B: NEUTRON SCATTERING INSTRUMENTATION

Edited by G C Stirling

1 INTRODUCTION

The stated aim of the workshop was to concentrate on specific technical aspects of neutron beam instrumentation rather than the physics design of particular instruments. In general this turned out to be the case in practice, though in a few instances it proved fruitful to compare different designs for instruments intended for similar applications.

A major role of the meeting was to provide a forum for information exchange. This is crucially important at the present time, with the explosion in neutron scattering R & D activities due to the recent approval and planning for the new neutron sources. An important result of the workshop will be to prevent unnecessary duplication of effort, and to generate new approaches to common problems A number of specific actions to be followed up have been noted. The consequences will doubtless be manifested in the designs for new instruments in the future.

The notes below summarise points discussed at the major working sessions. Reports on specific instruments are available elsewhere and are not included here, with the exception of two detailed inter-comparisons of closely related spectrometers, viz small angle scattering and μeV inelastic scattering.

2 GUIDES

Both the physics and technological problems associated with the construction of efficient guide tubes for neutrons are now well understood and the best performance is achieved using nickel-coated highly polished glass. The surface quality of the glass is very important in the thermal neutron range where local slope variations greater than 10^{-4} radian can become comparable with the critical glancing angles (∿ 1.7 mradian $Å^{-1}$ for Ni). The current cost of guide systems similar to those used at the ILL is £1500 per metre; this includes the cost of materials, assembly, alignment, shielding and installation.

The guide requirements of the ICANS members were summarised as follows:

Rutherford Laboratory

Two guides are required for the first five instruments. These are a) a thermal guide (characteristic wavelength λ* ∿ 0.5 Å) for a high resolution powder instrument and b) a cold guide (λ* ∿ 3 - 4 Å) for a μeV spectroscopy backscattering instrument.

Los Alamos

No requirements at present.

Argonne Laboratory

Guide requirements almost identical to those of the Rutherford Laboratory are envisaged. These are a) a thermal guide (length 20 - 50 m) for a powder instrument and b) a cold neutron guide (length 30 - 50 m) for a μeV energy inelastic chopper instrument.

KENS

Three cold guides are required for a) a small angle scattering instrument, b) a correlation cold neutron spectrometer and c) a cold polarised neutron spectrometer.

It is concluded that thermal guides for pulsed source instruments should be straight rather than curved and that the unwanted fast neutrons should be removed by choppers. The γ problem would remain though this can be overcome by appropriate gating as at Dubna where they intend to construct a 100 m long straight guide. The most suitable system might in fact be one which has an early curved section which is well-shielded to eliminate the fast neutrons, followed by a straight section.

When considering the usefulness of guide tubes for neutron transport there is a "break-even" distance for a particular wavelength, below which a guide does not increase the useful flux at the sample position. This occurs when the maximum solid angle of incidence matches that transmitted by the guide; for a (10 cm x 10 cm) moderator surface this critical distance is ∿ 30 m for 1 Å neutrons reflected on Ni and is inversely proportional to the wavelength.

Calculations using the code SIMBEN (J Hayter, ILL and J Penfold, Rutherford Laboratory) were made of two 100 m guide geometries. The two geometries were designed to be exactly 'line-of-sight' in length. The parameters used in the two geometries are given below:

	A	B
Guide length	100 m	100 m
Guide width	2.1 cm	5 cm
Guide radius	57 km	25 km
Random error in surface angle (Δ distribution)	± 0.1 mrad	± .1 mrad
Bulk reflectivity	0.99	0.99

The transmission of geometries A and B are shown in Figure 1. A value for the (relative) transmitted neutron fluxes (per cm^2) taking into account the initial neutron spectrum I(λ) and the solid angle Ω(λ) accepted by the guide is shown in Figure 2.

Assuming the total contributions to randomising the neutron direction amount to no more than 0.1 mrad these calculations appear to show that neutrons may be successfully transported in the thermal region. It was decided that a purpose-built computer code (for 3-d calculations) was required to facilitate further investigations into the optimum size and layout of the guide (eg straight, curved or curved-then-straight geometries). A study should be made of existing thermal guide installations to obtain quantitative estimates of their transmittances.

Some consideration was given to the possibility of producing cheaper and more flexible guides, particularly for cold neutrons where the surface quality of the mirror is less important. The use of stretched Mylar and thin glass (∿ 0.1 mm) substrates were briefly reviewed though the consensus of opinion was that all guides should be constructed from good optical quality glass.

3 SOLLER COLLIMATORS

3.1 Requirements The requirements for collimators on pulsed neutron sources were reviewed. The two areas of special significance were thought to be,

(a) Hot neutrons, E > 100 meV to 1 eV and beyond.

(b) Use of collimators in direct beam; problems of radiation damage.

3.2 RL Collimator Development The RL collimator development was reviewed. A description of the RL collimators (ie Gd or B on stretched Mylar film) and their construction was given. Experimental results are available for both the gadolinium and boron collimators$^{(1)}$. Typical transmission figures are:- gadolinium - 96%, boron - 85%. The background "wings" for the gadolinium collimators increase significantly for energies > 120 meV, whereas the boron collimators are good to 1 eV.

Reflecting collimators are suitable for long wavelengths, giving increased flux by means of a "square-like" transmission factor. Prototypes have recently been tested.

The tightest collimation available is currently 10'; work is now progressing to produce 5'. It is thought that 5' is the practical limit for a single unit; but it may be possible to align several such units in series.

It is thought that the use of an aluminium honeycomb as the conducting channel or the use of thin aluminium supports for the ends of the Mylar foils, could eliminate the problems associated with very thin channels.

3.3 Problem of higher incident flux (direct beam collimation) Mylar foil concept is satisfactory for secondary collimation, but due to radiation damage is not suitable for direct beam collimation. For radiation levels of several megarads the Mylar shatters - it has been suggested that the paint binder may be a problem as regards radiation damage, but RL experience suggests not. If doses in direct beam ∿ 100 rads/hour, then a Mylar collimator should last for ∿ 10,000 hours. Numbers associated with radiation damage should be checked. It is usually assumed that radiation damage is due to γ's; fast neutrons may accelerate damage.

Alternative suggestions for collimator construction included:

(a) Wire (see below)
(b) Stretched aluminium foils (a sample has been constructed at the RL)
(c) Thin glass foils (1/10 mm glass is available)

3.4 Two dimensional collimators The following topics were discussed regarding two dimensional collimators:

(a) Useful for large samples in SAS.

(b) Tapered tubing epoxyed together with a boron epoxy; suitable for SAS, though there may be a problem with structure in the beam. It may be possible to use steel or nickel tubing. Sizes available are 7¼" diameter and up to 6 m lengths.

(c) Channel plates (60%) holes.

(d) Converging or diverging collimators using tapered frames.

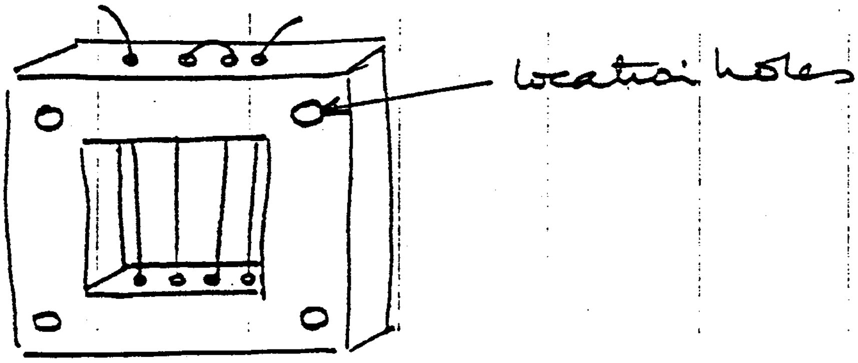
(e) Suggested that 2D, converging and diverging collimators are possible using wire frames.

(f) Crossed collimators may be useful as polarisers.

3.5 Preliminary design for wire collimator 2-D assembly

Wires

A wire, 0.0025" thick (∿ .06 mm), of an alloy of beryllium copper is available commercially. It is believed that this wire can be plated with gadolinium; 0.0005" thickness would be sufficient making a wire thickness of 0.0035" (∿ .09 mm). Once the wires have been produced they can be strung across a picture frame of aluminium so:



Once the wires are taut the ends can be spot welded to the aluminium frame, which would have location holes drilled in each corner.

1-D collimator, direct beam, 0-100 meV

Stack the frames together, the wires being aligned.

2-D collimator, direct beam, 0-100 meV

Alternate the direction of stacking.

2-D collimator, direct/indirect beam, diverging or converging, 0-100 meV

Alternate the direction of stacking, increasing the sizes of the plates and pitch of wires in direct proportion to the geometry required.

Attenuation for 10' collimator

30 cm long collimator, 1 cm spacing between plates, wire separation 0.87 mm to give α = 10'. Shadowing 10% thus maximum transmission 90%.

Transmission along wires 10^{-13} at 100 meV

Transmission at 10' through two end wires 2.10^{-2} at 100 meV

Transmission at 10' through two end wires 3.5 c 10^{-4} at 25 meV

Transmission at 10' through two end wires 2×10^{-8} at 5 meV.

4 BENDERS

RL development of benders was reviewed(2). Prototypes of following characteristics have been made and tested:

(a) Copper thin film or Mylar

(b) 50 foils, .25 mm spacing

(c) 5° bend angle

(d) $\lambda^* = 10$ Å

5 POLARISING GUIDES

RL development reviewed(3). Bender technology has been extended to polarisers using Co/Fe films on TPX, a non-reflecting substrate. Three have been built so far for use at ILL. Main characteristics are:

(a) λ^* 6.4 Å

(b) 1.5 x "line of sight", θ_{bend} - 1.50

(c) P $\sim$ 0.95%

(d) T $\sim$ 40% for + spins

It was noted that the Drabkin type devices have been found suitable for pulsed reactors, implying a general usefulness for pulses sources, although there may be a problem with a limit of λ^*.

6 CHOPPERS

6.1 <u>SNS choppers</u> The various types of chopper systems required for SNS instruments are summarised below(4):

(a) Fast neutron eliminators.

(b) Fast chopper/slopper combination with a burst time $\sim$ 1 μsec.

(c) Rotating magnesium/cadmium discs for defining energy windows, frame overlap choppers etc.

(d) Helical velocity selectors to select a narrow ($\Delta\lambda/\lambda \sim 0.05$) wavelength window.

Type 3 and 4 choppers are in common use at reactor facilities and most of the discussion was concerned with the conventional types 1 and 2 choppers.

6.2 Fast neutron eliminators consist of a 30 cm length of nickel alloy which shuts the beam at the instant of triggering (t = 0) and then opens at a preset time so as to become transparent to neutrons which have a wavelength which is longer than a selected minimum, eg λ_{min} = 0.5 Å is required for the SNS Small Angle Scattering instrument. Similar devices had been requested for two other SNS instruments. The WNR philosophy was to use'get lost' pipes and distant beam stops and not to use choppers for eliminating the very short wavelength component of primary beams. There was, however, space available within their shielding and crypt should a need be identified at a later stage. ANL have a similar view and will try to start without these choppers. It was, however, pointed out that the opposite view was being taken at Dubna where they aim to provide fast neutron eliminators for all their beams. It became clear that it will only become possible to assess the importance of these chopper eliminators after real experiments are attempted. They may be problematic to run and may cause some interaction problems with neighbouring instruments. It was suggested that those responsible for SNS instruments should reassess the need for chopper eliminators on their instruments.

6.2 Fast choppers are required for use in high energy transfer spectrometers both at the Rutherford and Argonne Laboratories. They may be used either alone or in combination with a slow rotating collimator ('slopper') which is used to minimise the scattered neutron background from the chopper. The ANL approach was to operate the fast chopper alone in the first instance and later to add the slopper if this was found to be necessary.

Two fast chopper systems were described in some detail:

(a) The Rutherford Laboratory are designing a 1 μsec burst time chopper for use with incident neutrons of energies ∿ 1 eV based on the Harwell spinning head. This is to have a 5 cm square aperture with a slit package consisting of alternate layers of aluminium frame 'slits' and aluminium/boron fibre composite 'slats'.

(b) The Argonne Laboratory is constructing a 3 μsec burst time chopper using a monolithic motor/rotor design running in hard bearings. The slit package has the same area as the Rutherford package and consists of alternate layers of aluminium frame slits and slats composed of spring steel coated on both sides with a ^{10}B loaded epoxy paint. This package is contained between cheeks of beryllium so as to give low transmission in the closed position.

6.3 Performance calculations The CHOPSUY code(5) has been developed at ANL for optimising chopper inelastic neutron scattering spectrometers. A more analytic approach has been used at the Rutherford Laboratory and it was generally agreed that it is fairly easy to work out a near-optimum instrument configuration without the need for extensive calculations.

6.4 Phasing of fast choppers with the proton pulse This was the major problem identified at the main session and this was later discussed further by a smaller working group. In those cases where it is possible to control the instant of beam extraction (Rutherford, Argonne) it was agreed that the best solution was to use a trigger pulse from a fast chopper (generally that of the highest resolution instrument) to control this instant. The machine itself could be operated in one of three modes:

(a) locked to the mains
(b) at its own natural frequency, or
(c) locked to a fixed frequency generator which could also be used to control the operation of the rotor.

There was an extensive discussion on the phasing problems experienced at WNR and it was concluded that these were due to a hunting oscillation in the motor control circuit.

7 DETECTORS AND ELECTRONICS

7.1 Detectors At the Rutherford Laboratory attention had been directed for a few years (using a small amount of effort) to the use of scintillators for detectors in instruments at intense pulsed sources. The reasons were:

(a) for some instruments the efficiency of conventional gas counters of adequate thinness for TOF work would be low and the dead time too long
(b) the use of solid neutron convertors provides adequate thinness, but detecting the charged particle products of a neutron event directly (by using, for example, a multi-wire proportional counter) means a foil

convertor thin enough to allow the escape of the charged particles, which in turn results in a low efficiency. The detector proposed by Jeavons(6) using a gadolinium foil convertor would be attractive for neutron wavelengths longer than 1 Å if the γ-sensitivity could be reduced.

(c) a solid converter in the form of a transparent scintillator allows reasonable efficiency to be obtained (a few 10's of %) for epithermal neutrons.

Problems to be solved are:

(a) how to use scintillators in PSD.

(b) how to provide adequate γ discrimination.

(c) how to reduce the cost of glass scintillators (eg, Nuclear Enterprises NE 905) from the present level of about £3 per cm^2.

Solutions to these problems were presented, viz:

(a) for detectors of neutrons of wavelength 1 Å or longer, not requiring a very high count rate capability, ^{6}Li loaded zinc sulphide scintillator (eg NE 425 or 426) can be used with a flexible fibre optic coding system enabling detector elements to be coded in batches of say ∿ 1000 using 20 phototubesper batch(7). Recent work had shown that the low light output from glass scintillator together with the shorter wavelength of peak light output made it impossible to use fibre optic coupling. For SNS instruments needing high count rate and PSD's for epithermal neutron energies (eg the single crystal diffractometer) a practicable solution is to use solid perspex light guides to couple the scintillator elements to the PM's. The economy in PM's is then much less than with fibre optic coding eg 4 elements per PM. Thus large numbers of PM's are required. A prototype detector module is being built for test on the new Harwell linac.

(b) the γ-sensitivity can be greatly reduced by having the scintillator in the form of a sandwich of 0.5 mm thick scintillating glass with 1 mm thick plain glass. The high energy recoil electrons from Compton scattering events then expend most of their energy in non-scintillating glass and thus produce small light pulses which can easily be reflected by simple pulse height discrimination(8).

(c) the thin scintillating sheets can be made by moulding crushed scintillator in the appropriate clear resin. Since this does not involve grinding and polishing whole sheets, the process is very much cheaper (∿ £1 per cm^2).

Prototype modules suitable for ring detectors on the SNS powder and liquids instruments are being built.

None of the other laboratories represented is actively developing new detectors. The Japanese work would start by using one dimensional banks of conventional gas counters. At the Argonne single crystal work would use the folded resistive wire, 2 dimensional detector developed at Oak Ridge by Kopp and Borkowski(9). This is a 20 x 20 cm^2, 3 atm ^{3}He detector with mm resolution. The wavelength range of the instrument is 0.7 Å - 5 Å and a detection efficiency of ∿ 50% is obtained. The count rate limit is 5×10^4 over the whole counter. One detector is being built at present and more will be ordered for the single crystal and SAS instruments at Argonne if the first is satisfactory. Doubts were expressed about the speed of this detector for use on SNS, although it is believed it could be fast enough for crystallographic work at IPNS. The accuracy of integrated intensity measurements should be 2 - 3%, which would be adequate for crystallographic work. The 5×10^4 c/s limit was set by positional accuracy requirements not the dead time of the counter. It is believed that IPNS will meet present and near future needs with gas detectors but would be looking into scintillators in the future.

At WNR there are no plans for a single crystal instrument. A small angle scattering instrument is being built which will use standard gas detectors arranged round a 'barrel'. At the moment it was not felt that new detector systems were required.

The following points from the general discussion of detectors are noteworthy:

- Non-UK participants said that the low level of activity on neutron detectors was due more to a lack of time and effort than to any belief that new detectors would not eventually be needed.

- The work on glass scintillators for epithermal neutrons was felt to be a welcome and necessary development.

- The ability to arrange the detector on various shaped surfaces was an important one.

7.2 Electronics Current RL thinking may be summarised as follows:

(a) detector address code transformations. In the PSD's being proposed for SNS instruments, the position of a detector element appears first in an encoded form. Eg in the fibre optic coded detector 3 PM's out of say 20 will have an output signal for a particular element. Methods of decoding this directly into the binary address of the element have been examined. An example was given in detail for a "3 out of 7" code and a practical circuit described, making use of a priority encoder and a read only memory. The address of the detector element of a particular event could be generated in 100 ns using MECL priority encoders. This can then be combined with the time of flight to give the complete event descriptor. Transformation of other codes, such as might be used with the glass scintillator detectors, have also been examined and solutions proposed. All transformations allow checks for invalid code words which could arise, for example if neutron counts occurred simultaneously in two different elements of a detector.

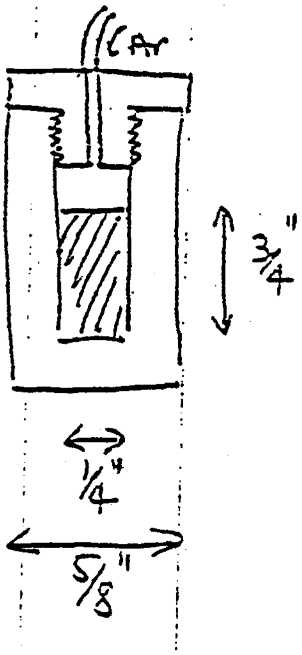
(b) bulk storage of data. It was considered that external dedicated memory was a lower cost option than computer memory and that sequential access would continue to be 3 to 4 times cheaper than random access memory. The usual disadvantage of sequential access viz the comparatively long access time, is offset by the fact that one component of the address, the time of flight, is itself sequential. A memory organisation was proposed which uses charge-coupled device (CCD) memories, which are currently available in elements with a capacity of 64K bits and so would hold 4K of 16 bit words. A store of 1 million 16 bit words would thus require 256 elements. Regarding these elements as single bit, 64K long shift registers with a clocking rate of 5 MHz, the memory can be cycled in 13 ms, well within the repetition rate of SNS. Several ways of using these elements were described, for example, a whole element can be allocated to one detector, words being stored serially by bit so that at the 5 MHz clock rate the word access time, which is also the timing channel width, would be 3.2 μs and the element would accommodate 4096 timing channels. The current cost of a mega-word of 16 bit store would be less than £15K including £10K for the 256 CCD elements and £5K for associated circuit and manufacturing costs. By 1980 it is anticipated that this cost will be reduced to between £5K and £10K.

(c) generation of timing channels. Circuits were presented for generating timing channels of constant width, width proportional to (time)^2. The circuits have a common element which is down counter with a zero detector the output of which reloads the down counter from a register.

It was advised that the 16 bit system should be extended to 24 bits at least to limit the number of overflows which could occur. This may be an inefficient use of chips but they are cheap. WNR is providing uniform time channels of width 50ns and doing any special arrangements in software. Argonne have opted for 8 bit words and hope to cope with overflows.

8 HIGH PRESSURE EQUIPMENT

Los Alamos have a project to look at the high pressure, high temperature phases of plutonium. They have built and tested to 20% above working pressure (4 kb at 350°C) a steel cell pressurised with argon gas. Design as follows:-



During tests the cell was filled with a dummy sample to limit the stored energy in the gas.

The cell is permanently set up on a TOF diffractometer at the WNR facility. The cell is surrounded with a cylindrical shield of boron nitride ("white graphite" and available commercially) with collimation holes for the entrant and through beams and one scattering angle. The collimation is such that only one third of the sample is seen (0.2 ccs) but none of the sample holder material is viewed. A measured diffraction pattern from copper is shown in figure 3.

Following a survey of pressure requirements in the UK(10), a pressurised gas type cell has been constructed which is capable of pressurising samples 10 mm in diameter and 24 mm high to 8 kb, over a temperature range from ambient to about 100°C. 0-4 kb is available at liquid helium temperature. The cells and equipment have been commissioned at ILL and will be available for work on the new pulsed sources in the future.

Pressures of 50-100 kb could be a goal in the future, though no active development work is currently in progress.

9 COMPARISON OF IPNS/SNS μeV SPECTROMETERS

Argonne National Laboratory and the Rutherford Laboratory have each developed designs for high resolution (μeV) inelastic spectrometers(11,12). At Argonne the high resolution is achieved by using a chopper to reduce the effective source pulse width to 10-50 μsec, a second chopper with very short pulses (τ = 1-3 μsec), long flight paths (L_1 = 50m, L_3 = 5m), small sample and detector thickness, and low incident neutron energies (E = 0.5-10 meV). The Rutherford design defines the incident neutron energy with a high speed chopper close to the source, a 40 m flight path, with energy analysis by back-scattering from a single crystal array. A quantitative comparison of the designs was attempted, raising the following points:

(a) At good resolutions (1μeV) the flux gain on the sample is x10 for SNS.

(b) Window for IPNS at least 800 μeV compared with 200 μeV for SNS. Also any features observed in poor resolution range from IPNS could be investigated further. SNS would have to scan.

(c) Sample geometry a limitation for IPNS, in particular sample orientation may need to be optimised for particular θ_s, however lower Q may be possible (λ_i = 13Å) for IPNS. SNS has always intrinsically 2x Q_{min} of IPNS, if not more, but $Q_{max} < 1$ Å^{-1} for IPNS, whereas Q_{max} for SNS ~ 2 Å^{-1}.

(d) With 2.5 metre flight path 7 x detector area required for IPNS.

(e) Analysers required for SNS.

(f) For poorer resolutions SNS fixed at 13 μeV whereas IPNS variable and adjustable to problem.

(g) At high $\hbar\omega$ machines essentially equivalent, except that on IPNS E_{min} sees elastic peak whereas on SNS not so. This may lead to calibration problems for SNS. Typical resolutions ∿ 200-250 μeV at 50 meV $\hbar\omega$.

(h) Cost (rough estimates only)

IPNS: £540K (1ster); £720K (2ster).
SNS: £170K (1ster); £220K (2ster).

10 SMALL ANGLE SCATTERING

Three instruments were discussed:-

- Rutherford Laboratory - low Q spectrometer proposal(13)
- Los Alamos Scientific Laboratory - Small Angle Neutron Scattering instrument(14)
- Ispra - Proposal for the design of a small angle neutron scattering facility(15)

(a) The proposed Rutherford Low Q Spectrometer was designed for a wide range of applications whereas the other machines were more restricted in their application. In particular the Kley spectrometer(15) was specifically designed to study irradiated materials at high temperatures where the separation of elastic and inelastic scattering events would be crucial.

(b) The calculations of Seeger (14) on the optimisation of a small angle apparatus with respect to intensity and resolution for samples which scatter isotropically show that the optimum set-up would consist of a SAS instrument in which the moderator to sample distance (L_1) would be double that of the sample to detector (L_2).

There was insufficient time during the workshop to resolve this difference to the satisfaction of all those who participated in the discussion; the comparison will be carried further (W S Howells, RL).

(c) The technique of separating elastically and inelastically scattered neutrons, by a combination of suitably phased choppers before and after the sample under study, proposed by Kley (15) for a pulsed source of pulse repetition frequency 200 Hz, should in principle be more efficient than the system proposed for the Rutherford low Q spectrometer (13) which consists of a velocity selector with TOF analysis of the detected neutrons. However the Kley system has the disadvantage that some of the high Q detectors would not completely surround the sample; this is not a problem if only samples which scatter isotropically are studied but would present problems for single crystal work. In addition a chopper is required very close to the moderator which would present some problems for the Rutherford machine. The merits and performance of the two systems will be compared (R J Stewart, Reading).

11 REFERENCES

1 C J Carlile, P D Hey, B Mack, *High-efficiency Soller slit collimators for thermal neutrons*, J Phys, E: Sci. Instrum. 10 543 (1977); C J Carlile, J Penfold, W G Williams, *High-efficiency Soller slit collimators for 1eV neutrons*, J Phys, E: Sci. Instrum. 11 837 (1978).

2 C J Sutherland, H Wroe, *A cold neutron beam bender using multiple thin plastic films as curved guide*, Proceedings Neutron Diffraction Conference Petten 1975, RCN-234 (1975).

3 J B Hayter, J Penfold, W G Williams, *Compact polarising Soller guides for cold neutrons*, J Phys, E: Sci. Instrum. 11 454 (1978).

4 H Wroe, *SNS chopper working party - first progress report*, SNS/UTL/N9/78 (1978).

5 M Kimura, J M Carpenter, *Some optimisation considerations in chopper inelastic neutron scattering experiments* (1978) [Unpublished].

6 A P Jeavons, N L Ford, B Lindberg, R Sachot, *A new position-sensitive detector for thermal and epithermal neutrons*, CERN 77-01 (1977).

7 P L Davidson, H Wroe, *The fibre optic coded position sensitive neutron detector*, SNS/UTL/N2/77 (1977) [Unpublished].

8 H Wroe, *Guidelines for cost and efficiency of various neutron detectors for SNS instruments*, SNS/UTL/N13/78 (1978) [Unpublished].

9 M K Kopp, C J Borkowski, *Position-sensitive proportional counters using resistance-capacitance position encoding*, ORNL-TM-5083 (1975).

10 C J Carlile, D C Salter, *High pressure techniques for thermal neutron scattering ecperiments*, RL-75-096 (1975).

11 C A Pelizzari, *High resolution quasielastic scattering spectrometer*, (1977) [Unpublished].

12 C J Carlile, *High resolution inelastic spectrometer for the SNS*, (1978) [Unpublished].

13 R J Stewart, *The small angle neutron scattering apparatus for the SNS*, (1978) [Unpublished].

14 P A Seeger, *Optimisation of geometric resolution in small angle scattering*, (1978) [Unpublished].

15 W Kley, *Proposal for the design of a small angle neutron scattering facility at a pulsed neutron source*, (1978) [Unpublished].

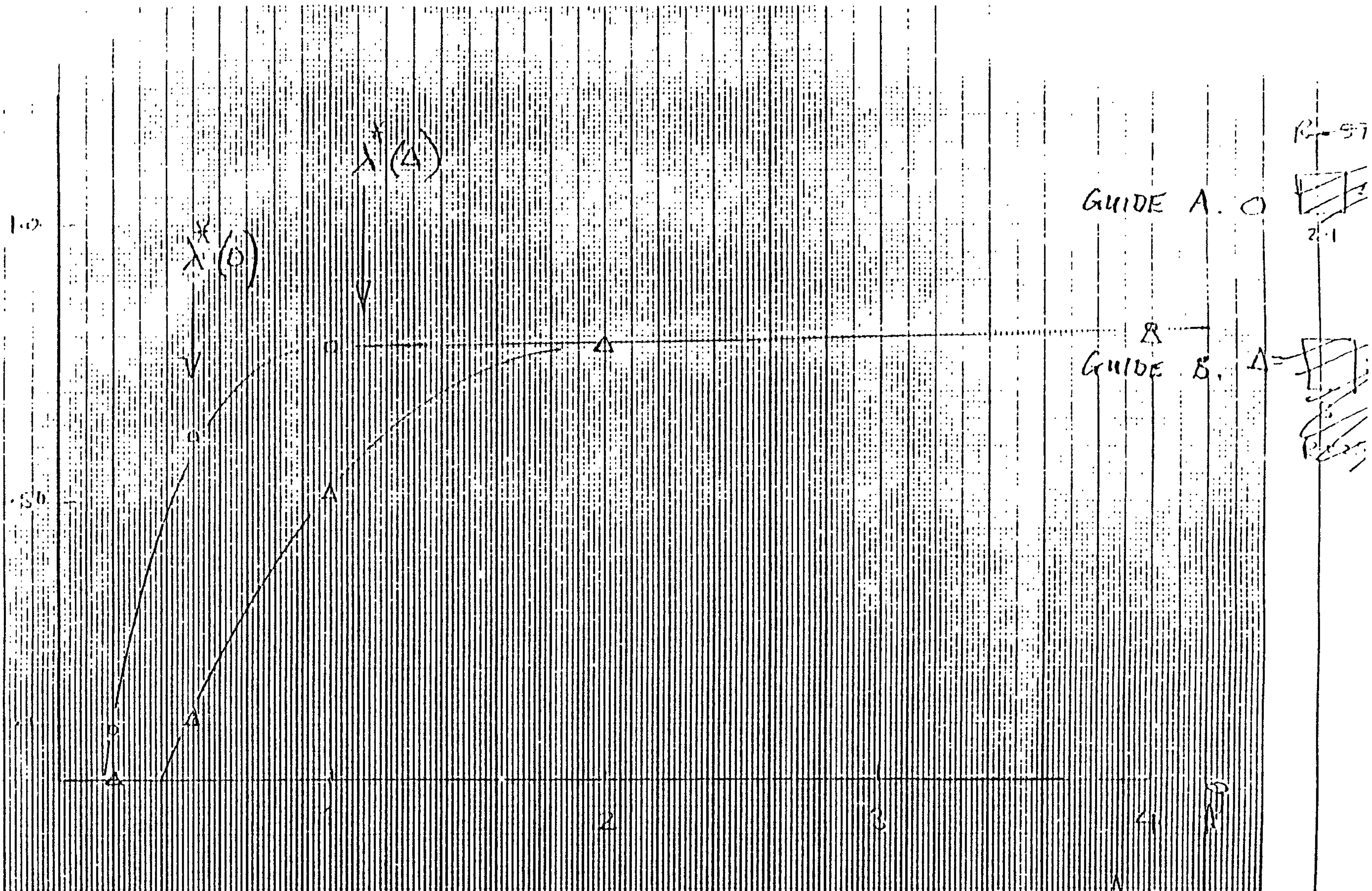


Fig 1

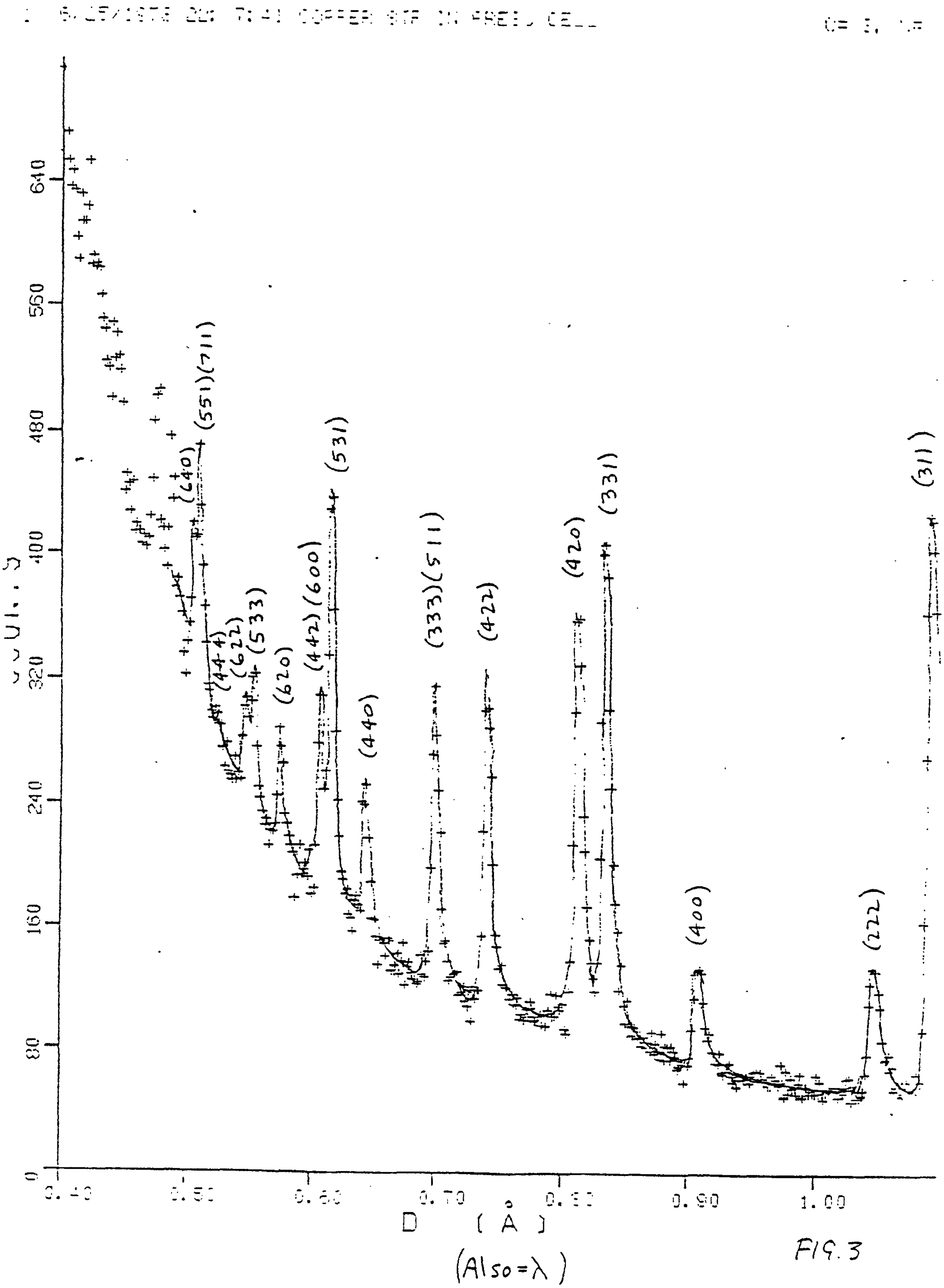

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FIG. 3

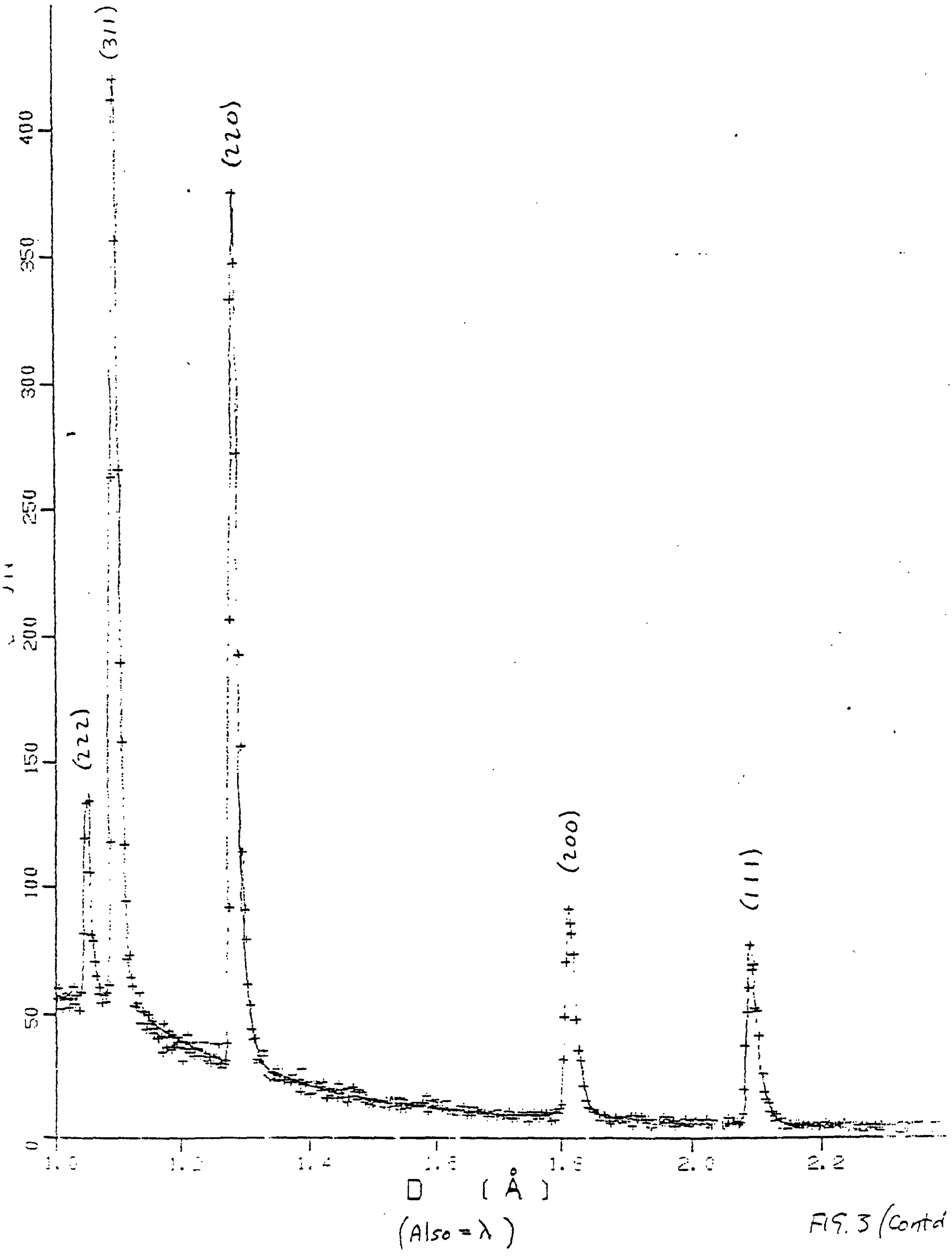
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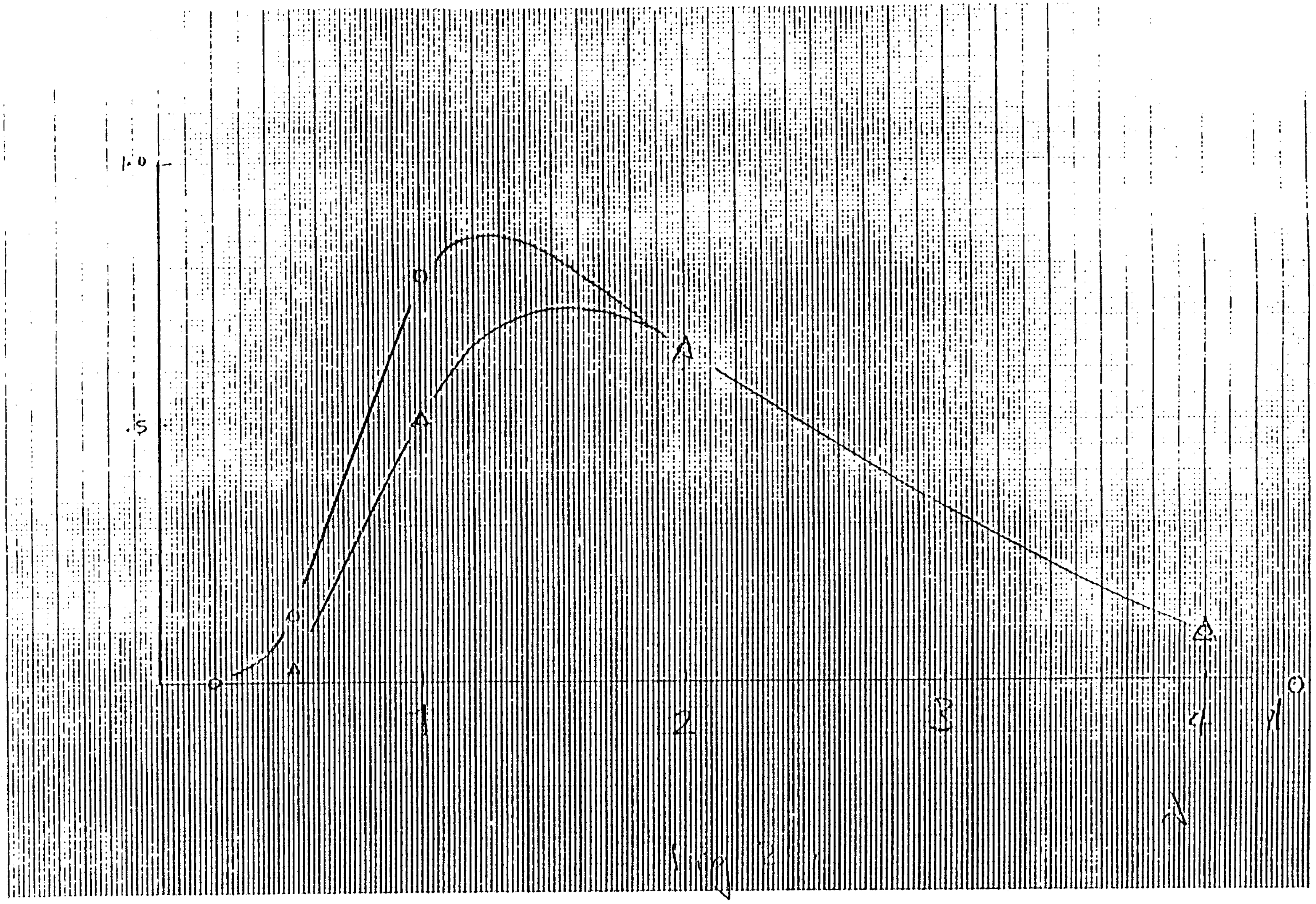
FIG. 3 (Contd)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