$ sample to an incident flight path of L = 40 m:

$$\lambda = 2 \cdot d_{hkl} \cdot \sin 2\Theta \qquad \text{and} \qquad \lambda = (h \cdot t) / (L \cdot m_n)$$

where t = total time of flight, measured in s and m_n is the mass of the neutron.

It follows that $d_{hkl} = \text{constant} \cdot t / L$

On HRPD the first magnetic reflection occurred at 60 ms and the last at 160 ms. On an IRIS type machine they would be recorded at 24 ms and 64 ms, respectively, filling the time frame of 40 ms.

Example #1:
We now assume that the magnetic structure is induced by the magnetic field and that it is not known at what times the Bragg peaks associated with the new magnetic structure would appear; therefore the field has to be scanned across the neutron window of 40 ms for a complete survey. We define the efficiency factor ζ as the inverse of the factor by which the total measuring time has increased :

$$\zeta = (\Delta t / 40\text{ ms}) \cdot (\nu_{Magnet} / \nu_{Source})$$

where ν_{Magnet} is the repetition frequency of the magnet and ν_{Source} that of the neutron source. We consider here only the efficiency in the utilisation of neutrons, not e.g. the efficiency based on power and energy consummation.

- Short pulse, 3 ms long ⇒ $\Delta t = 0.86$ ms and a repetition rate of 2 Hz:

no of steps in the time scan: 40 ms : 0.86 ms = 47
effect of reduced repetition rate : 25 Hz : 2 Hz = 12.5
⇒ factor by which total measuring time is increased : $47 \cdot 12.5 = 588$; ⇒ **$\zeta = 1/588$**

- Medium pulse, 10 ms long ⇒ $\Delta t = 2.86$ ms and a repetition rate of 1 Hz:

no of steps in the time scan: 40 ms : 2.86 ms = 14
effect of reduced repetition rate : 25 Hz : 1 Hz = 25
⇒ factor by which total measuring time is increased : $14 \cdot 25 = 350$ ⇒ **$\zeta = 1/350$**

- Long pulse, 140 ms long ⇒ $\Delta t = 40$ ms and a repetition rate of 1 shot per 2 minutes:

no of steps in the time scan: 40 ms : 40 ms = 1
effect of reduced repetition rate : 25 Hz : 1/120 Hz = 3000
⇒ factor by which total measuring time is increased : $1 \cdot 3000 = 3000$ ⇒ **$\zeta = 1/3000$**

Example #2:
Only one magnetic Bragg peak has to be investigated, e.g. to determine a (B,T) phase diagram or to study the anisotropy of the magnetic correlation length. This would be typically done with a single crystal. The position of the Bragg peak is known; no scanning required. A typical Bragg reflection has a line widths in the order of 0.1 ms. In order to detect line broadening and small shifts in the Bragg peak positions e.g. for incommensurate structures, the magnetic field should cover a time range of 0.5 ms.

- Short pulse, 3 ms long ⇒ $\Delta t = 0.86$ ms and a repetition rate of 2 Hz:

effect of reduced repetition rate : 25 Hz : 2 Hz = 12.5
⇒ factor by which total measuring time is increased : = 12.5 ⇒ **ζ = 1/12.5**

- Medium pulse, 10 ms long ⇒ $\Delta t = 2.86$ ms and a repetition rate of 1 Hz:

effect of reduced repetition rate : = 25
⇒ factor by which total measuring time is increased : = 25 ⇒ **ζ = 1/25**

- Long pulse, 140 ms long ⇒ $\Delta t = 40$ ms and a repetition rate of 1 shot per 2 minutes:

effect of reduced repetition rate : 25 Hz : 1/120 Hz = 3000
⇒ factor by which total measuring time is increased : = 3000

In this case, however, the signal during the rise and fall time of the magnetic field also provides information on a point in the (B,T) diagram. Therefore the efficiency factor is in this case 1/1000. ⇒ **ζ = 1/1000**

These two examples are two extreme cases, but nevertheless typical examples for neutron studies in a magnetic field.

Conclusion (?)

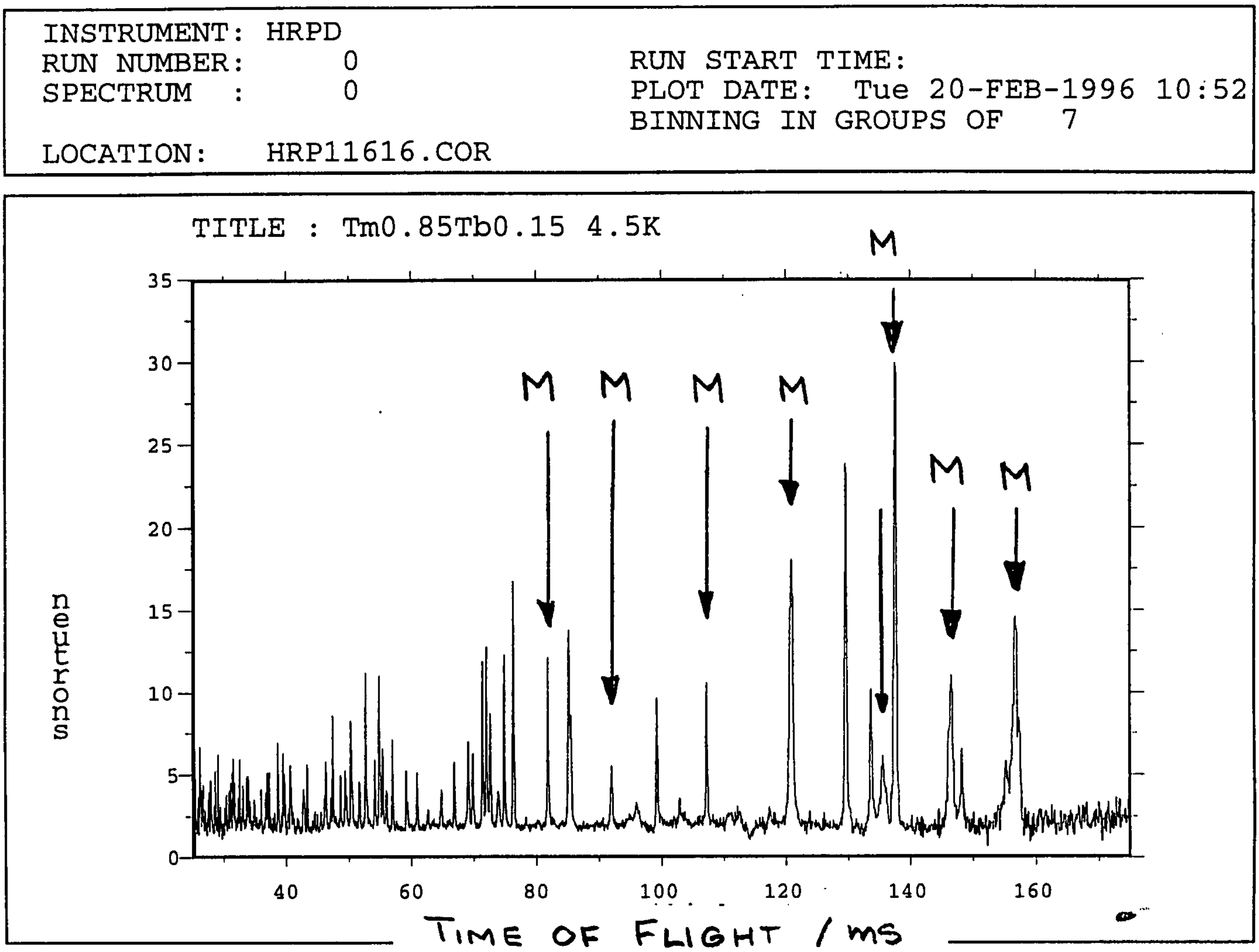
The crucial parameter of a pulsed magnetic field is the repetition rate $\nu_{\mathrm{Magnet}} \cdot \Delta t$.

If the technical difficulties can be overcome and in particular the repetition rate could be significantly improved in comparison to the preliminary estimates, the long pulse option offers a lot of advantages:

- If Δt for $B \geq 0.9 \cdot B_{max}$ can be matched to the neutron window (as discussed for a 40 m , 25 Hz machine) then this offers the most efficient way to determine new Bragg peaks
- The problems of heating of the sample through eddy currents is essentially eliminated.
- A long pulse option is also of interest to the reactor neutron community, thus widening the number of potential users.

The short pulse option has the advantage that the technical problems do not appear so severe. In particular it offers a higher repetition rate (but introduces problems through eddy current heating). It is significantly less efficient for searching for new structures. At next generation pulsed neutron sources with a 30 times higher neutron flux than ISIS, the short pulsed field would be the favourite option for an inelastic direct geometry spectrometer.

Uschi Steigenberger
February 1996



INSTRUMENT: HRPD
RUN NUMBER: 0
SPECTRUM : 0
RUN START TIME:
PLOT DATE: Tue 20-FEB-1996 10:52
BINNING IN GROUPS OF 7
LOCATION: HRP11616.COR

TITLE : Tm0.85Tb0.15 4.5K

Figure 1:

Diffraction pattern from a polycrystalline magnetic sample $Tb_{0.15}$ $Tm_{0.85}$ at 4.5 K taken on the powder diffractometer HRPD at ISIS. The data are displayed as a function of time of flight. The magnetic reflections are marked. There are more magnetic reflections at times shorter than 8 ms, but for reasons of clarity they are not marked.

Workshop on Pulsed Magnetic Fields and Pulsed Neutron Sources

29-30 June 1995
The Cosener's House, Abingdon, Oxfordshire, UK

organised by Birkbeck College, London
and the ISIS Facility, Rutherford Appleton Laboratory

Summary

The aims of the Workshop were:

- to bring together specialists in pulsed magnetic field techniques and in neutron scattering;
- to review the present technology in pulsed magnetic fields;
- to bring together the expertise to discuss a design which could eventually be implemented at the ISIS Facility and other pulsed neutron sources.

The Workshop was attended by 26 people: a list of the participants and the final programme is appended.

The aims of the Workshop were realised with the following conclusions:

(i) There was an awareness by the high field community that ISIS engineers already have considerable expertise in the design of power supplies for pulsed magnets used in accelerators. Scope for possible technology transfer and sharing of expertise is present.

(ii) There is an opportunity for both the high magnetic field (HMF) and the neutron scattering (NS) communities to broaden their user bases, as each community learns about the significance of both techniques.

(iii) A principal aim of the HMF community is to develop the *highest possible* field for experiments, which usually require only a small number of field pulses. This aim demands the development of the strongest possible materials for the coil windings. The neutron scattering experiments would require *a large number* of magnet pulses, perhaps 10^5-10^6 and so magnet reliability is of primary importance. Such a magnet would be operated well below the plastic limit of the coil windings. Stronger materials would benefit the NS community by leading to higher reliability. There are therefore common R&D interests.

(iv) Three design concepts for pulsed magnets for NS applications emerged as a result of the Workshop discussions:

(a) A short pulse (3-4 ms), high repetition rate (2 Hz) magnet. Such a magnet based on the conceptual design study of the Los Alamos /Tallahassee group would use available materials and existing technology for the magnet and power supply, and can certainly be built. The main question is the long-term reliability of such a magnet and the need to operate for at least 10^6 pulses.

(b) Professor Askenazy (Toulouse) proposed a long pulse (1-5 sec) magnet, operated on a 1:25 (for example) duty cycle, so that 25-125 sec was available for the magnet to be cooled between pulses. The advantage of this would be to reduce the number of pulses per NS experiment by a factor of 10^2 to 10^3. However, such a magnet would be physically larger because of the need to have a larger time constant, and it would need a larger power supply. Such a power supply could be either mains based or use a capacitor bank. Another important advantage of a long pulse magnet is that the eddy currents induced in the sample and cryogenic equipment would be very significantly less than for design (a).

(c) Dr Jones (Oxford) proposed the use of a "platform field". This design would combine a wide bore superconducting magnet (say 8-10 Tesla) with a pulsed field magnet inside it. In this case the magnet would have to be a short pulse, high repetition rate design, because a long pulse magnet would be larger.

(v) The installation of a pulsed magnet at ISIS would require special water cooling and electricity supplies. In order to bring in these supplies, and to reduce the unwanted effects of the pulsed field on other instruments, it would be highly desirable to develop a dedicated beam line for this facility. A possible beam line would be the guide adjacent to HRPD.

The way forward

The magnet designers agreed to consider the options (a)-(c) and to make design calculations of the new concepts of (b) and (c).

The neutron scatterers agreed to consider the relative merits of short pulse and long pulse magnets for typical experiments, at both pulsed and steady state neutron sources.

It was agreed that a further meeting should be held in approximately 6 months time to discuss conceptual designs based on (a), (b) and (c).

Keith McEwen & Uschi Steigenberger
August 1995

Second Workshop on Pulsed Magnetic Fields and Pulsed Neutron Sources

19 January 1996
The Cosener's House, Abingdon, Oxfordshire, UK

organised by Birkbeck College, London
and the ISIS Facility, Rutherford Appleton Laboratory

Summary

The purpose of this second meeting between the pulsed magnetic field and neutron communities was to discuss in detail the three options for a pulsed magnet for ISIS which were identified at the last meeting as the most promising ones. 15 experts from the major European magnet laboratories and the US National Magnet Laboratory attended the one day meeting.

Progress with the Tallahassee/Los Alamos short pulse design

Hans Schneider-Muntau, National High Magnetic Field Lab, Tallahassee

As a consequence of the recommendation, expressed at the previous workshop to extend the useful lifetime of the pulse magnet from 10^5 to $10^{7\text{-}8}$ pulses, the material fatigue problems were studied in more detail. It turned out that only very limited measurements and data are available in the literature. However, it was found that the fatigue life of materials is extremely reduced at elevated operating temperature.

As a consequence three measures have been taken:

1) A proposal has been put forward for funding for a two year material characterisation programme, aimed at investigating conducting and insulating materials for their fatigue life up to 10^8 stress cycles.
2) A preliminary design study assuming extremely low stress levels was carried out by Dr. Eyssa. The original pancake design has been replaced by a significantly understressed two thin coil Bitter design and an additional outer coil, with the relevant magnet geometries such as magnet gap, inner diameter, horizontal window access etc. unchanged. The design study confirmed that 30 T can still be achieved, however at the expense of an increased magnet volume, capacitor bank and power consumption.
3) The relative importance of working at liquid nitrogen temperatures against elevated room temperatures ($l\text{N}_2$ costs against increased power and cooling costs) will be studied.

Proposal for a long pulsed magnet

Salomon Askenazy, Toulouse

In order to achieve 30 Tesla the pulsed coil has to be boosted with a platform field. The following considerations focus only on the performance of the pulsed field insert.

Various options were presented and power and cooling requirements discussed:
(i) a platform field of 12 T, combined with a 18 T pulsed coil with a pulse length of 1 s, $\Gamma = l/a_2 = 0.8$, filling factor $\lambda = 0.92$ and a repetition rate of 1 shot per 5 minutes;

(ii) a platform field of 18 T combined with a 12 T pulsed coil with a pulse length of 1 s and a repetition rate of 1 shot per 2 minutes;

It was proposed to perform a small scale feasibility study for the following system :
A platform field of 12 T combined with a 18 T pulsed coil, pulse length of *0.1 s*, $2a_2 = 17$ cm, $2l^* = 23$ cm and a repetition rate of 1 shot per 5 minutes, cooled by lN_2. This could be achieved by making use of the transportable 135 kJ generator which is being built for the 100 Tesla feasibility study (some modifications would have to be made to the design). As platform field it is proposed to use either the 12 Tesla continuous magnet at Oxford or to build in Toulouse a 12 T pulsed coil operated with the Toulouse generator.

It was thought that now the time has come to start to do some experimental feasibility studies. The costs for the feasibility study could be kept moderate by making use of existing equipment.

The open questions are the feasibility of a 12 Tesla *split coil* platform field, its power requirements (in case of a resistive wire magnet) and the most appropriate and economic way of cooling. Also the overall operating costs have to be considered in detail.

The SNCMP would also be interested to join the development of a short pulsed system, in particular the development of a fast pulsed generator suitable for 2 Hz operation and the provision of reinforced filament conductors.

Certain merits are associated with a long pulse system, connected with the nature of pulsed neutron source. The question - short pulse versus long pulse is discussed from a neutron scattering point of view in a separate note attached to this summary.

Proposal for a platform field design
Marleen Van Clemputt & Harry Jones, Oxford

As superconducting magnets do not like rapid field changes, a superconducting platform field would have to be screened against rapid changes from the inner magnet; however, screens reduce the effective magnetic field and consequently a superconducting platform field would have to be very big. The cryogenic design would also be non-trivial.

The preliminary design by the Oxford team aimed for an understressed short pulsed magnet which could be cooled to $T_{initial}$ within 0.5 s. An understressed design would guarantee more an improved fatigue life - it is this area which is the big unknown. A design using radially separated coils (polyhelix) appears most appropriate. Such a magnet could deliver 20 T, with a pulse length of 3 - 4 ms and a repetition rate of 2 Hz, using a conductor partly steel (high strength) and partly Cu (good electrical conductivity); this magnet would have to be cooled with lN_2 to improve its life time, the strength of the steel and the electrical conductivity, requiring 1 ton of lN_2 per hour !! The maximum field could be enhanced by a 4 - 5 T platform field.

In general, the Oxford team could contribute their extensive experience with conducting wire; there is also interest to study cavitation effects in a lN_2 cooled "dilute" coil. A postdoc and some money for equipment are needed in order to progress with this project.

Pulsed magnets at NIMROD - 25 years ago
Paul Flower, RAL

A pulsed magnet was operating at the NIMROD accelerator 25 years ago. The magnet - a solenoid - was operated at 33T, with a 5 s repetition rate, using 200 kW mean continuous power; φ_{in} = 50 mm; φ_{out} = 120 mm; cooled with demineralised water; the life time of the magnet design depended strongly on B_{max} of operation : B_{max} = 25 T : life time = 200000 shots; B_{max} = 33 T, life time = 1000 shots.

The importance of developing diagnostic tools for early failure detection was stressed.

Unfortunately, all of the equipment has been disposed off. What remains is the know-how and enthusiasm of some experts involved in the project 25 years ago !

Availability of electrical power at ISIS
Adrian Morris, RAL

RAL receives 11 kV from Harwell which has a total capacity of 30 MVA; ISIS needs 11 MVA; 1-2 MVA capacity is available on substations around ISIS, but would require investment in transformers, switchgear, cables etc.; power at lower levels (up to 200 kW) could be installed from existing distribution equipment at relatively low cost; the question if the grid is stiff enough and if reactive power can be fed back into the grid has to be addressed.

Multipulse coils - some general remarks
Paul Frings, Amsterdam

In order to achieve the highest repetition rate, the design has to be optimised for highest dissipative efficiency, using highest conductivity and optimal shape. Small Cu magnets appear to be most favourable, although they would have only limited life times (10^4 to 10^5 shots); a smaller size might have the advantage that the magnet itself is less expensive and easier to replace; certainly the power supply will be less expensive for a smaller magnet - it is better to start small ! 25 T could be achieved, with pulse lengths of at least 10 ms and potentially a 1 - 2 Hz repetition rate, in a bore of 25 mm. Such a magnet would probably be water cooled, although lN_2 cooling should also be considered. Even for the same overall duty-cycle this pulse length is considered by Frings as superior to a magnet with longer pulse times, assuming a sinusoidal field dependency.

Alternative power supplies (i.e. direct mains connection or motor generator, 2 MW continuous power, 200 kW drive, 20 (?) MW inductive power) have to be investigated, also with respect to capital and operating costs.

Typical examples :

- coil at 300K, 10ms, 1Hz (duty cycle 1%) -:
  $P_{resistive} = 7.5$ MW , $P_{magnet} = 34$ MW , $P_{drive} = 75$ kW (& losses -> 100 kW)
- smaller coil :
  $P_{resistive} = 15$ MW , $P_{magnet} = 9$ MW , $P_{drive} = 150$ kW
- coil at 77K :
  $P_{resistive} = 1.3$ MW , $P_{magnet} = 34$ MW , $P_{drive} = 13$ kW

More detailed design calculations are necessary once a decision has been taken which option to pursue in more detail. A postdoc would be needed to perform these calculations and to test a small prototype. Amsterdam would be interested to contribute if the proposed magnet design would bear similarities to the Amsterdam 60 Tesla project or the 40 Tesla design.

Comments and points of discussion:

Oxford Instrument is presently developing a 15 T continuous superconducting magnet for the Neutron Scattering Centre at the Hahn Meitner Institute in Berlin.

An international collaboration on R&D for a pulsed magnetic field facility for neutron scattering should be aimed for. DGXII in Brussels runs a programme on "Co-operation with industrialised countries"; this should be looked into.

Some participants felt that the resources available through the present network for the 100T feasibility study were not enough to extend the scope of that study and include the neutron magnetic field feasibility study .

Oxford Instruments expressed an interest in becoming involved in the design of a non-magnetic cryostat for use in a pulsed field insert.

It is now very important that the Neutron Community defines their requirements and the most appropriate magnet design.

Financial support from the EPSRC is gratefully acknowledged.

Uschi Steigenberger & Keith McEwen
February 1996

Workshop on
Pulsed Magnetic Fields and Pulsed Neutron Sources

to be held on **29.-30. June 1995**
in the Cosener's House, Abingdon, Oxfordshire, UK

organised by the ISIS Facility, Rutherford Appleton Laboratory
and Birkbeck College, London

Programme

Thursday 29 June 1995 :

9:15 Professor Keith McEwen, Birkbeck College, London
Welcome and Introduction

9:20 Dr Andrew Taylor , Head of the ISIS Facility
The ISIS Facility

9:30 Professor Keith McEwen, Birkbeck College, London
Pulsed neutron sources and pulsed magnetic fields - :
Experimental techniques

9:50 Dr Uschi Steigenberger , ISIS
Pulsed neutron sources and pulsed magnetic fields - :
Design considerations

10:10 Professor Masa Arai, Kobe
Neutron scattering in a high magnetic field at KENS

10:25 Dr Rob Robinson, Los Alamos
Scientific opportunities in research with high magnetic fields
Report from Tallahassee meeting

10:40 **Coffee**

Review of existing and planned pulsed magnetic field facilities for neutron and non-neutron research

11:00 Professor Mitsuhiro Motokawa, Sendai
Recent development of a high field magnet for neutron scattering

11:25 Dr H Schneider-Muntau, National High Magnetic Field Lab, Tallahassee
Pulsed magnets and pulsed magnet technology

11:50 Professor Gerald Badurek, Vienna
The pulsed field neutron diffractometer at the TRIGA reactor Vienna

12:05 Dr Dragomir Georgiev, Dubna
The pulsed magnetic field facility at IBR-2

12:20 Dr Vladimir Voldemarovich Nietz, Dubna
The use of pulsed magnetic fields in condensed matter research by neutrons

12:30 **Lunch**

13:45 Dr Paul Frings, Amsterdam
Pulsed magnetic fields: mechanical limitations, power limited design

14:05 Dr Harry Jones, Oxford
The Oxford pulsed magnetic field facility

14:25 Dr Nick Kerley, Oxford Instruments
Production of milli-Kelvin sample temperatures in pulsed fields up to 60T

14:45 Dr Walter Joos
Pulsed High Magnetic Fields with SHOTS

15:00 - 18:00

Discussions on pulsed magnetic field designs for the application in pulsed neutron scattering :

Possible topics :
- The magnet design
- The power supply
- The sample environment
- Interaction/interference with surrounding beam lines
- Cost considerations (Capital and operating, also manpower)

16:00 **Tea**

19:30 **Workshop Dinner**

Friday 30 June 1995:

9:15 The way forward:
- Summary and conclusion from the technical discussion
- Discussion on possible future collaborations, including

Professor Lawrie Challis, Nottingham
The European High Magnetic Field Project

- Possible financial resources
- Workshop summary

10:30 **Coffee**

12:30 **Lunch**

End of Workshop

Afternoon : Opportunity to visit the ISIS Facility.

2. Workshop on Pulsed Magnetic Fields and Pulsed Neutron Sources

19 January 1996
in the Cosener's House, Abingdon, Oxfordshire, UK

organised by the ISIS Facility, Rutherford Appleton Laboratory
and Birkbeck College, London

Programme

Friday 19 January 1996 :

9:00	*Welcome and Introduction* Professor Keith McEwen, Birkbeck College, London
9:10	*Progress with the Tallahassee/Los Alamos short pulse design* Dr Hans Schneider-Muntau, National High Magnetic Field Lab, Tallahassee
9:30	*Proposal for a long pulsed magnet* Professor Salomon Askenazy, Toulouse
10:00	*Proposal for a platform field design* Dr Harry Jones, Oxford
10:20	Discussion
10:30	**Coffee**
10:50	*Pulsed magnets at NIMROD - 25 years ago* Paul Flower, RAL
11:00	*Availability of electrical power at ISIS* Adrian Morris, RAL
11:10	*Comments on the proposals* Dr Walter Joss, Grenoble
11:30	*Comments on the proposals* Dr Paul Frings, Amsterdam
11:50	Discussion

12:30 **Lunch**

13:30 Discussion, continued, to include

choice of design
potential collaborations (e.g. through a European network)
potential sources of funding
critical R&D issues
manpower required
resources needed for a prototype

The meeting is expected to finish at 16:00. Transport to Heathrow will be arranged.

List of participants :

1. Workshop on Pulsed Magnetic Fields and Pulsed Neutron Sources

29 - 30 June 1995, The Cosener's House, Abingdon, Oxfordshire, UK

1. Professor Masa Arai
University of Kobe & KENS/KEK, Japan

2. Professor Salomon Askenazy
Service Nationale des Champs Magnétiques Pulsés, Toulouse, France

3. Professor G Badurek
Institute of Nuclear Physics, Tech. University Vienna, Austria

4. Mr Brian Boland
ISIS Facility, CCLRC, UK

5. Dr Helen Brownlee
EPSRC, UK

6. Dr Colin J Carlile
ISIS Facility, CCLRC, UK

7. Professor L J Challis
University of Nottingham,UK

8. Professor Bruce Forsyth
ISIS Facility, CCLRC, UK

9. Dr Paul Frings
Van der Waals-Zeeman Laboratory,
University of Amsterdam, The Netherlands

10. Dr Dragomir Georgiev
Joint Institute for Nuclear Research,
Frank Laboratory of Neutron Physics, Dubna, Russia

11. Dr Mike Harold
ISIS Facility, CCLRC, UK

12. Dr Harry Jones
Clarendon Laboratory, University of Oxford, UK

13. Dr Walter Joos
Service Nationale pour des Champs Intenses, Grenoble, France

14. Dr Nick Kerley
Oxford Instruments, UK

15. Dr Kevin Knight
ISIS Facility, CCLRC, UK

16. Professor Jochen Litterst
Technical University, Braunschweig, Germany

17. Professor Keith McEwen
Birkbeck College, London, UK

18. Mr Adrian Morris
ISIS Facility, CCLRC, UK

19. Professor Mitsuhiro Motokawa
Tohoku University, Sendai, Japan

20. Dr Vladimir V Nietz
Joint Institute for Nuclear Research,
Frank Laboratory of Neutron Physics, Dubna, Russia

21. Dr Robert A Robinson
Manuel Lujan Jr Neutron Scattering Center, Los Alamos, USA

22. Dr Hans Schneider-Muntau
National High Magnetic Field Laboratory, Tallahassee, Florida, USA

23. Dr Uschi Steigenberger
ISIS, CCLRC, UK

24. Professor Michael Steiner
Hahn Meitner Institut, Berlin, Germany

25. Dr Norbert Stüßer
Hahn Meitner Institut, Berlin, Germany

26. Dr W Gavin Williams
ISIS, CCLRC, UK

2. Workshop on Pulsed Magnetic Fields and Pulsed Neutron Sources
19 January 1996, The Cosener's House, Abingdon, Oxfordshire, UK

1. Professor Salomon Askenazy
   Service Nationale des Champs Magnétiques Pulsés, Toulouse, France

2. Dr Helen Brownlee
   EPSRC, UK

3. Dr William Duncan
   Oxford Instrument, UK

4. Mr Paul Flower,
   CCLRC, UK

5. Professor Bruce Forsyth
   ISIS Facility, CCLRC, UK

6. Dr Paul Frings
   Van der Waals-Zeeman Laboratory, University of Amsterdam, The Netherlands

7. Dr Harry Jones
   Clarendon Laboratory, University of Oxford, UK

8. Dr Walter Joos
   Service Nationale pour des Champs Intenses, Grenoble, France

9. Professor Keith McEwen
   Birkbeck College, London, UK

10. Mr Adrian Morris
    ISIS Facility, CCLRC, UK

11. Dr Hans Schneider-Muntau
    National High Magnetic Field Laboratory, Tallahassee, Florida, USA

12. Dr Uschi Steigenberger
    ISIS Facility, CCLRC, UK

13. Professor Michael Steiner
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