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INTERNATIONAL COLLABORATION ON ADVANCED NEUTRON SOURCES

ICANS 78 - Workshop on Utilisation, Rutherford Laboratory,

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FOREWORD

This record has been compiled from the written contributions of many of those participating in ICANS-78. Editing has been kept to a low level and this is reflected in some variation of style in the different sections.

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A. TARGET ASSEMBLY/TARGET STATION WORKSHOP

Edited by A Carne

1. INTRODUCTION

The overall programme for the Workshop on Target Assembly/Target Station had been presented to the participants prior to the Workshop. It had the form of an organogram showing the links between the main areas, with final links to a) Instrument and b) Operational Requirements. This programme was largely followed, as the timetable, figure 1. shows.

The aims of the sessions were:

i) to recognise problems that could be studied within the timescale of the week.

ii) To recognise problems that could be resolved during the weeks and months immediately after the workshop.

iii) To exchange information and experiences on the various aspects and to compare solutions to common problems.

An Action Sheet shows the work recognised under points i) and ii) above. It shows two problems were resolved during the week, also the many more to be dealt with in the near future. The main purpose of the Action Sheet, however, is to help maintain the momentum that was generated during the week and to keep this area of ICANS a continuing collaboration.

As far as point iii) is concerned, a Report list is provided of the reports made available during the meeting. (Participants requiring individual reports are advised to obtain them from the Authors.) In the following sections are presented summaries of the various sessions.

2 CODES

2.1 Neutronic

a) TIMOC. RL uses the TIMOC[(1)] neutron transport code which was originally developed at Ispra for the design of the SORA pulsed reactor. It has been installed on the Rutherford Laboratory IBM 360/195 computer. The code used cross-section data from the ENDF/B library (via the CODAC code) and may be used for time-independent or time-dependent neutron flux calculations.

A code validation exercise was carried out in August 1977, when the code was used to predict the Φ (1eV) flux for various geometries used in the MUSTA benchmark experiments. The detailed results for the 10 separate geometries are given in the MUSTA description. Overall the fluxes predicted by TIMOC appeared to be systematically 15% higher than those observed, and had a random variation, $\delta \sim 15\%$.

Recently a new code, THERMAL[(2)], has been written which calculates the matrix of scattering probabilities between the thermal region energy groups (for H_2O or $(CH_2)_n$). This matrix may be included in the cross-sections used by TIMOC to produce more realistic neutron transport in the thermal region. The results for Φ (ε,t) obtained by this method are presently being compared with expected energy and time distributions.

[(1)] H RIEF, R JAARSMA, EUR 5016e.
[(2)] M W JOHNSON, Unpublished work.

b) NMTC + MCNG. LASL (WNR) uses the NMTC + MCNG program package. Results from the package are described in the Report list, nos 6 and 7. The package includes time dependence in neutron transport, also gamma transport and energy deposition. Thermalisation is not included. NMTC is used as a source for MCNG. Future work to be done includes the effects on the neutron time pulse of reflector and decoupler. Generally the codes are due for updating.

c) Comparison of NMTC/MCNG with TIMOC. The results of the two cases were compared during the meeting, the TIMOC code using the RL IBM 360/195. The WNR target geometry was used, for which the neutron fluxes time dependence in the epithermal energy range were compared. The results are satisfactorily similar. The comparison is described in the Report list, no.20, and appended to this report (pp 24-28).

2.2 Target

a) HETC. RL uses the HETC program package which, although working, is not fully operational as it cannot, yet, satisfactorily reproduce experimental data.

A flow-diagram for the package is shown in Fig. 2. The boxes at the bottom of the figure indicate the general areas where results are wanted. The two main-line codes HET and O5R share a common geometry package which allows simulation of layouts in a realistic way. Gamma transport is not implemented yet, and is included with dashed lines to show its relationship with the overall calculation.

The major changes introduced are:

A. fission into HET

B. a revision of the fission treatment in O5R

C. the use of ENDF/B IV neutron cross-section data with O5R

Fission is modelled in HET by allowing competition with neutron emission at all stages of the evaporation, that is fission occurs after the high energy intranuclear cascade is complete. Computation with the model is made by using the systematics of fission in the literature for both probability and post fission parameters. The significance of including fission may be judged from the following results (Note: that all refer to production at the HET stage and require the transport to the target surface by O5R for completion); the neutron spectrum contained an overall increase of 30%, with an increase of $\sim$ 60% for those above 2 MeV. The average total fragment recoil energy is $\sim$ 160 MeV and leads to a factor of $2\frac{1}{2} \rightarrow 3$ on energy deposition.

For O5R a modified weighting scheme is used for fission neutrons, plus the following of the whole 'fission-cascade' in a single run. The records for the history tape have been extended to carry extra information particularly to allow energy density analysis.

The cross-section group averaging code XSECT has been replaced with a new code, XSCEND, developed at the Rutherford Laboratory. This allows use of ENDF/B cross-section data. Much of the data is in resonance parameter form, these are unfolded before group averaging. We note that we need to introduce Doppler broadening to this data.

The code gives excellent agreement with experiment for nucleon-nucleon scattering (Table 1 and Figs 3 and 4).

First checks with nucleon nucleus data shows significant disagreement; for the ^{59}Co (p, spallation) system at 370 MeV the code seems to evaporate ∿ 20% too many nucleons. The isobaric yield curves are displaced significantly from the experimentally determined systematic of Rudstam[(1)] (Fig. 5).

The conclusion at this stage of checking, is that the evaporation parameters used in our version of the code do not form a matched set and will need correcting. The effect of altering the coulomb barrier penetrability (to 75% and 60% of the programs current value) and the level density parameter from A/8 to A/14 is also shown in Fig. 5. This conclusion ties in with the suggestion by Russell (LASL) that the predicted neutron spectra seems too soft.

[(1)] G RUDSTAM, Z Naturforschung <u>21A</u>, 1027 (1966).

b) <u>HETC + VEGAS CODES on Mass Distribution</u>. During discussion on codes it was suggested that the BNL intranuclear cascade/evaporation code VEGAS was better than that of HET.

In 1972, the results of a 'code-battle' were published[(2)]. Comparative calculations on two systems, ^{27}Al(p, spallation) and ^{181}Ta (p, spallation) at 150 and 300 MeV were made using VEGAS, the Bertini code (used by HET) and a third code from Dubna.

The conclusions of this study were that despite model differences these codes gave results which were in good agreement with each other. Particularly the residual mass distribution agreed well despite excitation and prompt particle energy differences.

The conclusion must be that there is (up to 1972) no reason for expecting the VEGAS code to be better than HET.

It was agreed that LASL try and find out if any subsequent modifications have been made which alter this conclusion.

(1) K CHEN et al., Phys. Rev. 166, 949 (1968); 176, 1208 (1968); C4, 2234 (1971).
(2) W S BARASHENKOV et al., Nucl. Phys. A187, 53 (1972).

c) NMTC + MCNG. LASL (WNR) uses this package as described above.

3. PHYSICS DESIGN OF TARGET/MODERATOR/REFLECTOR ASSEMBLY

3.1 Target Assembly Studies for SNS at RL

Several candidate geometries exist for the SNS target assembly. A four moderator Wing geometry utilising the reference target design was described. Calculations have shown that a penalty ∿ 2 is found between a moderator viewing the front and rear of the target in a reflected geometry. Losses of only ∿ 10% in the intensity of a single faced front moderator are incurred by:

a) opening up both faces of the moderator
b) replacing downstream reflector by a rear moderator.

The decoupling energy in these calculations was 170 eV. This configuration provides considerable flexibility, eg 4 moderator types and 8 moderator faces are available to match to the 18 proposed beamlines; orientation of the moderators with respect to the proton beam allows maximum utilisation of the experimental hall. Other geometries are possible, including a slab system (∿ 50% gain in intensity but with less flexibility) and a Slab/Wing combination. The choice of the final system is yet to be made.

WNR reported no instrumental difficulties in viewing their target through the moderator. They will report the effect of going to an offset beam.

3.2 Cold Moderator Studies for KENS

Several tests have been performed to obtain the optimum cold moderator and cooling system geometry, using an electron linac and lead target. A solid mesitylene moderator (similar to solid methane at 20K) was placed 5 cm above the target and the neutron flux density was measured as a function of vertical distance h. The results, for 3 different moderators, are given in the Report list, no.1, showing that the neutron peak intensity is insensitive to h (at about 4 cm) when the moderator broad dimensions exceed 10 cm. However the distance between target and moderator is very important.

A solid mesitylene moderator at 20K, 3 cm thick by 10 x 10 cm^2 gave a neutron flux with a peak at about 3 meV with $E(\phi)_{max}/E|_{1ev} \sim 10^3$. The pulse width was 80 μsec (FWHM) at 4 Å. The moderator was surrounded by Be, and Cd decoupler was used.

4. TARGET/MODERATOR/REFLECTOR. BENCHMARKS AND EXPERIMENTAL RESULTS

4.1 Mock-Up Experiments at RL

Static measurements have been made using a small Ac-Be source on reflected and unreflected moderator configurations. A full description is given in the RL report RL-77-140/A.

A full scale dynamic mock-up experiment on Nimrod, MUSTA, has been performed, the main details of which are given in the Report list, no.18. A comparison with TIMOC shows good agreement and establishes TIMOC as an operational code in SNS design optimisation. Details of fast neutron production in uranium and lead targets are given. Pulse widths extracted by diffraction from the (220) planes of beryllium were found to be in agreement with data from a poisoned moderator on the Harwell linac.

4.2 LASL-WNR Operation, Development and Experiments

The emphasis of effort at the WNR facility is moving away from major construction to reliable facility operation. The fast kicker system is in the shakedown phase. The target/moderator cooling and borated water decoupling systems for target 1 have been recently implemented. Two types of moderators are available for experimenters:

a) the low-power water cooled CH_2 moderators have been used successfully when the energy deposition in each of the two pieces is ≲ 20 watts; this corresponds to 0.2% of LAMPF, at design intensity, striking the WNR Ta target.

b) high-power Al canned H_2O moderators have also been built to accept higher fractions of the LAMPF current on the WNR target.

The vacuum inside the target 1 crypt is routinely kept at ∿ 30 microns. The fast chopper system is being modified to enable the selection of a single LAMPF micropulse every microsecond. For high-energy (bare target) neutron experiments this could mean a proton repetition rate as high as 4000 Hz.

The WNR has been operated routinely at 1.6 μA average current which is about a factor of 6 below design level. The proton current will be increased as rapidly as possible.

WNR Development and Experiments

An attempt will be made to simplify the design of the WNR target canister. Measurements are in progress to obtain absolute thermal and epithermal neutron flux distributions from the WNR moderator. The angular distribution of thermal neutrons from the WNR moderator will also be measured.

The objectives of the Fertile-to-Fissile Conversion (FERFICON) program using LAMPF/WNR is as follows:

- Measure neutron leakage from Pb, Th, and U targets
- Measure fertile-to-fissile conversion efficiency in Th and U targets
- Measure energy deposition in Th and U targets
- Compare experimental results with calculated predictions.

Neutron/proton measurements have been made on a 9.85 cm dia. by 40.7 cm long Pb and 10.0 cm dia. by 40.7 cm long depleted U targets; data reduction and analysis are proceeding. See Report list nos.8,9.

Work on cold moderators should be started in the near future.

4.3 ZING-P'. A summary of the measurements taken on ZING-P' is given in the Report list, no.10.

4.4 Target-Moderator-Reflector Mock-up Experiments for KENS. Several Target-Moderator configurations were tested both for bare and reflected systems. Moderators used were of polyethylene; Cd was used as decoupler (though future measurement will use B_4C); the reflector used has graphite, though a small amount (about 6 litres) of BeO was used close to the target and moderators. The "target" was an Am-Be source. The results and comparison with similar measurements made elsewhere are given in the Report list, no.3.

The values of $E\phi(E)$ at 1eV measured by KENS, IPNS and RL(SNS) give the following values for target-moderator-reflector coupling efficiency (n $ster^{-1} n_f^{-1}$ per 100 cm^2 moderator face):

(KENS) 8×10^{-4}; (IPNS) 4×10^{-4}; (SNS) 2.5×10^{-4}

The high value given by KENS is partially accounted for by the use of Cadmium as a decoupler (E_d = 0.5 eV). Details of the IPNS calculation were not available and the discrepancy was not resolved.

5. BULK SHIELDING, BEAM PORTS AND PLUGS

The various pulsed neutron source projects are at differing stages of development and the states of the bulk shield designs reflect this. The WNR shield is complete and neutron experiments are in progress. The performance of the shield has been measured and has demonstrated that the design method - of using Monte Carlo neutron cascade calculations - has been highly successful. The detailed design of the KENS shield is complete and includes some work on the performance of the shield close to the beam tubes. These effects were not included in the WNR design. The SNS bulk shield design is in its early stages and preliminary calculations have been made on the gross dimensions of the shield. Shielding layouts for IPNS-1 show the neutron scattering and irradiation effects target to be within the same shielding assembly.

5.1 Bulk Shield at LASL

Detailed Monte-Carlo calculations were done for various configurations and materials. Codes used were the NMTC intra-nuclear cascade model transport code for particle energies above 20 MeV, and MCN, the standard code used for neutron transport at Los Alamos for energies below 20 MeV. Changes were made in the codes to make them more compatible, but extensive experimental tests of the codes were not performed. Statistical uncertainty in dosage results is ~ 20%, but no estimate of accuracy is claimed beyond a qualitative "factor of two".

a) Choice of Material

Iron and lead were compared, and found to have nearly the same attenuation length. Iron was chosen as the most cost-effective high density material for the bulk shield. Because of cross-section windows, especially at 26 keV, there must be some other element as well. Calculations for the ING had recommended a hydrogen content of $0.008 \times 10^{24}/cm^3$; LASL considered various ratios of H/Fe, and settled on a smaller value to keep the average density higher. From construction considerations, a mix was used of 64 parts steel to 9 parts heavy concrete to 1 part void (by volume), for a net H content of $0.00073 \times 10^{24}/cm^3$ and an average density of $7.22\ g/cm^3$. The outer 30 cm layer of the shield is heavy concrete containing boron glass frit.

b) Shape of Shield

The WNR proton beam is directed vertically downward, striking a heavy metal target viewed by horizontal beam tubes. The shielding is therefore a vertical cylinder. Calculations immediately showed that leakage under the floor would be a major source of radiation in the experimental area. The essentially forward-directed high-energy neutrons diffuse outwards readily. The iron cylinder is therefore extended 0.75 m below floor level, and a plinth of heavy concrete 3 m thick extends below that.

c) "Get-Lost" Hole

Three forms of forward neutron beam stop were calculated:

1) a 91 cm diameter x 2.8 m deep hole, lined by 55 cm of iron;

2) a naval gun barrel of diameter 41 cm and length 2.8 m; and

3) a solid plug of Fe/concrete mix.

The difference in dose rates in the experimental area were not statisticall significant. The third case - no "get lost" hole - was chosen as easiest to build. This case also minimises the possibility of radiation reaching ground water under the facility (not a problem at Los Alamos), and minimise the total amount of dense material needed. As constructed, the volume below the target is lead instead of iron.

d) Beam-tube penetrations

The penetrations were not included in the calculations. At WNR, the beam tubes are large but generally well filled with steel, so that the actual penetrations are "small". The pipes are stepped, and the volume around the pipes was filled with poured lead.

e) Measurements

Radiation dose measurements with WNR running at about $^1/_3$ of design power have not shown measurable levels on the face of the shield, on the floor, near a closed beam path, nor near a properly shielded experiment. Levels near an unshielded open port of about 4 cm diameter were above tolerance. To date, we have not observed any discrepancies with the calculations.

5.2 KENS Shielding

The biological shield was designed so as to satisfy the following conditions:

a) The maximum dose equivalent rate at the surface of the shield in the horizontal direction is less than 0.8 mrem/hr.
b) The annual dose equivalent at the nearest site boundary should be a small fraction of the natural background radiation.
c) The maximum distance from the target to the surface of the shield should be less than 4 m; the height of the shield should not be greater than 4 m.
d) The total budget was limited.

Details of the design are given in the papers, Report list nos.4 and 5.

5.3 SNS Bulk Shield Design

Preliminary calculations have been made for the bulk shield around the SNS target. The design goal is to reduce the radiation level at the surface of the bulk shield to 0.75 mrem/hr. It may be possible to relax this requirement on the top and bottom faces of the shield when the consequences to experiments of "skyshine" and "ground shine" have been further evaluated.

The shield thickness was calculated using a neutron spectrum calculated by Fullwood et al[(1)]. This neutron spectrum was converted to a dose equivalent spectrum. The angular dependence of the high energy neutron spectrum was also taken from reference (1). It was found that the shield must provide an attenuation of $\sim 3 \times 10^8$ in the forward direction and $\sim 10^8$ in the sideways directions, the difference being due to the greater penetration of the high energy component which is peaked forward.

Due to the "windows" in neutron cross-sections for iron a composite structure is envisaged for the shield with layers of iron alternating with layers of iron loaded or boron loaded concrete. The precise details of the composition of this sandwich will be established using the HETC package but preliminary figures for the shield thickness is 5.3m in the forward direction and 4.9 m in the sideways direction.

The shield will probably be constructed in two main parts. The inner 3.0 → 3.5 m being permanently cast shielding and the outer layer being made from blocks. This may then allow easier access to collimators, shutters etc. in the beam tubes. An attempt is being made to design the shield in such a way that it will be possible in the future to change the neutron beam tube layout. The most promising way of achieving this is to have the beam tubes contained in an insert into the main shielding. A geometry somewhat like a "pill box" is envisaged.

At present detailed design work is underway using the HETC package investigating the following problems.

a) Details of the shield materials
b) 'Weakening' of the shield due to the beam holes
c) Energy deposition in the inner layers of the shield - is cooling required?
d) Incorporation of choppers, shutters and collimators
e) Skyshine and groundshine
f) The overall geometry of the shield

In addition the design will recognise the possible requirements of facilities for non-thermal neutron users of the SNS. eg fast neutron beams, charged particle beams, etc.

(1) "Neutron Production by Medium-Energy Protons on Heavy Metal Targets". R R Fullwood et al. LASL Report LA4789 (1972).

6. TARGET/MODERATOR/REFLECTOR ENGINEERING

6.1 KENS Cold Moderator

For KENS it is proposed to use a solid methane cold moderator of 130^W x 50^D x 150^H mm^3 placed 19 mm above the target. The moderator will operate around 20^oK, cooled by helium gas from a 40W Phillips PG105 Cryogenerator. The heat load is not yet known in detail, but because of geometry will be due to neutrons rather than γ-heating. Container will be of pure aluminium (high k at 20°K), and a window will allow inspection of the methane. Cooling will be arranged to give a lower temperature at the bottom of the moderator rather than at the top to avoid deep boiling problems. A safety pump system will be installed to remove gaseous CH_4 in an emergency.

More details of the KENS proposal and the mock-up experiments are given in Report list no.1. Though methane is regarded as the best material for cold neutrons it was pointed out that for SNS intensities the life-time of the methane would be too short.

6.2 IPNS-I Engineering System

The engineering design for IPNS-I is scheduled to begin in full in October 1978. The target will have 7 "Savannah River Modified Alloy" uranium discs, diameter 10 cm and 2.2 cm thick. The plates will be clad in Zircaloy-2, 0.254 mm thick. Coolant will be by water flowing at 1m/sec. The maximum centreline temperature will be 275°C. A tantalum target will also be built as a back-up. A status report and a summary report on target design are given in the Report list, nos.13 and 14; detailed considerations are given in reports no.12 and 16.

The neutron scattering target will have 3 moderators, but no cold moderat The radiation effects and neutron scattering targets will be the same to allow easy interchange. The cooling systems will be redundant for each other. A layout drawing was presented (see Report list, no.17).

In operation, it is proposed not to shut-off Booster II in the event of a target fault, but to divert the beam to a beam dump.

6.3 SNS Target System

The proposed SNS target will use "Springfields Adjusted" uranium, in plates of thicknesses in 4 batches of 5 mm to 10 mm. Cladding will be Zircaloy-2, 0.254 mm thick. The coolant will be D_2O so that the target containment vessel cooling wings can also serve as reflector. The cooling gaps will be 2 mm wide, but will be allowed to reduce to 1.5 mm under plate irradiation swelling. The target plates will be curved to a large radius to resolve non-uniform buckling throughout the pack. The target containment vessel will be of Inconel 718 to resolve radiation damage to the window.

A series of nucleate boiling tests have shown burn-out safety factors greater than 3 on the proposed nucleate boiling regime, of static pressure 2.6 bars, bulk temperature 30^{o}C, flow rate 12 m/sec.

In view of potential problems of quasi-static and cyclic stress the target parameters are under review - including the type of uranium alloy and centre-line temperature.

6.4 Hybrid Moderator Systems

Kley (Ispra) proposed a hybrid moderator system in slab geometry. The beam and target would be "flattened" to ensure strong coupling to the moderators. The proposed beam profile is 10(v) x 1(h) cm^2; the target dimensions roughly 12(v) x 2(h) cm^2 by 20 cm long. The target would be a stainless-steel walled vessel packed with uranium plates, cooling by vertical flow of water. Above and below the assembly would be Be reflector 4-5 cm thick, at each end would be Be and H_2O (poisoned ?) agai 4-5 cm thick. Two moderators are proposed:

a) Thermal and cold neutron source. The moderator would have a water section with a curved face, plan dimensions 12 x 4 cm^2, and a true cold section with hydrogen at 20K. This combination is then faced with a large Be or C single crystal also at 20^{o}K. Beam ports viewing the moderator would have diameter 15-20 cm normal to the moderator:at other angles 10 cm diameter. The combination of large coupling and thin cold section maximises the ratio of flux to pulse width. A practical feature is the reduction of cryogenic heat load sincethe major part of thermalisation is taken by the water part of the moderator.

b) Epithermal-thermal neutron source. In this case the water section is considerably reduced and the true moderator consists of 4-5 cm thickness of (A) Titanium hydride at 600^{o}C, or (B) Zirconium hydride at 850^{o}C, or (C) Yttrium hydride at 1200^{o}C. The moderators are held under 1-4 atmospheres pressure of hydrogen: cooling is by hydrogen plus helium gas flow. Beam ports viewing the moderator are as in (a).

Bauer (Jülich) suggested a slab geometry system for the SNS. The target would be similar to that proposed by Kley and using vertical flow cooling. On each side of the target would be one parallel slab and two angled slab moderators. The advantages of such a system are:

1. 3 beam lines per moderator giving the planned 18 beam lines
2. Easy horizontal target removal
3. Good coupling to give good neutron beam intensities.

7. SAFETY, OPERATION AND DISPOSAL

Overall safety studies of all of the systems at the various laboratories will be required as the designs become firm. All systems, in part or as a whole, will require appropriate formal safety assessments and documentation. Though the laboratories have different approaches to particular areas, it was agreed that for reference purposes safety related documents should be exchanged amongst ICANS members.

Disposal was not discussed in any detailed way.

7.1 IPNS-1

Conceptual designs for the removal and insertion of targets are being evaluated. Basic requirements include:

i) ability to change targets and moderator/reflector assemblies independently
ii) need for a single system to permit rapid change to enhance operating efficiency.

The latter requirement is necessary since target assembly optimisation to match experimenter's needs may not be readily possible through calculations. Failures can be expected; and experimentation with different configurations will be needed for future optimisation studies.

Diagrams were presented of several target and T/A removal schemes, the preferred target removal system using linked discs, horizontal at the target becoming vertical through a tube of generous radius, as detailed in Report list, no.17.

The work expended on IPNS-I is expected to establish a precedent for IPNS-II and similar systems.

7.2 WNR

Some aspects of WNR operation have been discussed in 2.3 (b) above. Difficulties have been experienced with the final HARP monitor. At present a thermocouple embedded in the Ta target is being used as a beam monitor where the beam is tuned for maximum temperature. There has not been sufficient running time to see deterioration in the performance of the thermocouple.

Details of the existing WNR handling system are shown in the Report list, no.21. It is hoped to replace the present system by having disposable targets rather than just individual parts.

7.3 SNS

It is proposed to cantilever the Target Assembly from a massive removable shielding door. By withdrawing the shielding door in a downstream direction the target assembly is brought within a Hot-cell equipped with remote manipulators. The aim is to build the target assembly in as "standard" way as possible with all functions compatible with the requirements for remote handling. At shutdown target activity is expected to be of the order of 10^5 curies.

A full scale model of the target assembly was presented, showing the stages of breakdown to give access to the separate components.

ACTIONS ARISING FROM TARGET ASSEMBLY/TARGET STATION WORKSHOP:

ICANS MEETING 10-14 JULY, 1978

	ACTION	TITLE
1.	RL	Use TIMOC code on LASL Target/Moderator geometry to compare with NMTC/MCNG results.
2.	RL	Time dependence calculations on polythene moderator, rather than H_2O, to check time dependence given by G Russell as standard deviation $\sigma(ns) \sim 654/E^{0.457}$ with E in eV. (These two actions were completed during the ICANS meeting.)
3.	LASL	To repeat calculations on LASL Target Assembly with decoupler to check effects of decoupler strength on time pulses in reflected system.
4.	RL/LASL	RL to obtain a version of MCNG code for gamma transport and comparison purposes.
5.	LASL	To transmit information on recent LASL FERFICON MEASUREMENTS also on future thin target measurements, for code checking.
6.	RL/LASL	Mass split predictions of HETC to compare with LASL VEGAS code.
7.	LASL	NMTC/MCNG check on HETC prediction for evaporation neutrons for ^{54}Co(p, spallation) at 370 MeV.
8.	LASL	Experimental determination of thermal neutron distribution over face of moderators.
9.	LASL	Send data on latest radiation survey to RL, including effects of mis-steer of the beam (7½ nA lost).
10.	LASL	Information on Beam Plug design to RL.
11.	LASL	To provide information on neutrino fluxes from beam dump experiment.
12.	KENS	To seek to obtain Cascade neutron spectra 800 MeV p on W, Ta (also possible ^{238}U ?), (Watanabe).
13.	ANL/LASL/RL	Exchange Safety Analysis Reports or Functional Specifications as mutual aids in developing safe operational systems for Target Stations.

REPORTS AVAILABLE AND/OR RECEIVED AT TARGET ASSEMBLY/TARGET STATION SESSIONS

1. "KEK Neutron Source and Neutron Scattering Research Facility", Y Ishikawa and N Watanabe, Tohoku University, Japan. July 1978.

2. "Application of 500 MeV Proton Beam from KEK Booster Synchrotron to Neutron and Meson Physics and Medical Use", H Sasaki, Natl. Lab. for High Energy Physics, Japan. July 1978.

3. "Target-Moderator-Reflector Mock-Up Experiments for KENS", N Watanabe, M Misawa and S Yamaguchi, Tohoku University, Japan.

4. "Shielding Design for KENS", N Watanabe, K Katoh and R H Thomas. Note 6, KEK-78-7, July 1978.

5. "Transverse Shielding for KENS:II", R H Thomas, Note 5 KEK78-7, 1978.

6. "Initial Target/Moderator Configuration, WNR Facility", G J Russell, Trans. Amer. Nucl. Soc. 27, Pbl. 1977.

7. "Calculated Neutron Leakage Characteristics for WNR (as built) Ta Target", Office Memo. G Russell, LASL, May 1978.

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10. "The ZING-P' Neutron Source", K Crawford, ANL.

11. "IPNS Target Optimisation Studies", S Das and T Worlton, ANL, June 1978.

12. "Evaluation of Target Materials and REcommendations for IPNS-1", B A Loomis, ANL, 1978.

13. "Target Design: Introduction and Objectives", (notes of) N Swanson, ANL, July 19

14. "Target Station Status, IPNS", (notes of) N Swanson, ANL, July 1978.

15. "IPNS Design: Health Physics on Booster II", R L Mundis, ANL, June 1978.

16. "IPNS-1 Target Cooling Conceptual Design", L Carlson, ANL, June 1978.

17. "IPNS-1 Target Handling Concept Drawings, 1st set", N Swanson, ANL, July 1978.

18. "Spallation Target-Moderator-Reflector Studies on Nimrod", RL, July 1978.

19. "Sketches for Proposed Hybrid Moderators for SNS", W Kley (Ispra) July 1978.

20. "Comparison of WNR Proton/Neutron Transport Codes with TIMOC", M W Johnson and A Taylor. ICANS Meeting, July 1978.

21. "Characteristics of WNR and Target System", Transparencies, G J Russell, LASL.

	1000 MeV		380 MeV	
	HET	EXPT.	HET	EXPT.
σ_{TOT}	47.8	47.55	23.5	24.4
$\sigma_{el.}$	26.5	26.8 28.2	22.2	?
$\sigma_{pp\pi^o}$	3.4	3.7	0.02	0.05 (?)
$\sigma_{pn\pi^+}$	17.9	17.2	0.26	0.3→0.4
$\sigma_{pp\pi^o\pi^o}$	∿ .02	?	0.0	0.0

p-p Scattering cross-sections

	630 MeV		200 MeV	
	HET	EXPT.	HET	EXPT.
σ_{TOT}	39.1	37	41.6	42.7
$\sigma_{el.}$	27.6	26 ± 3 @ 576	41.6	
$\sigma_{np\pi^o}$	7.4	?		
$\sigma_{nn\pi^+}$	1.9	?		
$\sigma_{pp\pi^-}$	2.2	1.68 @ 600 ∿2.4 @ 780		

n-p Scattering cross-sections

[Hydrogen target: 2 cms dia. x 10 cms:0.04264 nuclei $Å^{-3}$, axially illuminated.]

TABLE 1 : COMPARISON OF HET RESULTS WITH EXPERIMENT

ICANS - R20 SCHEDULE (A CARNE)

	TUESDAY 11th	WEDNESDAY 12th	THURSDAY 13th	FRIDAY 14th
MORNING	TARGET - HETC αVARIANTS SPECIFIC EFFECTS (h e fission) CODES TARGET, REFLECTOR, MODERATOR CODES (i) TIMOC (ii) MORSE (iii) VIM (iv) MCMP	TARGET/MOD/REFLECTOR BENCHMARKS (EXPERIMENTAL RESULTS) (I) MUSTA - A Taylor (II) WNR - G Russell (FERFICON) (III) ZING-P' - N Swanson (IV) KENS - N Watanabe (V) OTHER EXPERIMENTS	TARGET/MOD/REFLECTOR HARDWARE ENGINEERING (MOD/REFL) (I) COLD MODERATOR (En Dep) Y ISHIKAWA (KENS) G RUSSELL (LASL) R WIMBLETT (RL) TARGET ENGINEERING TEMP, STRESS, GROWTH (N SWANSON)	VISIT - AERE LINAC
AFTERNOON	TARGET ASSEMBLY PHYSICS DESIGN FAST NEUTRON → THERMAL NEUTRON MODERATOR → INSTRUMENTS (OPTIMISATION)	BULK SHIELDING etc (I) SNS - T Broome (II) WNR - P Seeger (III) KENS - N Watanabe	SAFETY, OPERATION & DISPOSAL (I) ANL - N SWANSON (II) LASL - G RUSSELL	(I) SUMMARIES (II) FUTURE COLLABORATION
ODDITIES AND SPECIAL REQUIREMENTS			4.30 AERE LINAC DESCRIPTION p.m. BEAM LAYOUT → INSTRS REQUIREMENTS	

FIG: 1 TARGET ASSEMBLY/TARGET STATION PROGRAM

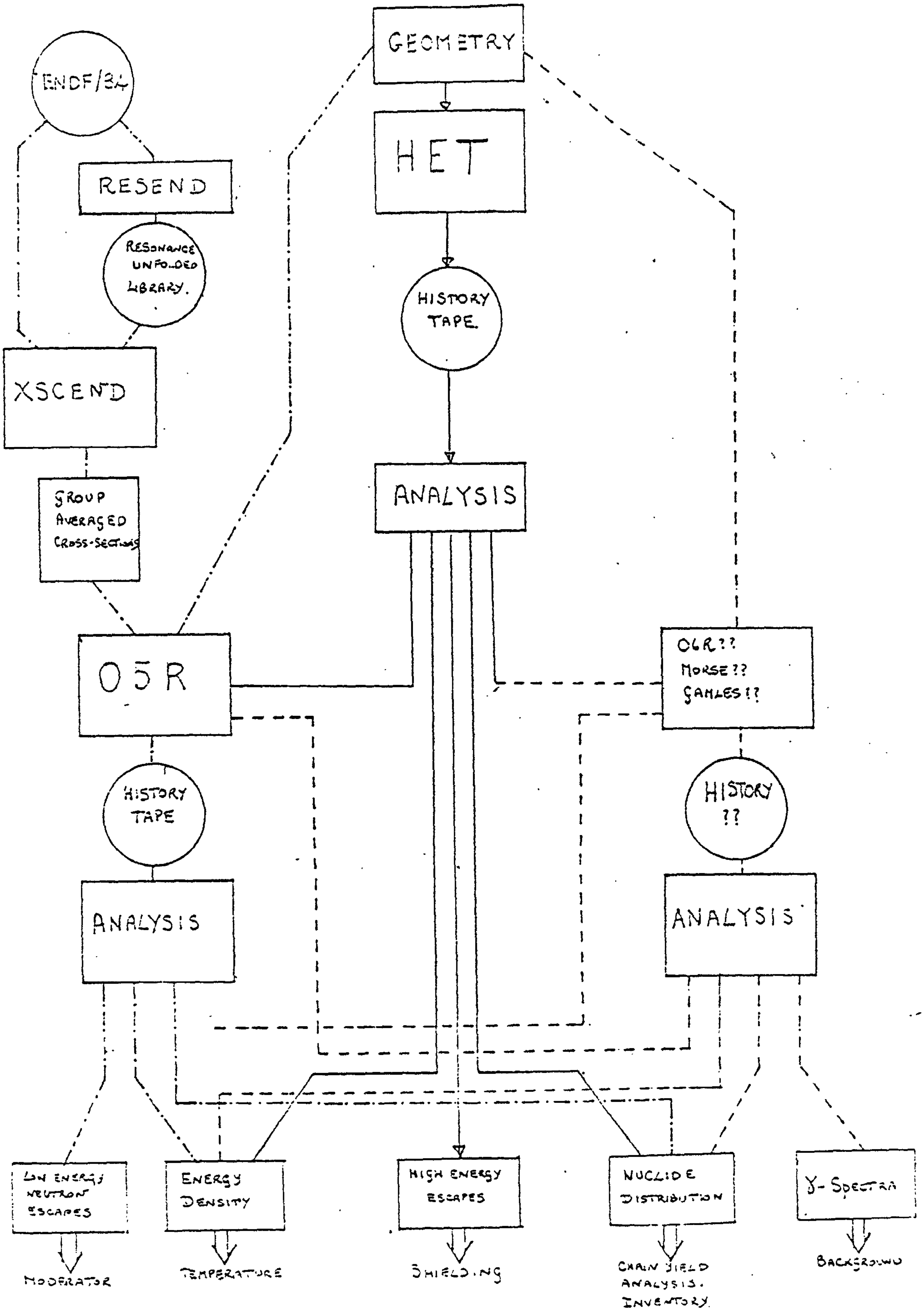


FIG.2: HETC Program, Flow Diagram for Target Calculations

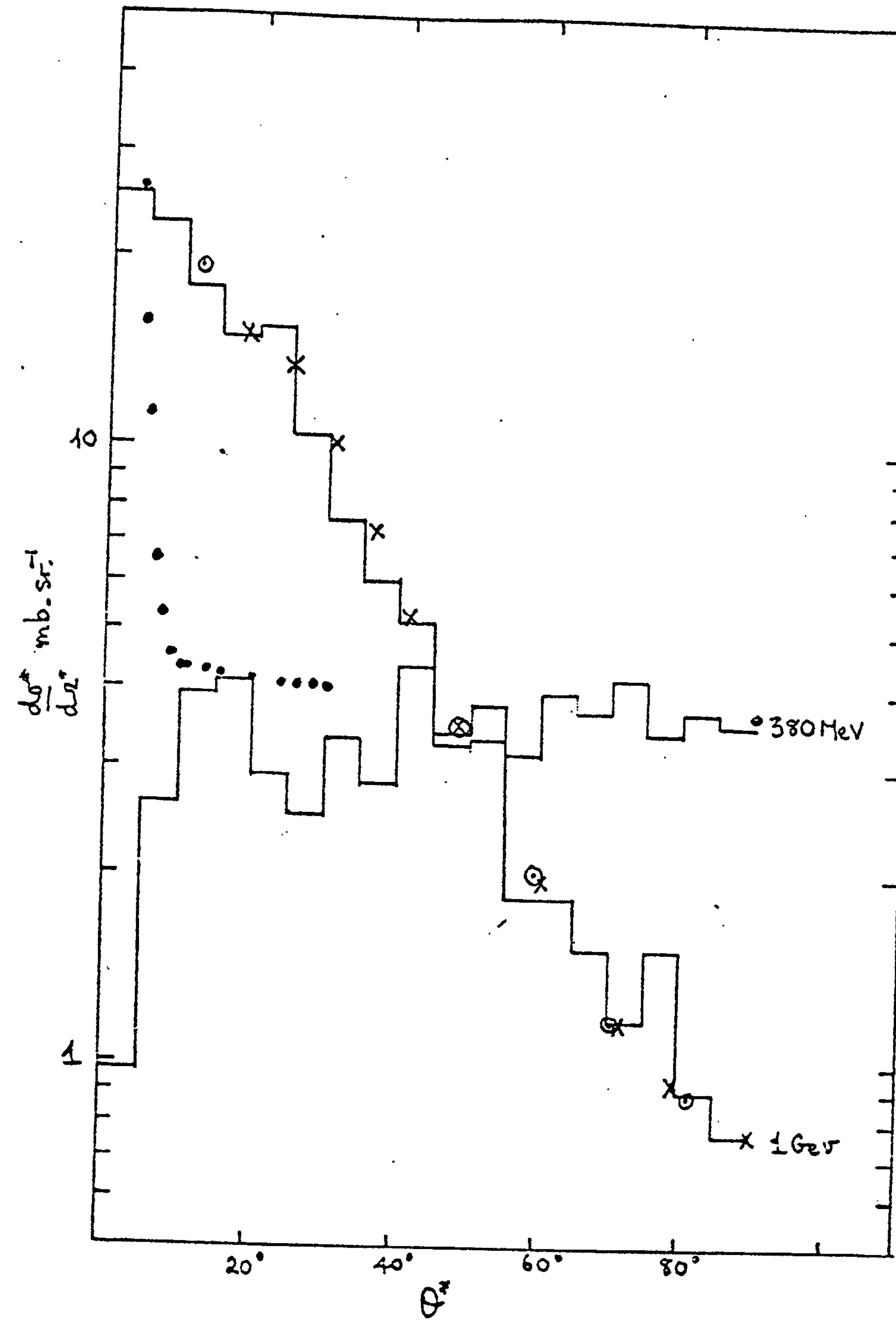


FIG.3: P-P Elastic scattering from HET. The experimental results are from: ⊙ McFarlane et al., Nuovo. Cim. 28, 943 (1963) at .97 GeV; X Dowell et al. Nuovo. Cim. 18, 818 (1960) at 1 GeV; • Holt et al., Proc. Phys. Soc. 71, 781 (1958); Harting et al., Proc. Phys. Soc. 71, 770 (1958) at 380 MeV.

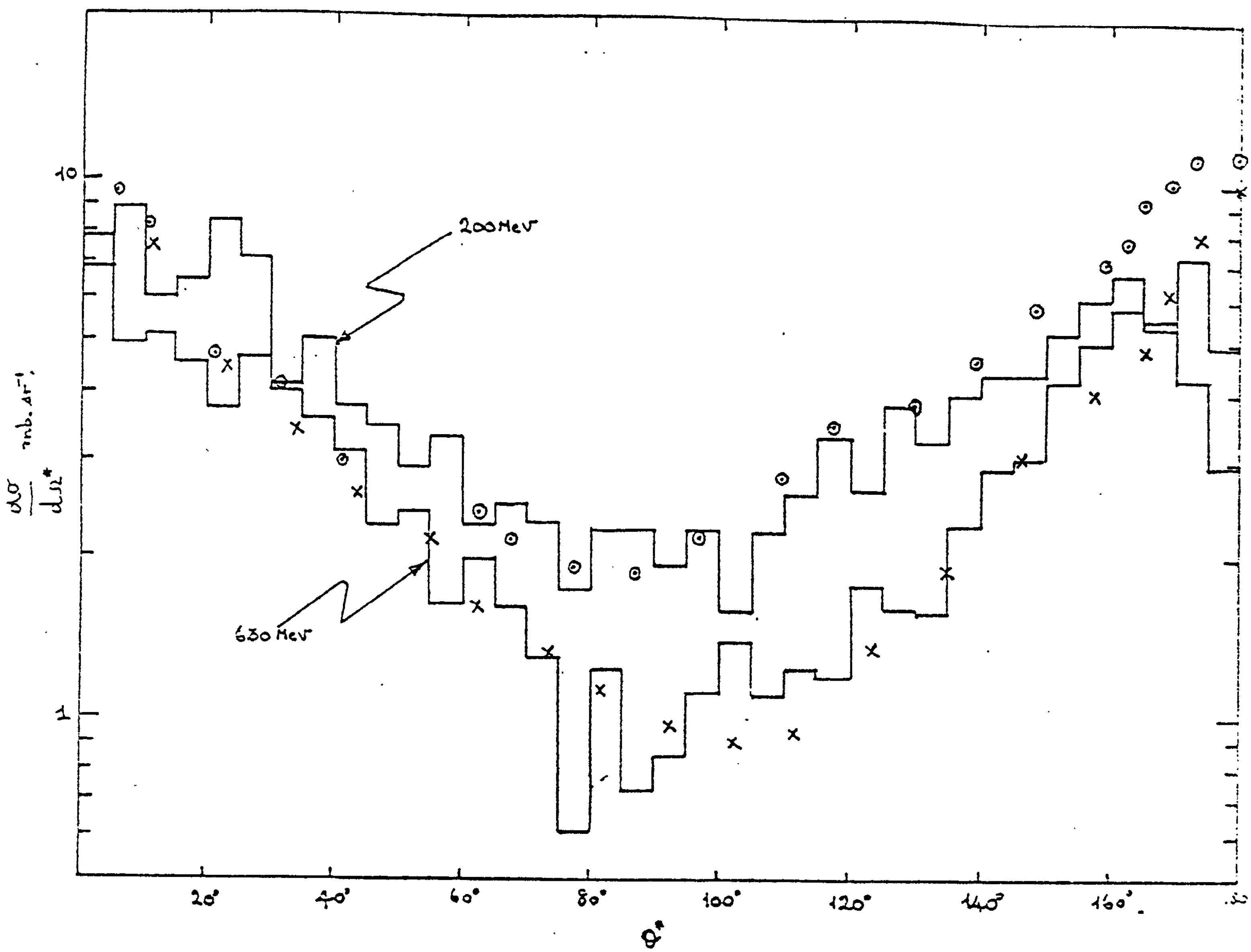


FIG.4: n-p elastic scattering from HET. The experimental points are from:
× Kazarinov and Simonov, Sov. J. Nucl. Phys. 4, 100 (1967) at 630 MeV;
⊙ Kazarinov and Simonov, Zh. Eksperim. Teor. Phys. 43, 35 (1962) at 200 MeV as reported in Thomas et al., Phys. Rev. 67, 1240 (1968).

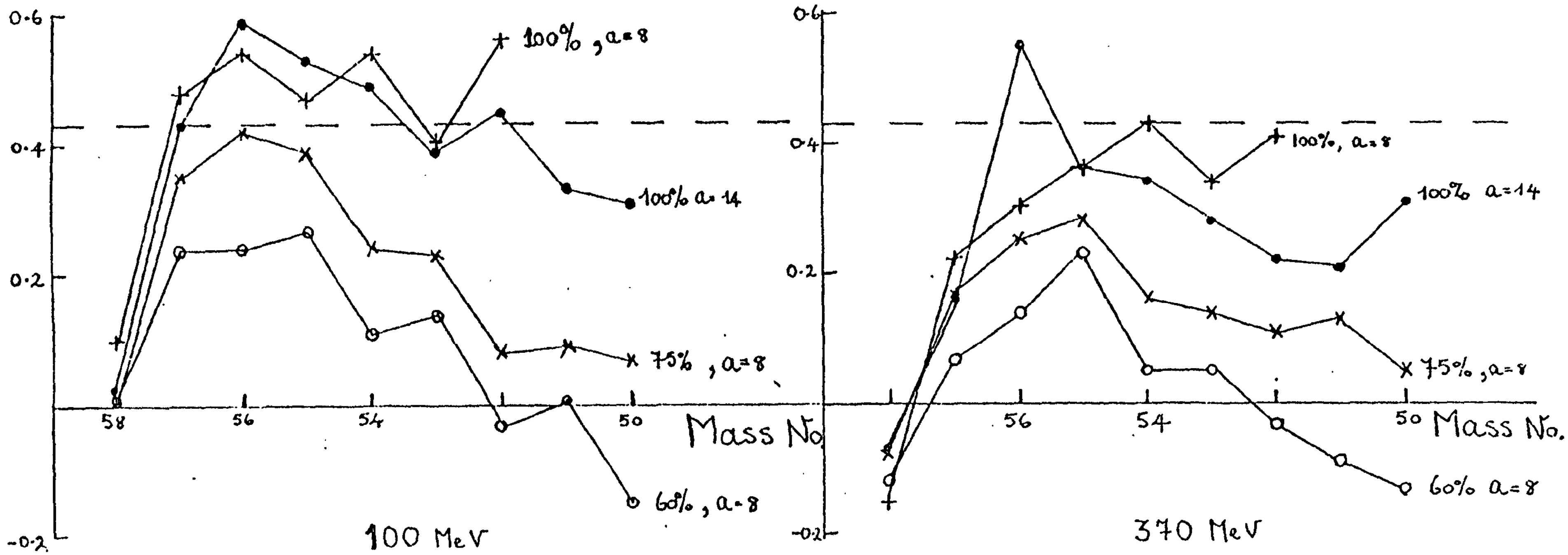


FIG.5: Deviation ΔZ of the mean charge for Isobaric yields of HET from the predictions of Rudstam[1].

The results are for 100 and 370 MeV proton bombardment of ^{59}Co. Also shown is the effect of (arbitrary) changes to the level density parameter a and the coulomb penetrability (% of value in current version of HET). The dashed line at ΔZ ≑ 0.43 is the mean separation between adjacent masses. The lines connecting the points are to serve as a guide to the eye.

APPENDIX 1

Comparison of WNR Proton/Neutron Transport Codes with TIMOC

The geometry used in the comparison is shown in Figure 1.

Neutron Flux Intensity

The results obtained by the WNR Monte Carlo codes, which transport both protons and neutrons may be succinctly expressed:

$$\Phi(E) = 0.00962\ E^{0.0961} \quad \text{n/p.lethargy.st}$$

where $\Phi(E)$ is the epithermal neutron flux averaged over a 0.5 st conical solid angle emerging from the 15 cm diameter central area of the polythene moderator shown in Fig.1. This flux is shown as the lower line in Fig.2.

The flux obtained by the TIMOC (Rutherford Laboratory) code for the same geometry is shown as the upper line in Fig.2. The two results have the same energy dependence but the absolute value at 1 eV is

$$\left.\begin{aligned} \Phi(1\ \text{eV})_{WNR} &= 0.00962 \\ \Phi(1\ \text{eV})_{TIMOC} &= 0.0110 \end{aligned}\right\} \quad \text{n/p.eV.st}$$

Note 1: Since TIMOC only transports neutrons, and not protons, the effect of the proton beam was simulated by incorporating a quasi fast neutron source, within the Ta target and suitably distributed along it. This quasi source was given an energy distribution:

$$\chi(E)\ \alpha\ \sqrt{E}\ \exp\{-E/A\}$$

where A = 1.4 MeV

which was found to reproduce the observed neutron energy distribution on the surface of a bare Ta target.

2: WNR results are expressed in units of neutrons/proton whereas TIMOC results are in neutrons/n_f. For the purposes of the comparison a ratio of $n_f/p = 10$ has been assumed.

Neutron Time Dependence

In the epithermal region the WNR codes predicted a variance in the leakage pulse of

$$\delta_{WNR} = 654 \times E^{-0.457} \quad (ns)$$

This is shown as the straight line in Fig.3. The TIMOC results, for the same geometry, are shown as the histogram on Fig.3. It will be seen that at $\sim$ 100 eV they appear to differ by $\sim$ 20%.

M W Johnson
A D Taylor

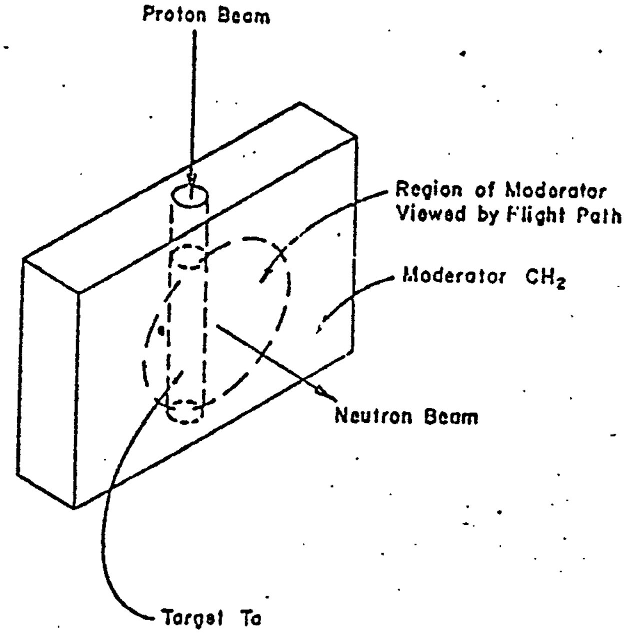


Fig. 1. The initial WNR target/moderator configuration. The top of the target is below the top of the moderator.

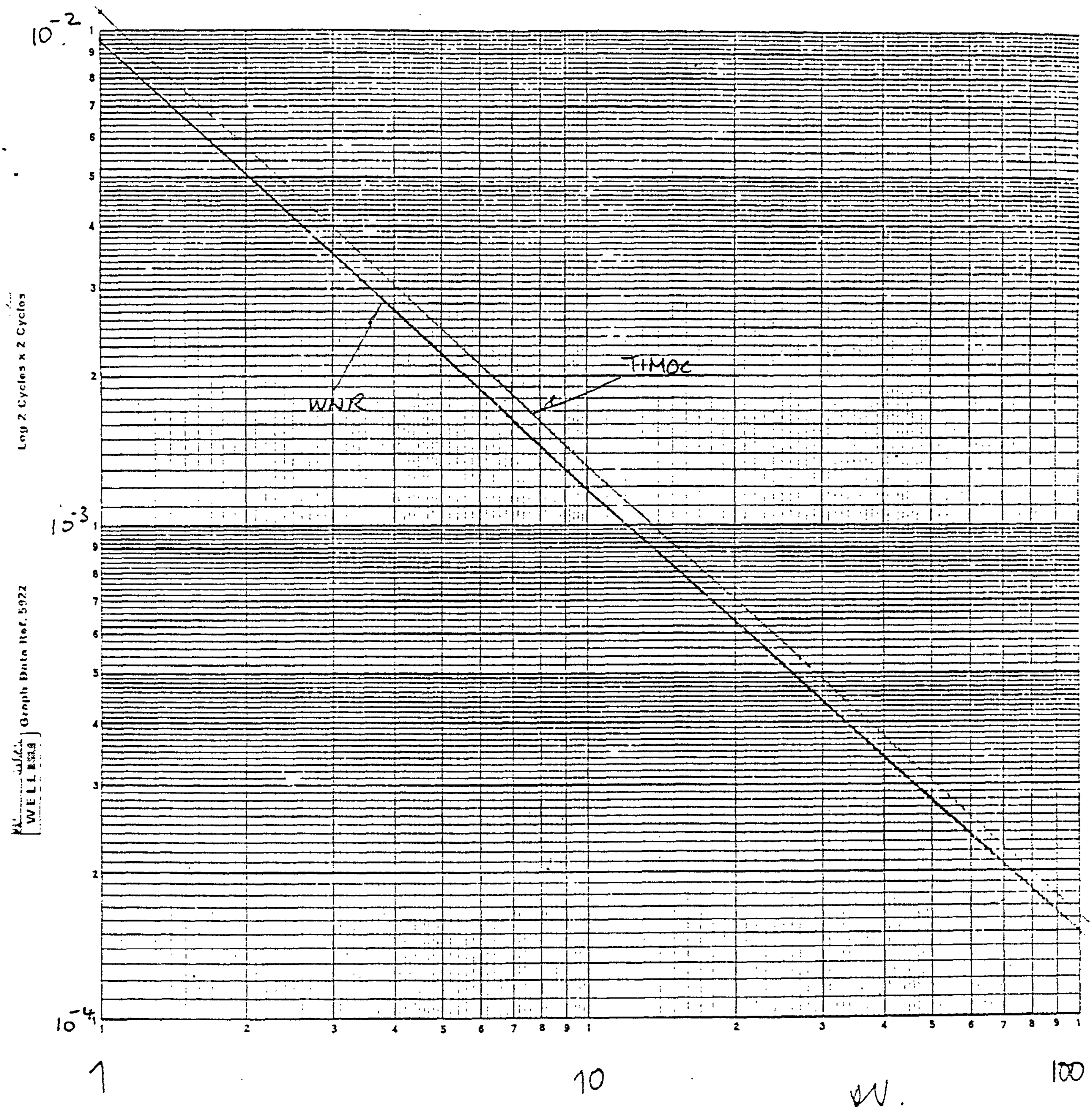

10^-2
10^-3
10^-4
1
10
100
w.
WNR
TIMOC
Log 2 Cycles x 2 Cycles
WELLESLEY Graph Data Ref. 5922

Fig 2

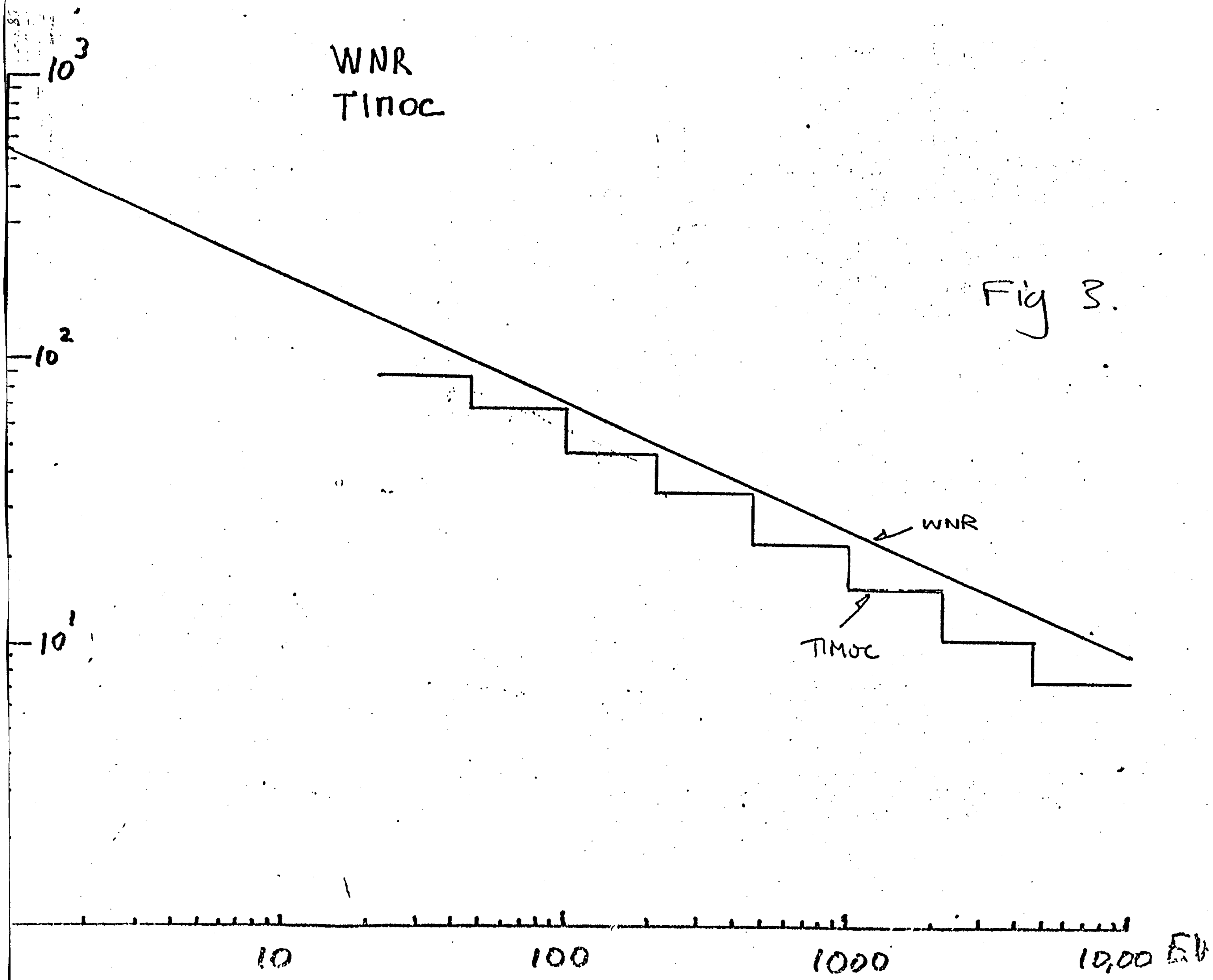


Fig 3.

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 ($\sim$ 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 $\lambda^* \sim 0.5$ Å) for a high resolution powder instrument and b) a cold guide ($\lambda^* \sim 3 - 4$ 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 $\sim$ 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 $I(\lambda)$ and the solid angle $\Omega(\lambda)$ 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.

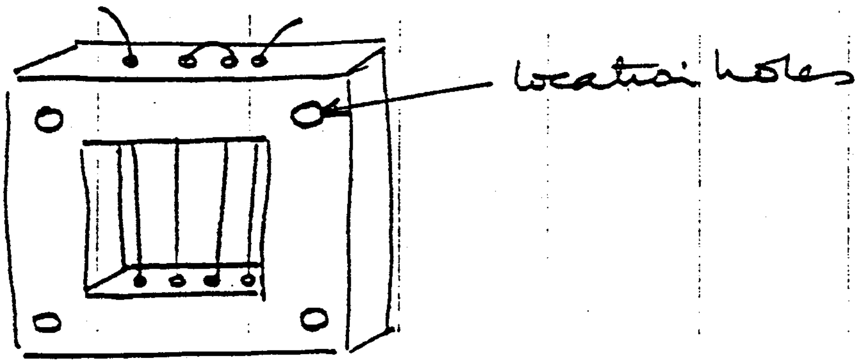
(e) Suggested that 2D, converging and diverging collimators are possible using wire frames.

(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^{o} 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 ^3He 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 wasfelt 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.

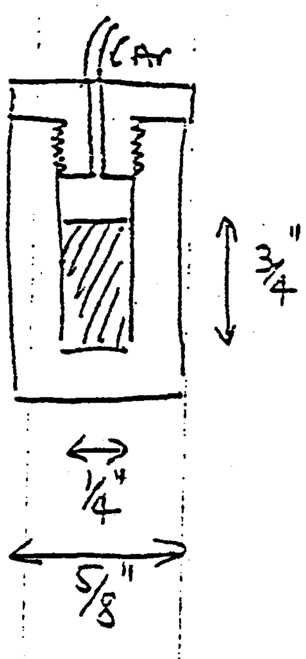
(b) bulk storage of data. It was considered that external dedicated memory was a lower cost option than computer memory and that sequential access would continue to be 3 to 4 times cheaper than random access memory. The usual disadvantage of sequential access viz the comparatively long access time, is 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 $(\text{time})^2$. 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 $100^{\circ}C$. 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).

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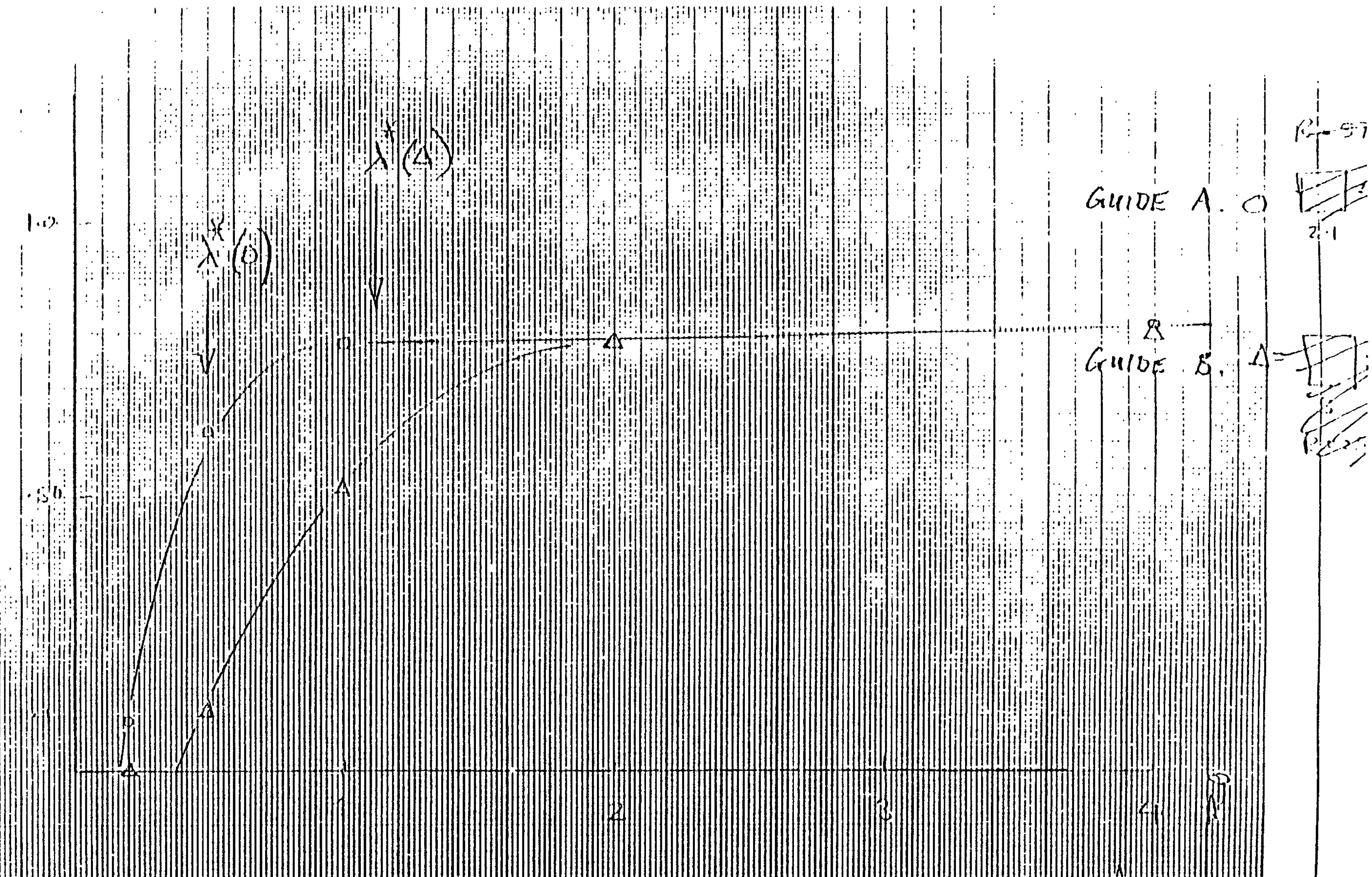
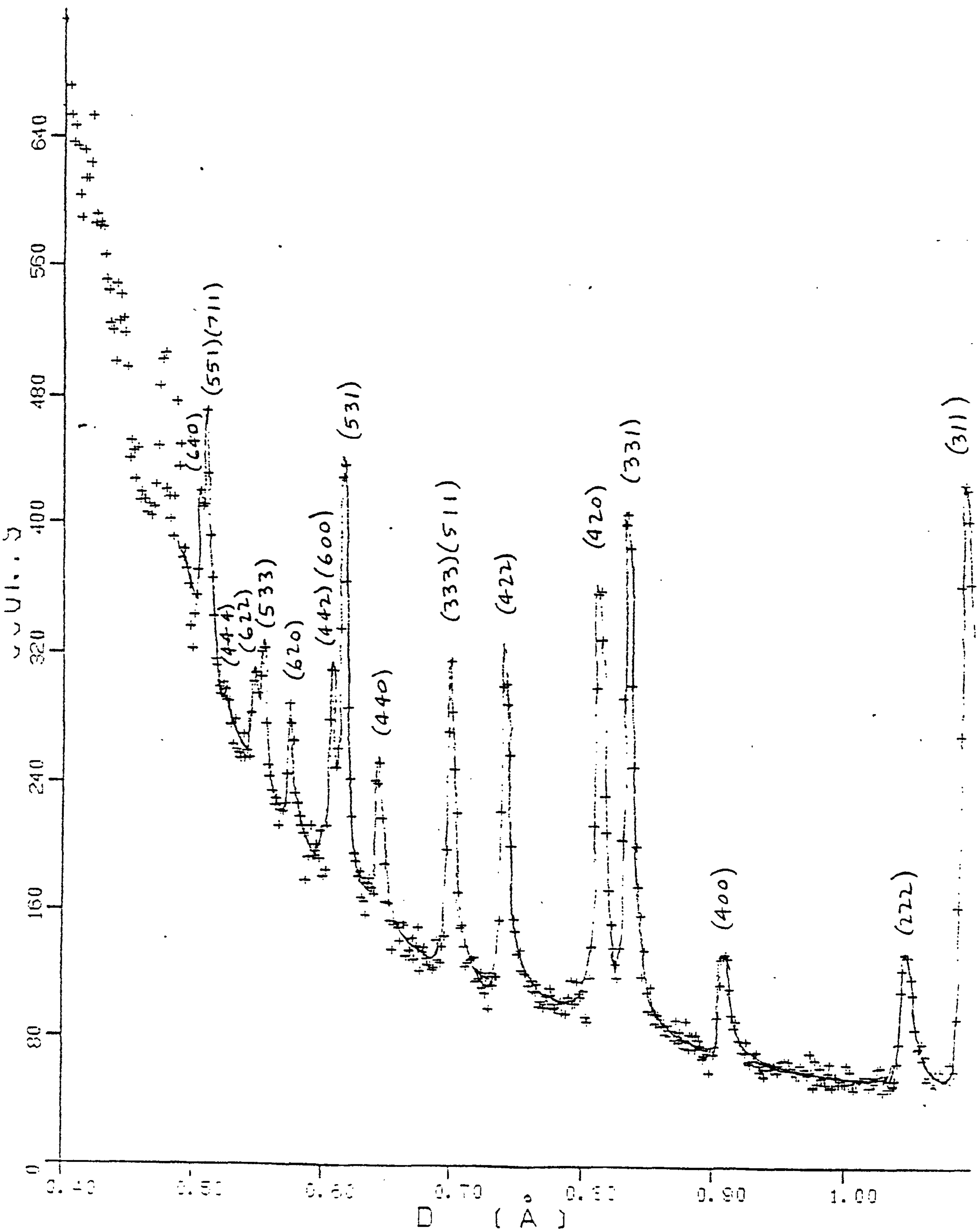


Fig 1


640
560
480
400
320
240
160
80
0
0.40
0.50
0.60
0.70
0.80
0.90
1.00
D (Å)
(551)(711)
(640)
(444)
(622)
(533)
(620)
(442)(600)
(531)
(440)
(333)(511)
(422)
(420)
(331)
(400)
(222)
(311)

(Also = λ)

FIG. 3

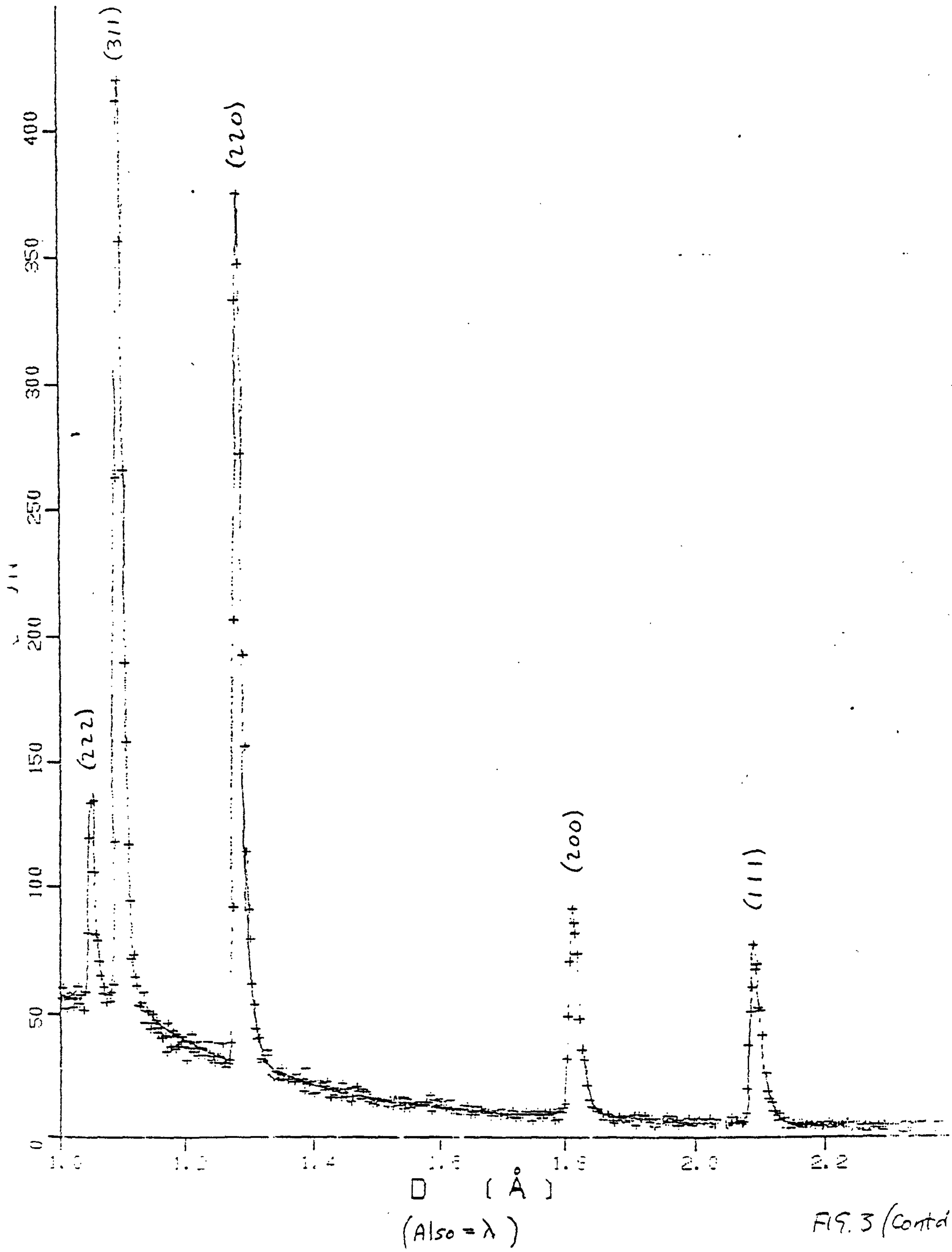

(311)
(220)
(222)
(200)
(111)
400
350
300
250
200
150
100
50
0
1.0
1.2
1.4
1.6
1.8
2.0
2.2
D (Å)
(Also = λ)

FIG. 3 (Contd)