Engin: An Engineering Strain Scanner at the ISIS Facility

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Introduction

Under an EC initiative (the Brite EuRam programme) funding has been made available to develop the measurement of internal stress using the time-of-flight neutron diffraction technique. The project, which has the title 'PREMIS' (PREcise Measurement of Internal Stress) is being jointly undertaken by researchers from Germany (Kiel), Italy (Ancona) and the UK (Cambridge, Open University and RAL). While the technique of neutron strain measurement has been developed considerably since its inception in 1980 [1], this has largely been on reactor neutron sources. The use of the time-of-flight method offers some potential advantages, but requires development to realise these advantages.

The PREMIS project includes the construction of a dedicated strain measurement instrument ENGIN, incorporating for the first time the use of radial collimators to achieve a sampling volume < 2 mm, and a 2-D array of detectors to shorten data acquisition times and improve strain sensitivity. In addition, two 90° scattering angles will be used to enable the simultaneous measurement of strain in two perpendicular directions. The primary advantages of a dedicated facility will be:

- reduced setting up time
- precision sample positioning
- an optimised detector array offering efficient data collection
- the simultaneous measurement of strain in orthogonal directions.

With pulsed sources, a white incident spectra is used with the result that the entire diffraction pattern from a single volume element within the sample is measured simultaneously. By measuring the entire diffraction pattern, a number of major advantages are obtained:

- the strain in both phases of a composite material may be measured simultaneously
- anisotropic sample behaviour can be identified, quantified and, if necessary, allowed for

- the presence of texture can be determined
- the lattice parameter (and hence the strain) may be determined to a greater precision.

The initial aim of the programme is to build a dedicated strain scanner together with its ancillary equipment (furnaces, stress rig etc.) and analysis software. The final aim of the programme is to use this equipment to develop the technique in a number of key areas:

- determination of full stress tensors
- the stroboscopic study of thermally cycling material
- the study of fatigue cracks

The economic justification for such a programme has been given elsewhere [2], and this paper will concentrate on the technical aspects of the instrument design.

Instrument Design Criteria

These may be simply listed:

1. To measure internal strain to better than 50 microstrain.
2. To make this measurement on a gauge volume which may have any dimension 2 mm or less.
3. The gauge volume may be up to 50 mm below the surface.
4. The gauge volume should be positioned with an accuracy of 0.01 mm for specimens of up to 100 kg in weight. Heavier specimens (up to 200 kg) should be accommodated with reduced precision.
5. Small samples should be able to be temperature controlled to $\pm$ 5K in a range up to 1000c.

Instrument Design

The traditional collimation design of neutron strain measuring instruments on reactor sources is shown in Figure 1a [3]. A parallel, monochromatic neutron beam is masked down to the size required (typically 1-5 mm) and similar masks on the outgoing collimation define the gauge volume. This technique is extremely effective for measuring the d-spacing of one reflection chosen such that $2\theta \sim 90°$.

Such a design may be copied for use on time-of-flight instruments, but since the flux over a given wavelength range is generally lower, individual neutron peaks take longer to record. The white beam, time-of-flight technique is able to record diffraction patterns at any scattering angle, and thus the intensity of time-of-flight diffraction peaks can be improved if the collimation geometry shown in Figure 1b can be realised. This uses a radial collimator to define the gauge volume and allows the solid angle of the detectors to be increased by a factor of ~ 50.

The theory of such collimators is straightforward. Assuming the vanes of the collimator to be black, the ray diagram for a single element of the collimator is shown in Figure 2. Calculation of the solid angle subtended by the detector for each point on the incident neutron beam (e - g) shows that the gauge volume is defined along the beam direction by a triangular response function with

$$FWHMH = jl/(L-l)$$

In the other orthogonal directions the shape of the gauge volume is determined by the incident beam.

In the PREMIS instrument it has been decided that the gauge distance along the beam direction should be 1.41 mm (FWHMH), which corresponds to a rectangular distribution with a width of 2 mm. It was further decided that the radial collimator should start 150 mm from the gauge volume. This distance is obviously a compromise: making it larger makes the instrument easier to use, but makes the collimator vanes closer together (for a given gauge size). As the collimator vanes become closer, the radial collimator loses efficiency (from its mark/space ratio) and becomes progressively prone to manufacturing error.

The collimator design used in ENGIN is in fact an extension of the parallel 'Rutherford Collimators' that have been used for many years. They are constructed from mylar film coated with gadolinium-oxide loaded paint and are manufactured by L&H Designs Ltd. Gloucester, GL3 4AA,UK.

Detectors will be located at the rear of the radial collimator, and occupy a solid angle of 0.125 sr. They will consist of 46 vertical, 5 x 300 mm strips of Li-loaded scintillator, each directly viewed by two photomultipliers. The width of the detectors is, coincidentally similar to that of the spacing of the large end of the collimator. This is purely a coincidence: the dimension of the collimator is chosen to define the gauge volume, the width of the detector is determined by the Δd/d resolution required. This resolution is largely dictated by the primary flight path (15m), and the detector width has been chosen to match the beam divergences in the incident and diffracted beam.

The instrument will also include a large XYZω translator, to enable the sample to be accurately positioned in the beam. A diagram of the translator is shown in Figure 3, and a plan view of the instrument in Figure 4. Also shown in the plan view of the instrument are the 2 theodolites which are rigidly mounted and aligned to intersect on the axis of the ω-rotation.

In addition, a glass walled furnace is being constructed to enable precisely positioned components to be thermally controlled, thus permitting the in-situ study of thermal relief procedures or thermal cycling effects. Design criteria for this device include a low thermal inertia to provide quick response times and temperature control allowing for well-defined heating and cooling conditions up to 1000°C as well as synchronisation of the temperature in neutron-stroboscopic thermal-cycling studies.

Results from an ENGIN Prototype

The instrument described above is the instrument that will be installed between June - December 1993. In advance of this construction programme some results have been obtained using a similar (but smaller) collimator, also positioned on the TEST beam at ISIS.

The aims of these tests were to establish that a radial collimator of this type could be successfully constructed and to measure the gauge volume defined by the radial collimator. The prototype radial collimator contained 20 vanes, was 600 mm long and had dimensions of 150 x 117 mm at the detector end which was 750 mm from the sample. To achieve the required gauge volume (1.4 mm FWHMH) at a working distance of 150 mm from the sample, the mylar sheets were 1.12 mm apart at the front of the collimator. To investigate the gauge volume definition achieved by the collimator, a nickel rod of 2 mm diameter was scanned along the incident neutron beam (i.e. across the collimator's field of view) and the intensity of the (111) reflection plotted as a function of position (see Figure 5). The width of this distribution is the convolution of the viewing window of the collimator and the specimen itself. It is straightforward to show that the second moment of the observed convolution (σ_o) is related to those of its constituent functions by:

$$\sigma_o^2 = \sigma_g^2 + \sigma_r^2$$

The observed σ_0 = 0.832 mm, and since σ_r = 0.5 mm the derived value of σ_g for the gauge volume is 0.66 mm, in close agreement with that expected (0.58) for a triangular distribution with FWHMH = 1.4 mm.

The experiments with the prototype also enabled us to evaluate the resolution and counting times that would be required in the full scale instrument. Figure 6 shows a typical spectrum recorded for a steel sample in 10 minutes. Extrapolation to the larger, ENGIN detector shows that such patterns will be recorded in 3 minutes with a similar $\Delta d/d$ resolution of 1.4×10^{-4}.

References

1. Allen A J, Andreani C, Hutchings M T, & Windsor C G (1981) 'Measurement of internal stress within bulk materials using neutron diffraction', NDT International, October, pp249-54.
2. BRITE-EURAM II proposal #5129, submitted to CEC in March 1992.
3. Hutchings M T, 'Neutron diffraction measurement of residual stress fields: overview and points for discussion' pp 3-18 in ' Measurement of Residual and Applied Stress Using Neutron Diffraction' Eds. M T Hutchings & A D Krawitz, Kluwer Academic Pub. , NATO ASI Series Vol.216 (1992)

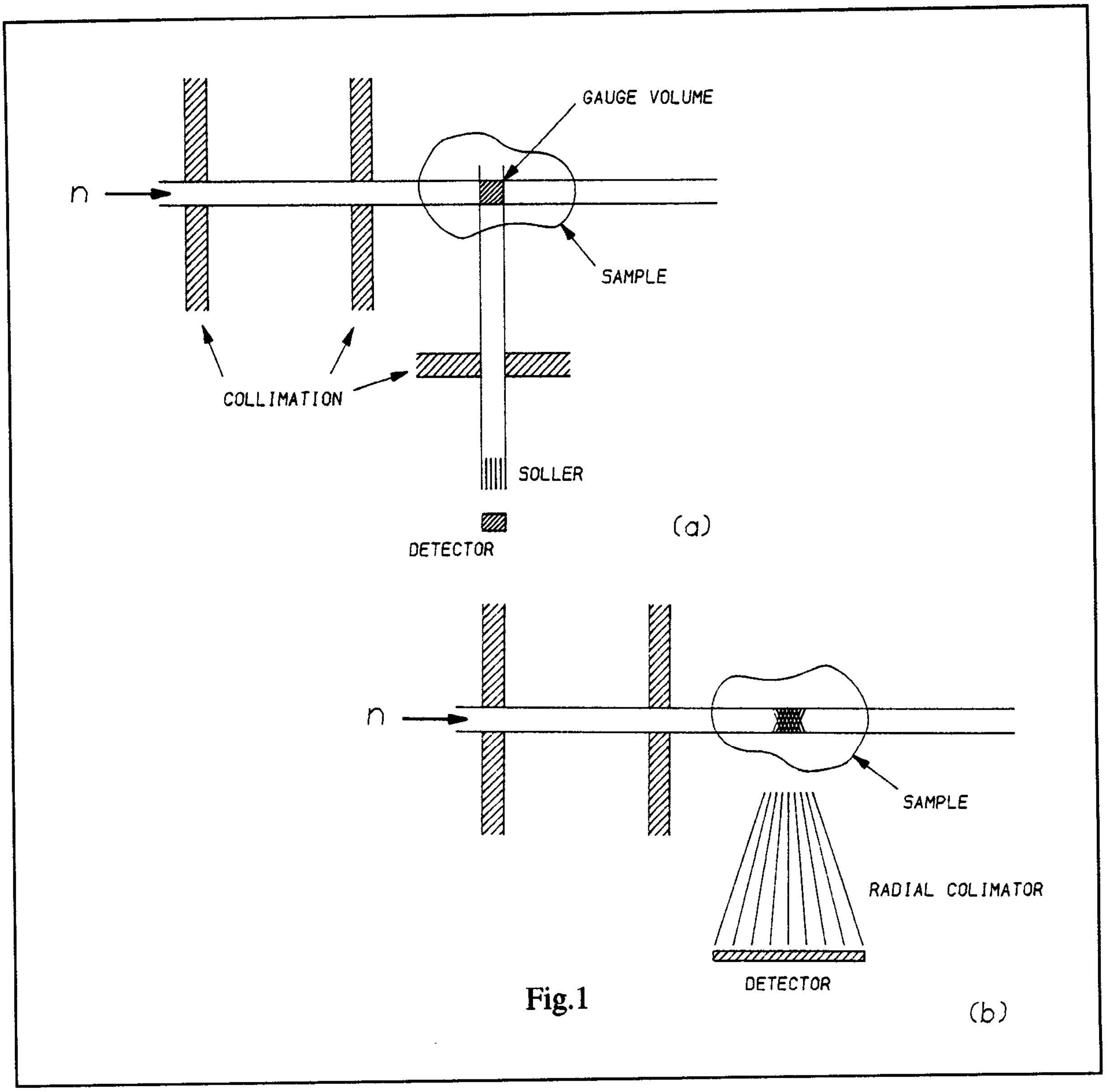
GAUGE VOLUME
n
SAMPLE
COLLIMATION
SOLLER
DETECTOR
(a)
n
SAMPLE
RADIAL COLIMATOR
DETECTOR
(b)

Fig.1

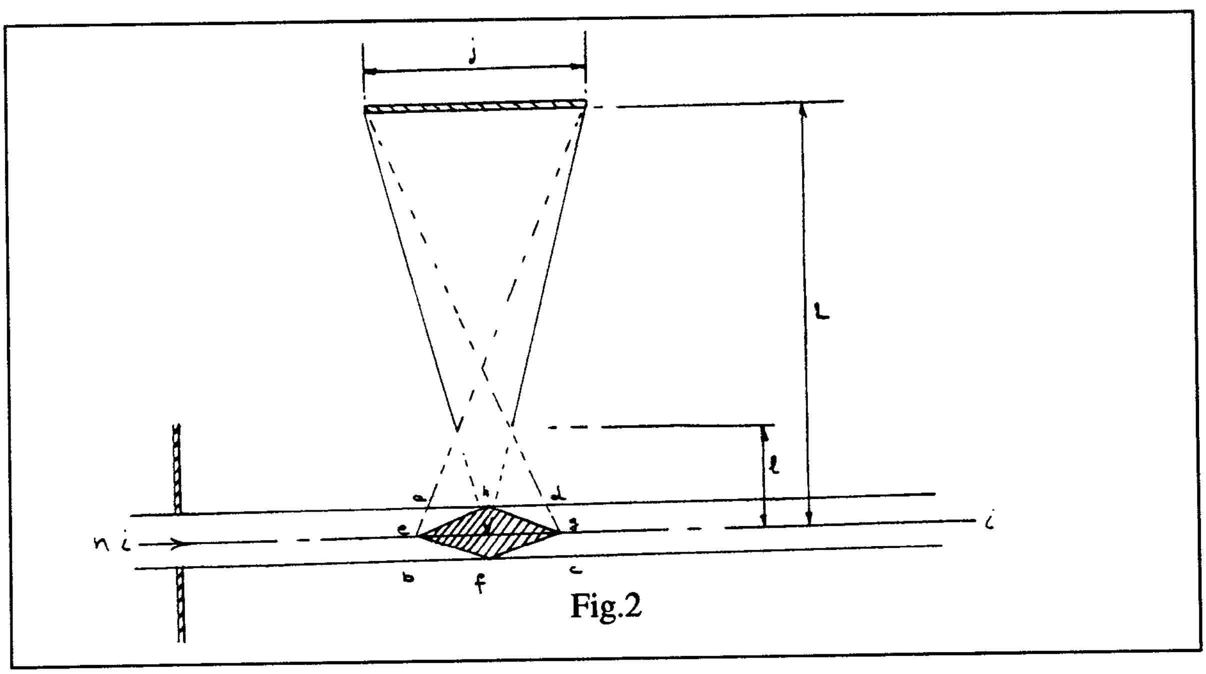
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Fig.2

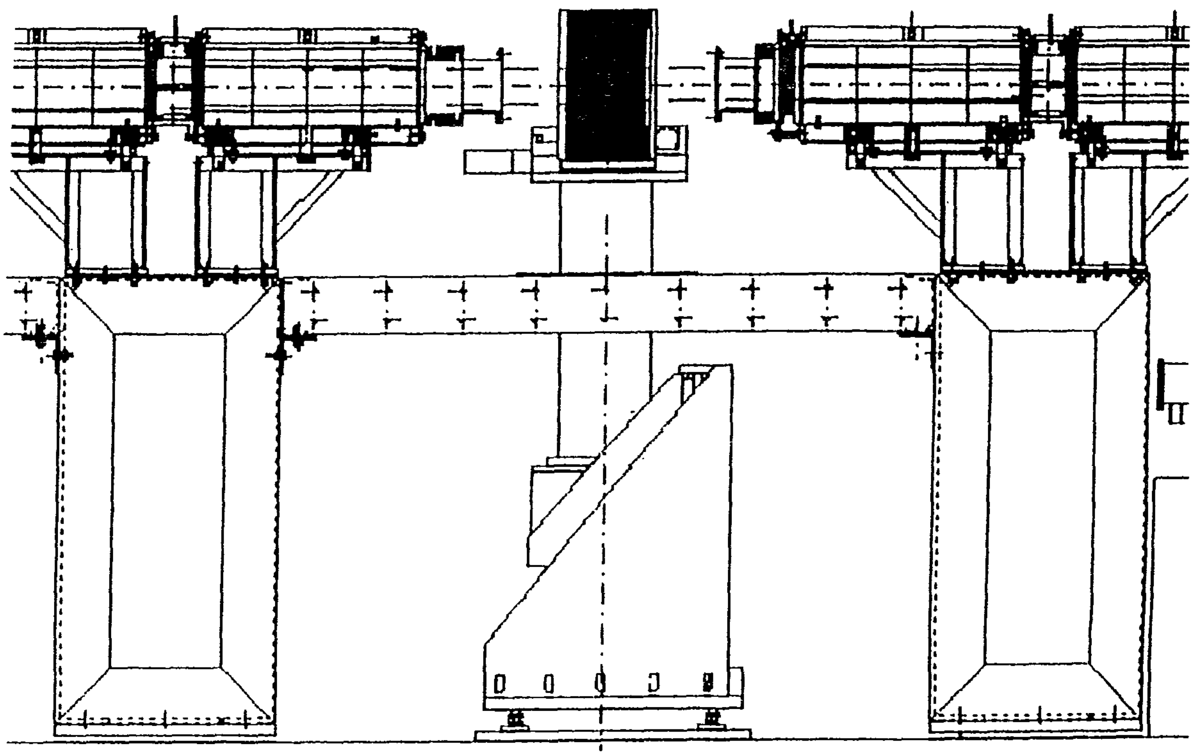


Fig.3

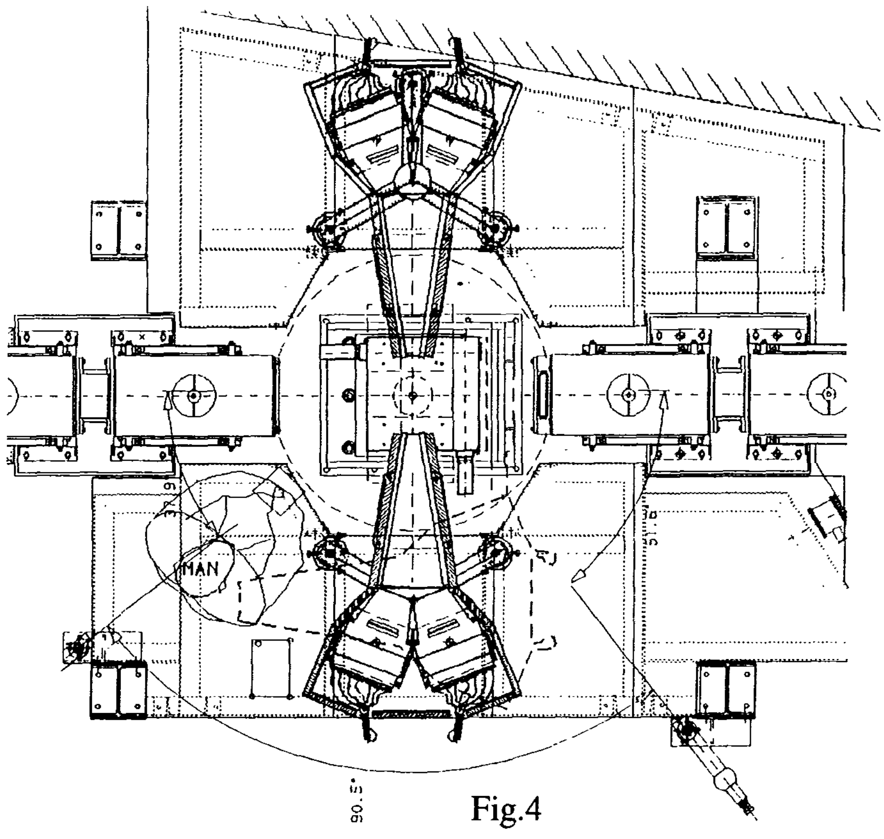


Fig.4

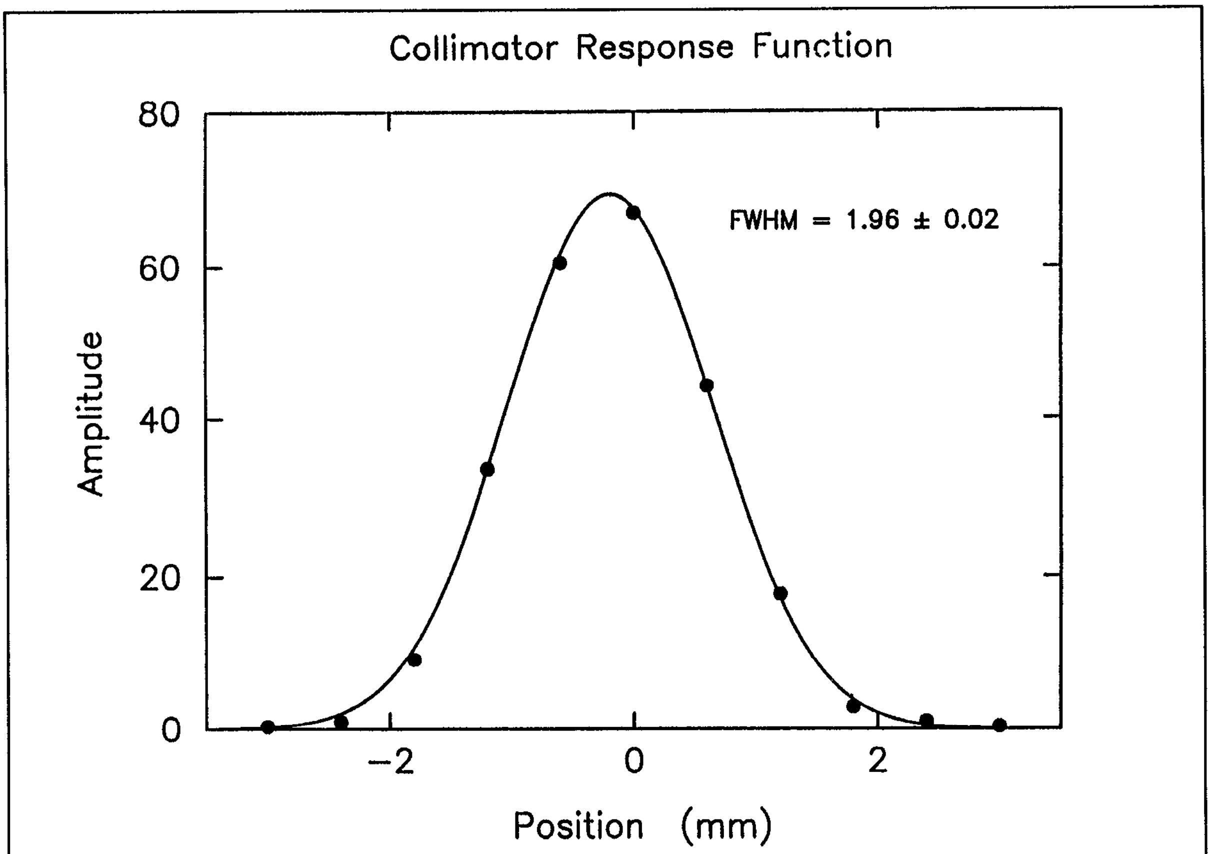
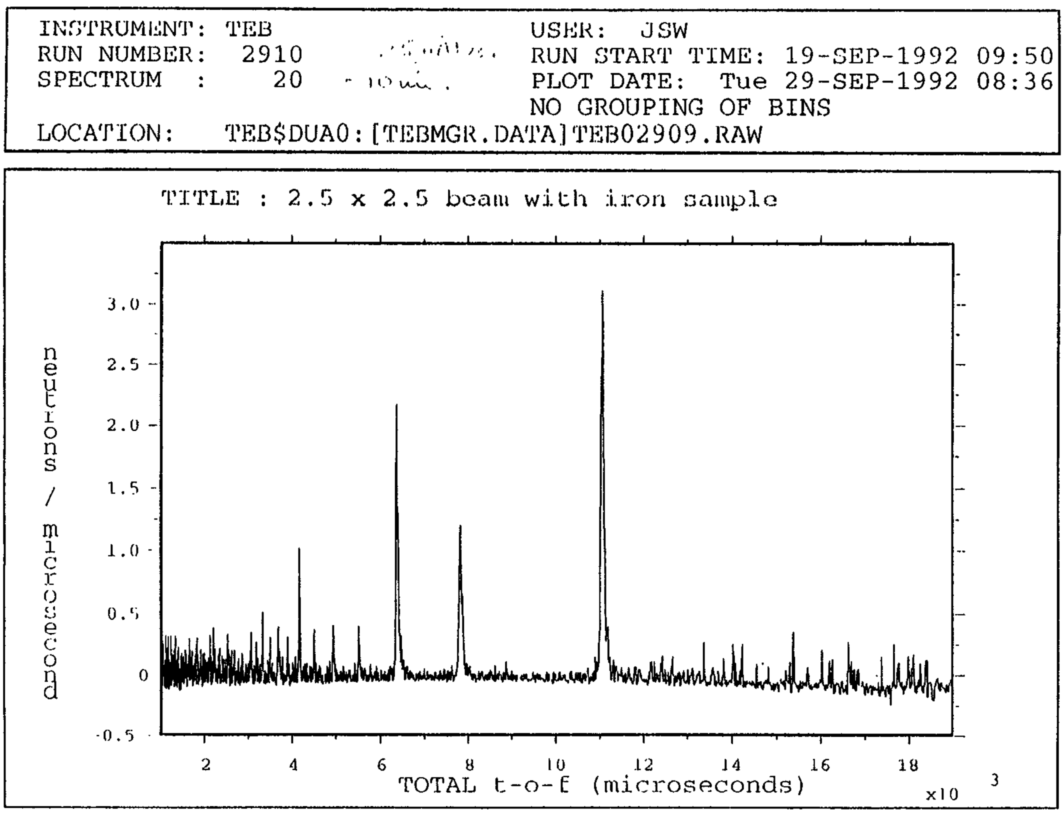

Collimator Response Function
FWHM = 1.96 ± 0.02
Amplitude
Position (mm)
80
60
40
20
0
−2
0
2

Fig. 5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RUN NUMBER: 2910
SPECTRUM : 20
USER: JSW
RUN START TIME: 19-SEP-1992 09:50
PLOT DATE: Tue 29-SEP-1992 08:36
NO GROUPING OF BINS
LOCATION: TEB$DUA0:[TEBMGR.DATA]TEB02909.RAW
TITLE : 2.5 x 2.5 beam with iron sample
neutrons / microsecond
TOTAL t-o-f (microseconds)
x10 3

Fig. 6