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# AUSTRALIAN ATOMIC ENERGY COMMISSION
## RESEARCH ESTABLISHMENT
## LUCAS HEIGHTS

## PROGRESS REPORT OF PHYSICS DIVISION
including
APPLIED MATHEMATICS AND COMPUTING SECTION

1st APRIL 1969 - 30th SEPTEMBER 1969

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CONTENTS

## INTRODUCTION

A complete review of A.A.E.C. methods of reactor calculations and associated nuclear data is being undertaken by a working party to ensure that an adequate coverage of reactor core physics assessment is available. Codes acquired from various centres together with adaptations of our own are making heterogeneous calculations possible at a reasonable level of sophistication. The Winfrith code WIMS was supplied by the U.K. Central Electricity Generating Board and is now operating on the A.A.E.C. IBM 360 computer. New methods and theories are being developed to cope with the greater complexity necessary in detailed reactor assessments, the aim being to obtain accuracy and speed of calculation.

The nuclear data library is under review and it is proposed that a new evaluation of certain data will be made, particularly fission product cross sections. The previous fission product library, now some three years old, was based on relatively simple theory. The intervening time has seen very marked changes in, for example, the theory of statistical and high energy regions which can now be handled properly so that the whole energy range can be covered in a consistent evaluation.

A study of shielding problems has begun for such work as the shielding of the new Critical Facility. Discussions with electricity authorities on shielding methods have been taking place. An increasing involvement in such studies is expected.

In keeping with the proposals for extending existing computer facilities, a PDP9L computer has been installed and its Link to the IBM 360 computer is due for delivery in October, 1969. The Link was designed within Applied Maths. and Computing Section and is now being produced commercially in the United States. Action is in hand to extend the central core storage of the IBM 360 to 512K bytes. The increased computer facilities are expected to provide adequate support for the extra computing effort resulting from the return of staff from overseas. One restrictive feature in this Section has been the considerable number of staff resignations occurring during the period.

# PHYSICS DIVISION

## PROGRESS REPORT : 1ST APRIL, 1969 - 30TH SEPTEMBER, 1969

## CHIEF OF DIVISION : DR. J.L. SYMONDS

## INDEX

# 1. EXPERIMENTAL PHYSICS SECTION

## 1.1 Exponential Experiments

### 1.1.1 $^{235}$U-BeO and $^{239}$Pu-BeO experiments

Analysis of results is essentially complete and reports are in a draft stage.

### 1.1.2 Reactor neutron spectrometry

(a) Proportional counter spectrometry (P. Cripps)

An improved recoil proton proportional counter was built and has operated successfully at 3.6 keV but the quality of spectrum has deteriorated with time. This has been greatly reduced by thorough outgassing of the counter before pressurising with hydrogen-methane mixture and a technique has been devised for obtaining a gas sample from the aluminium or copper sample holder under vacuum. The percentage of oxygen and other contaminants can therefore be measured as a function of time.

Using a nanosecond pulse generator, the supporting electronics have been adjusted to provide gamma ray discrimination. The spherical detector, ordered 18 months ago from Twentieth Century Electronics, has now arrived and should enable comparison with the detector built locally to begin immediately. The recoil proton counters will be tested using an accelerator beam and a resolution check will be made in the thermal column of MOATA in October/November 1969.

(b) Time-of-flight spectrometry (A. Dalton)

Calculations of performance of the Mk I chopper have indicated that operation at a speed of 28,000 rev/min would be permissible. Preparations are in hand to check the chopper stability up to this speed experimentally.

The use of carbon filaments reinforced in epoxy resin is being investigated as a means of producing a chopper of much higher speed.

### 1.1.3 Neutron streaming (D.B. McCulloch)

No aluminium plates were completed or delivered in this period. The recently installed air-conditioning equipment in the tape-controlled mill room should now enable machining of plates to proceed.

## 1.2 MOATA

### 1.2.1 Operations

| | Days | % |
|---|---|---|
| Operation | 80 | 64 |
| Days lost through defects | 9 | 7 |
| Modifications and planned maintenance | 14 | 11 |
| Assembly of experiments | 23 | 18 |
| Total | 126 | 100 |

Total integrated power 633 kWh

### 1.2.2 Modifications and new equipment

Towards the end of the period all the reactor fuel was unloaded and work commenced on the modifications to the shield tank. A graphite duct will extend outwards to the end of the concrete shield. A steel fabrication will support and align the extra graphite and the concrete blocks that replace the original water shield. The modifications will allow greater utilisation of the reactor by providing additional sources of thermal neutrons.

A completely transistorised logarithmic amplifier is being installed in the log N channel, replacing the unreliable thermionic amplifier that has been causing problems. Elimination of spurious period trips will provide greater operational reliability.

The core tank overflow lines will be removed and replaced with larger diameter piping to enable higher coolant flow rates to be obtained when required.

### 1.2.3 Experiments

(a) Surface barrier detectors for fission fragment detection were calibrated and the quality and performance of thin $^{235}U$ and $^{233}U$ electrosprayed foils were investigated.

(b) Various experimental fission chambers were calibrated to determine pulse rise time characteristics and counter efficiency.

(c) The keV neutron flux in a filtered beam was measured by the observation of gamma rays with a Ge(Li) detector from the 0.5 and 2.5 keV resonances in copper.

(d) Further time-of-flight measurements were made.

(e) A.S.N.T. student training experiments were carried out.

(f) Thirty irradiations were carried out in the Rabbit facility and in various other beams available on the reactor.

### 1.2.4 Future use of MOATA

With the availability of the Critical Facility in mid-1971 and with current availability of beam holes in HIFAR, consideration has been given to the possibility of uprating MOATA from 10 kW to 100 kW. Several keV neutron capture experiments, using a thermal column beam, have already indicated that a factor of 10 gain in intensity would permit valuable experiments to be carried out. Increasing electrical interference in HIFAR has prevented progress on the fission studies contemplated there. These experiments appear to be possible on MOATA at 100 kW.

The present fuel inventory would appear adequate for at least 5 years operation if a 13-plate element is used rather than the current 12-plate element. This is the solution already used by Scottish Universities reactor groups for their 100 kW MTR-100 type reactor. Some modifications are required to the heat removal circuits and, before operation can commence, a new safety submission will be presented to the Reactor Safety Committee.

## 1.3 Heavy Water Physics (D.B. McCulloch)

Analysis of all the fast fission ratio data obtained in the ZERLINA collaborative experiments was completed at Lucas Heights. Outstanding problems regarding foil enrichments etc. were resolved by further measurements at Luca-

Heights. Some discrepancies now exist between results of analyses of the same raw data sets at B.A.R.C. and Lucas Heights. Several discrepancies are due to application of data rejection criteria, and correspondence is being exchanged to clarify the situation. The confirmed foil enrichment data in the Lucas Heights analysis now gives satisfactory agreement between calibrations made using the double fission chamber and $^{140}La$ counting techniques.

Polystyrene mouldings to simulate reduced density water (2-phase steam/water mixtures) were made for use in the planned ZERLINA collaborative experiments to measure $^{238}U$ capture/$^{235}U$ fission rate ratios in uranium dioxide rod-cluster fuelled lattices. This involved some 500 mouldings in 5 different geometries. All equipment for the experiments was assembled and tested, and it is anticipated that work in India will begin at the end of October.

The theoretical models of the ZERLINA reactor required for comparison of the $\delta_{28}$ experimental results with MONTE code calculations were set up and finalised. All the necessary theoretical results have now been obtained for comparison with the final experimental values as soon as they became available.

Owing to imminent availability of an IBM 360/50 version of the WIMS code, and the nearly completed development of more sophisticated collision probability codes in the Theoretical Physics Section, the broadly-based comparison of experimental $\delta_{28}$ values with MONTE calculations was not resumed. It is intended to take up a similar programme of comparisons with the new theoretical methods when they are available.

A comparative reactor physics performance study of $U_3Si$ and $UO_2$ fuels in heavy water cooled and boiling light water cooled heavy water moderated reactor lattices using the METHUSELAH scheme is almost completed.

1.4 HIFAR (D.B. McCulloch)

Work on the DSN/CRAM physics models for HIFAR was essentially completed. A report has been published and a second is nearly finished. The report of the modified fuel accounting burnup program HIBURN was published.

An investigation of the use of heterogeneous methods for HIFAR calculations using the SOS-1 code made some progress, but has been temporarily shelved because of preparations for the Critical Facility.

1.5 Critical Facility (W. Gemmell)

Discussions have continued with the contractor G.A.A.A.[x] on the principles involved in the design. In early September several G.A.A.A. project staff visited Australia and considerable progress was achieved in all areas. Two major instrumentation problems remain unresolved but it is expected that the design will be complete by the end of 1969. Following approval of the mechanical design of the machine proper and the control rods, manufacture of the control rod prototype has begun and an intensive testing and development programme is under way. Approval of the machine itself has allowed the contractor to proceed with pattern manufacture.

Work at Lucas Heights has commenced on analogue computer studies of simple reactivity accidents which might occur as the tables close. Other analytical studies are in progress on possible modes of severe accidents occurring. Ultimately these studies are for the facility safety assessment.

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x Groupement Atomique Alsacienne Atlantique

Several specific shielding calculations were performed on various aspects of the proposed design, and have played an important role in achieving progress with the Contractor. An investigation is underway to provide a suitable method whereby the density and the fixed water content of the cell wall concrete can be determined experimentally, preferably in situ.

An investigation is also being conducted into the properties of aerosols likely to affect the safety of the facility. This covers the settling behaviour of aerosols in confined volumes and their penetration characteristics through filters, sand beds and concrete.

## 1.6 3 MeV Accelerator

### 1.6.1 Accelerator operation

The accelerator operated without any major breakdowns in this period using the same tube and belt. After routine maintenance, it was available for 89% of the elapsed time and usage was 75%, giving 2931 hours of experimental running. The slight lowering of usage compared with the previous period was due mainly to changeover in experimental apparatus and techniques and completion of various phases of experimental runs of major users, namely fission, transport and capture groups. Details of the time allocation are given in Table 1.

The new duoplasmatron source was tested in the test rig which simulates the reactor terminal and progress was made towards installation of the klystron buncher.

### 1.6.2 PDP7 analyser

Owing to increased demand on PDP7 time for accelerator experiments with subsequent analysis and for program modifications, greater use has been made of the IBM 360 for data analysis.

New programs developed include :

- GPLOT - for plotting of spectra and storage on a magnetic tape filing system
- LISTUP - an updating program which sorts and deletes from the file data no longer required
- VCRL - a program obtained from UCRL for calculating backgrounds in spectral analysis and tailored to suit neutron capture experiments
- RAMES - for interpolation, smoothing and subtracting of related spectra.

The multiscaler program on the PDP7 has been developed so that the computer is now used for remote control of detector position along a lathe bed. A program which compensates for the leading edge walk from NaI detectors in fast timing experiments is being tested. A program monitor was written to facilitate debugging of new programs by intimately controlling their operation and allowing full register inspection at any point in time.

### 1.6.3 Neutron capture studies (J.R. Bird)

Results for gamma ray spectra from keV neutron capture in elements from calcium to zinc were analysed and a report was prepared summarising the information obtained. This report and a paper on the observation of high spin state transitions in even-Z target nuclei were presented at the International Symposium on Neutron Capture Gamma Ray Spectroscopy, Studsvik, Sweden, August 1969.

Papers on resonance capture gamma rays from $^{57}Fe$ and single particle states in medium weight nuclei were presented to the International Conference on the Properties of Nuclear States held at Montreal, Canada, August 1969. Three additional papers on neutron capture were presented to this conference, describing work carried out by University personnel supported by A.I.N.S.E.

### 1.6.4 Pulsed neutron studies (A.I.M. Ritchie)

#### (a) Sine wave pulsed experiment in BeO

The attenuation constant $\alpha$ and phase shift constant $\omega$ were measured in BeO in the frequency range 0-500 Hz at a temperature of 22°C and normalised to a density of 2.96 g $cm^{-3}$. The quantities $\alpha^2 - \xi^2$ and $2\alpha\xi$ were evaluated and are shown in Figures 1 and 2. In one-group theory these quantities are given by

$$\alpha^2 - \xi^2 = B^2 + 1/L^2 \quad \text{and} \quad 2\alpha\xi = \omega/vD \ .$$

Curves are shown in Figures 1 and 2 using these relationships and data derived from an earlier $\lambda(B^2)$ experiment on the same sample of BeO. Also shown are theoretical curves due to Wood (1969) who has used an essentially $B_0$ multigroup calculation. It can be seen that Wood's calculations overestimate the slope of the $2\alpha\xi$ curve (too large a transport cross section), whereas the one group theory gives better agreement. Wood's $\alpha^2 - \xi^2$ is in better accord with experiment. Work is in hand to carry out multigroup calculations using data deduced from the $\lambda(B^2)$ experiment to see if Wood's calculations can be improved on.

In the range 0-500 Hz there was no sign of continuum behaviour. Both the attenuation and phase shift behaved as if an asymptotic energy spectrum had been established. Tentative measurements indicated that this was not true beyond 500 hz. More detailed measurements have now been completed covering the range 500-1000 Hz in 50 Hz steps and 1000-2000 Hz in 200 Hz steps to investigate possible continuum behaviour further.

#### (b) Theoretical studies (K. Maher)

Work continued on predicting the time and space dependent reaction rate of a $^{239}Pu$ fission counter embedded in a block of BeO. The space dependence is treated by superposition of three-dimensional Fourier modes, whose amplitudes are obtained from multiple runs of the time dependent energy multigroup code TENDS. Recently this Fourier space mode - multigroup approach has been extended to solve not only the time dependent multigroup diffusion equations but also the time dependent multigroup P1 equations. Preliminary results from this code (TIMEX) indicate that in large assemblies the $^{239}Pu$ reaction rates predicted by the P1 theory and the diffusion theory are not markedly different.

The operator $\frac{\partial}{\partial x} D(x) \frac{\partial}{\partial x}$ has been studied in systems where D(x) changes in a step-wise fashion and the eigenfunctions of this operator have been found for a two region system, and a five region system is now under study. The orthogonality and completeness of the eigenfunctions are being studied and these eigenfunctions, if complete, should prove more useful in heterogeneous systems than Fourier modes. This project is being carried out in cooperation with the Mathematics School of the University of N.S.W.

### 1.6.5 Fission studies (J. Boldeman)

#### (a) Dependence of $\bar{\nu}$ on incident neutron energy

The energy dependence of $\bar{\nu}$ for $^{235}U$ and $^{233}U$ for neutron fission was

measured in the range 0-2 MeV and an evaluation of this data and previous information has been made. It is observed that no fine structure appears in the $\bar{\nu}$ ($E_n$) dependence which can be interpreted as an effect due to the discrete nature of the low-lying fission channels. This observation implies strong coupling of the collective degrees of freedom of the saddle point nucleus to the nucleonic degrees at scission. An important feature of the observed $\bar{\nu}$ ($E_n$) dependence for both $^{233}U$ and $^{235}U$ is the change in slope of $d\bar{\nu}/dE_n$ at the pairing gap. Experiments are in progress to obtain similar data for $^{239}Pu$ and $^{241}Pu$.

(b) Dependence of the average total kinetic energy on incident neutron energy

Measurements of the dependence of the average total kinetic energy of the fission fragments $\bar{E}_K$ with incident neutron energy from 0 to 1 MeV were completed for $^{235}U$. It is found that $\bar{E}_K$ is constant over the entire energy range and these data confirm the lack of structure observed in the $\bar{\nu}$ ($E_n$) dependence described above.

(c) Delayed fission gamma rays from the spontaneous fission of $^{252}Cf$

The delayed gamma ray yield per spontaneous fission of $^{252}Cf$ is being measured and data obtained will include the half life and the decay scheme for fission fragment isomers with $T_{1/2}$ between 2 and 50 μs.

(d) Fragment time-of-flight studies

Delivery was taken of the fission fragment time-of-flight detector system and it is now being assembled.

1.7 Dense Plasma Focus Device (G. Hogg)

The basic vacuum system for the device has been constructed and is being used for vacuum tests on the components of the coaxial plasma gun, as they are completed, and for vacuum gauge calibration. The 30 kJ energy source has been shipped from the manufacturers and delivery is expected in December 1969. Considerable attention has been paid to the problem of electrical screening of the energy source and gun. An independent earthing system has been installed in the experimental area and this will now allow the construction of the energy source screening cubicle to proceed.

A survey of the diagnostic techniques required to monitor and investigate the operation of the plasma focus device has been made. Components have been assembled which will permit detection and recording by oscilloscope photography of the current and voltage characteristics of the device. The angular distribution of neutron energy will be measured by a time-of-flight system under construction and the X-ray characteristics will be investigated by means of a pin-hole camera and a semiconductor detector flux intensity system. It is anticipated that the plasma focus device will be in operation shortly after the installation of the energy source.

## 2. THEORETICAL PHYSICS SECTION

### 2.1 Nuclear Data Group

#### 2.1.1 Data analysis (J. Cook)

Work has continued on the development of multilevel resonance parameter analysis aiming at the stage where light nuclides and the fissile nuclides can be represented accurately with a fully rigorous theory. Associated with this

project is the calculation of asymmetry parameters which will be used to improve the description of self shielding in reactor situations.

### 2.1.2 Resonance parameter analysis (A. Musgrove)

The statistical best estimate for the average level spacing in even-A and odd-A nuclei was calculated. The expected error in the estimate is considerably greater than usually quoted and is influenced by the spin of the target nucleus.

### 2.1.3 Elastic and inelastic scattering (W.K. Bertram)

Investigations were carried out into the possibility of reliably predicting the elastic and inelastic scattering cross sections of nuclei for which experimental data are either incomplete or non-existent.

The optical model code COMPOST was written to calculate differential elastic cross sections, polarisations, transmission coefficients, etc. for the scattering of charged and uncharged particles. One of the optical potentials available in the program is that derived from Perey and Buck's non-local potential which was found by D. Wilmore in 1964 to be very successful in predicting differential elastic scattering cross sections for most nuclei with mass numbers greater than 40 and for incident neutron energies above 1 MeV. In view of this an attempt is being made to extend the method to the calculation of inelastic scattering cross sections using the Hauser-Feshbach method suitably modified to include excitations of the nucleus to energies where individual levels are not known and are replaced by a continuum of levels.

Inelastic cross sections for $^{27}Al$, $^{56}Fe$, $^{208}Pb$ and $^{238}U$ were calculated for incident neutron energies between 0.1 and 7 MeV. These were found to be in good agreement with experiment except at low neutron energies where the calculated cross sections were too large. The cause of this discrepancy was thought to be the effects of fluctuations in the compound nucleus levels. Therefore the program was modified to include fluctuation corrections and subsequent calculations have shown a remarkable improvement.

The results of this investigation indicate that the program COMPOST can now be used to predict with reasonable accuracy the elastic and inelastic scattering cross sections of nuclei with mass numbers above approximately 25.

### 2.1.4 (n,2n) reactions (W.K. Bertram)

A study was made of the applicability of the statistical theory to (n,2n) reactions. It was found that calculated cross sections agreed very well with the experimental cross sections provided that certain parameters in the theory were suitably adjusted. However there appeared to be some inconsistencies when the parameters were compared with results obtained from the analysis of other reactions to which the theory had previously been applied. In order to shed some light on this problem the (n,2n) cross sections were also calculated from the Hauser-Feshbach theory using the computer code COMPOST. Here too the results from the analysis of (n,2n) data were found to conflict with the results obtained from inelastic scattering. It now appears that the only way in which these difficulties can be resolved is by looking at the emission spectra of inelastically scattered neutrons for high incident neutron energies. Unfortunately this is no easy task as experimental results for these are very scarce.

### 2.1.5 Fission physics (A. Musgrove)

Studies of the energy balance at the scission point of $^{236}U$ have been

carried out with a view to explaining on a simple model the observed distribution of the fragment kinetic energies. The roles of deformation energy and relative kinetic energy of the fragments at the scission point on the observed width and skewness of the distribution are being studied.

### 2.1.6 Overseas data

A revised version of the Winfrith data file was obtained. These point data are being processed to supplement the GYMEA multigroup libraries.

## 2.2 Reactor Physics Group

### 2.2.1 Collision probability methods (G. Doherty)

A few region multigroup spectrum calculation has been programmed to enable the GYMEA group structure to be collapsed to a reasonable number for main transport calculations. Cluster geometry collision probability routines have been written and tested, including a method based on the Bonalumi approximation which is extremely rapid and probably of acceptable accuracy for design calculations. The speed of this routine would also enable it to be used in computing condensation spectra in cluster geometry and the advantages over the conventional pin cell approach are being investigated. The derivation of a satisfactory cluster equivalence relation and the provision of reaction rate edit facilities are the two developments remaining for the completion of a comprehensive lattice code based on GYMEA and the Lucas Heights nuclear data library.

### 2.2.2 Fast reactor calculations (I. Donnelly)

A program to establish the accuracy of the high energy cross section data available in the GYMEA libraries has commenced. It consists of calculating a series of typical sodium-cooled and plutonium-fuelled fast reactor configurations for which the critical parameters are known. After the correction of high transport cross section for Fe, the calculated critical size and flux spectrum are in reasonable agreement with the accepted values. However the energy dependent importance function is too flat and this leads to discrepancies in the sodium void coefficient, knowledge of which is essential for safety analysis of a sodium-cooled reactor. These discrepancies, which are probably due to the shape of the $^{239}Pu$ fission and the $^{238}U$ capture cross sections as a function of energy, are being investigated.

### 2.2.3 Thermal lattice calculations (G. Robinson)

With the recent acquisition of the U.K.A.E.A. lattice code WIMS, and the proposed improvements to the local lattice program nearing completion, the number of experimental lattices for which realistic analysis can be made has greatly increased. It is intended to intensify the effort on thermal lattice calculations to validate the local calculation methods and obtain a more precise definition of shortcomings in the nuclear data. For the present, natural uranium heavy water lattices will be considered but it is intended to take advantage of the very comprehensive comparisons between WIMS and experiment to extend the range of lattices under study.

### 2.2.4 Neutron transport theory - Chandrasekhar's Method (B. Clancy)

The feasibility of this method for calculation of neutron albedos has now been established. Computing speeds are an order of magnitude faster than direct solution of the $S_N$ equation for thick slabs. The computer storage limitations at present restrict the application of the method to 10 neutron groups, $P_3$ scattering and an $S_{32}$ representation of angular fluxes. However use of backing store should remove this restriction.

## 2.3 Reactor Codes Group

### 2.3.1 GYMEA (data preparation code) (J. Pollard)

Changes to GYMEA over the period include

(a) updating of data for $^{238}U$ using Schmidt resonance parameters (KFK 120) to bring the data in line with that of the code PEARLS,

(b) addition of data for $^{23}Na$ prepared from the AEEW library using BOMB,

(c) addition of transfer matrices with fast data prepared from the AEEW library using BOMBO,

(d) modification of the resonance equivalence relation used in cell calculations carried out in conjunction with WDSN or ICPP to that recommended by Chiarella (Ph.D. Thesis 1969), and

(e) extension of the output facility to enable data to be prepared for direct use with the codes DOT and 05R.

### 2.3.2 WIMS (Winfrith general purpose neutronics code) (G. Robinson)

The Winfrith lattice cell code WIMS was obtained and is now considered operational. The code can be used for rod on plate geometries in both regular arrays and clusters. A basic library of 69 groups makes the code suitable for a wide range of systems. Solution of the transport equation by the DSN method as well as approximate and exact collision probability methods are available and have been tested. The code incorporates a comprehensive leakage treatment, extensive edit facilities and a burnup routine.

Considerable effort was devoted to adapting the code to make it more efficient on an IBM 360 computer. Typical running times to solve a problem with 18 groups in the main transport routine are 10 to 15 minutes.

Calculations on a set of 69 experiments with natural uranium metal rods in $D_2O$ were made and revealed a serious error in the code for very thermal systems. This error was corrected and the revised results for $k_{eff}$ are rather low, being fairly constant at 0.985. This set of experiments has been calculated previously using GYMEA-WDSN and an intercomparison of the codes may help to reveal the shortcomings of both.

Additional edit facilities are being incorporated in the code to enable METHUSELAH type and output to be produced.

### 2.3.3 PEARLS (collision probability, resonance absorption code) (J. Pollard)

The code is now fully operational except for the following :

(i) the only data available for $^{238}U$ is at T=300, 600, 900, 1200 and 1500°K,

(ii) no provision has yet been made to include moderators with slowly varying cross sections (such as $^{23}Na$),

(iii) extensive edit facilities are yet to be implemented.

The code prints the flux in each region along with the resonance capture rate at regular intervals. This output is sufficient for comparison with codes

using approximate resonance theories such as GYMEA.

A typical 2-region calculation for the full energy range takes 2¼ hours on the IBM 360 computer.

### 2.3.4 Shielding calculations (B. McGregor)

Shielding calculations were performed for the concrete shield on the proposed critical facility, including the effects of holes, ducts and air return. The Monte Carlo code, GMCM, was used and the results show the practicability of carrying out such calculations with Monte Carlo methods. The results also show the requirement for fine detail in the high energy ( ~ 1 MeV) cross sections for shielding isotopes, especially oxygen. The anisotropy in the centre of mass system of scattering with oxygen is also important and work is continuing with OSR to study this effect. Other points highlighted by the calculations were the importance of the water content in the concrete and the large percentage ( ~ 70%) of transmissions resulting from neutrons incident at energies above 5 MeV.

### 2.3.5 Benchmark problem (B. McGregor)

A small critical sphere was accurately calculated with DSN and WDSN using ROACH 6-group data. The calculated multiplication factors are close to the expected answer and compare reasonably with the same calculations performed overseas with similar codes.

## 3. PUBLICATIONS

### 3.1 Papers

Bird, J.R. - Single particle states in medium weight nuclei, Proc. Conf. on Properties of Nuclear States, Montreal, 1969.

Bird, J.R., Allen, B.J. and Kenny, M.J. - keV neutron capture in the mass region A=40-70, Proc. I.A.E.A. Symposium on Neutron Capture Gamma Ray Spectroscopy, Studsvik, 1969 (see also AAEC/TM511).

Kenny, M.J., Bird, J.R. and Allen, B.J. - Resonance capture gamma rays from $^{57}Fe$, Proc. Conf. on Properties of Nuclear States, Montreal, 1969.

Wall, T. and Stroud, D. - Irradiation width of 132 eV in $^{59}Co$, Proc. Conf. on Properties of Nuclear States, Montreal, 1969.

### 3.2 Reports

#### AAEC/E Series

Allen, B.J., Bird, J.R. and Kenny, M.J. (1969). - Compilation of keV neutron capture gamma rays in the mass range A=40-70. AAEC/E200.

Doherty, G. (1969). - Solution of some problems by collision probability methods. AAEC/E199.

Doherty, G. (1969). - Solution of the multigroup collision probability equations. AAEC/E197.

Musgrove, A.R. deL. (1969). - Resonance parameters for measured keV neutron cross sections. AAEC/E198.

AAEC/TM Series

Clancy, B.E. (1969). - SLABBO - A discrete ordinate neutron transport code in plane geometry with anisotropic scattering. AAEC/TM505 .

Clancy, B.E. and Donnelly, I.J. (1969). - Outer iteration scaling in neutron transport codes. AAEC/TM507.

Cripps, P.B. (1969). - Theoretical calculations and comparison with experimental results on BeO-U235 and BeO-$ThO_2$-U235 assemblies at the centre of a low power reactor. AAEC/TM496.

Culley, D. (1969). - Burnup studies of HIFAR MkIV hollow fuel elements. AAEC/TM509.

McCulloch, D.B. and Trimble, G.D. (1969). - A method of estimating fuel burnup and higher isotope production in the reactor HIFAR. AAEC/TM508.

Musgrove, A.R. deL. (1969). - The statistical estimation of the average resonance spacing in even-A and odd-A nuclei. AAEC/TM515.

3.3 Lectures

Symonds, J.L. - Physicists in the Nuclear Industry, Proc. A.N.Z.A.A.S. Symposium on 'Physicists in Industry, Defence and Education', Adelaide, August 1969.

## TABLE 1

## ACCELERATOR TIME ALLOCATION

| Topic | Expt. No. | Title | Personnel | Origin | Running Time (hours) 1st Apr.-30th Sept. 69 |
|---|---|---|---|---|---|
| Fission | 11 | Nubar | Boldeman, Walsh | Physics | 440 |
| | 31 | Kinetic Energies | Ajitanand, Boldeman | Colombo Plan/Physics | 150 |
| | 41 | Prompt Fission $\gamma$ Rays | Ajitanand, Boldeman | Colombo Plan/Physics | 9 |
| Transport | 25 | Sine Wave Modulation | Whittlestone | Physics | 133 |
| | 45 | Time, Energy Spectra | Ritchie | Physics | 457 |
| Neutron Capture | 17 | keV Spectra | Allen, Bird, Kenny | Physics | 110 |
| | 27 | Resonance Shapes | Broomhall | Melbourne | 149 |
| | 37 | Cross Sections | Stroud | Melbourne | 201 |
| | 47 | keV Fast Timing | Kenny, Bird | Physics | 49 |
| Radiation Damage | 16 | Crystals | Pollard | U.N.S.W. | 48 |
| | 26 | Cells | Davy | Health Physics | 74 |
| Nuclear Analysis | 18 | Microanalysis | Price, Bird | U.N.S.W./Physics | 93 |
| | 38 | $^{18}O$ Concentration | Campbell | Isotopes | 133 |
| | 48 | $^{18}O$ Activation | De Bruin | Flinders | 7 |
| | 58 | Depth Analysis | Chapman | U.N.S.W. (Contract) | 72 |
| Charged Particle Reactions | 39 | Al (p,$\gamma$) | Myint | Colombo Plan/U.N.S.W. | 147 |
| | 59 | (p,$\gamma$) Reactions | Lasich | Queensland | 25 |
| | 69 | (p,$\gamma$) Reactions | Boydell | Melbourne | 87 |
| Atomic Physics | 24 | Ionisation | Petersen | Health Physics | 75 |
| | 44 | Proton Channelling | Price | U.N.S.W. | 158 |

| | | |
|---|---|---|
| Total Operating Time | : | 2931 hours |
| Tests | : | 300 hours |
| Maintenance | : | 433 hours |


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# APPENDIX (PHYSICS)

## STAFF

### Experimental Physics Section (Section Head : Mr. W. Gemmell)

#### General Reactor Physics Group

RS: Mr. A.P. Marks (O)
Mr. P. Duerden
Dr. A. Dalton
EO: Mr. T. Wall

TO: Mr. K. Brown
OA: Mr. R. Farmer
Mr. D. Hyde

#### Heavy Water Group

RS: Mr. D.B. McCulloch
Mr. W.J. Turner (O)
EO: Mr. G. Durance
Mr. D. Culley
Mr. A. Rose

TO: Mr. R. Jones
Mr. D. Stevenson
TA: Miss J. Bursell

#### Neutron Physics Group

RS: Dr. J.R. Bird
Mr. J.W. Boldeman
Dr. M.J. Kenny
Mr. B.J. Allen (O)
EO: Mr. R.L. Walsh
Mr. M. Scott

TO: Mr. H. Broe
Mr. J. Copland
OA: Mr. A. Croal

#### Pulsed Neutron Group

RS: Mr. A.I.M. Ritchie
EO: Mr. S. Whittlestone

TO: Mr. L. Russell
TA: Mr. G. Upex

#### Special Duties

RS: Mr. J. Connelly
Dr. G. Hogg
EO: Mr. P. Cripps
Mr. D.J. Wilson
Mr. J. Daniel

TO: Mr. A. Van Heugten
Mr. J. Sawyer
Mr. J. Fredericks

### Theoretical Physics Section (Section Head : Mr. B.E. Clancy)

#### Nuclear Physics Group

SO: Dr. W.K. Bertram

#### Nuclear Data Group

RS: Mr. J.L. Cook
EO: Mr. H. Ferguson
Mr. A. Musgrove
Mr. E. Clayton

**Reactor Physics Group**

RS: Mr. I.J. Donnelly
EO: Mr. G. Doherty
Mr. K. Maher
Mrs. E. Rose

**Reactor Codes Group**

RS: Mr. J. Pollard
EO: Mr. B. McGregor
Mr. G. Robinson
Mrs. B. Harrington

**Technical Support Group**

TA: Mr. G.D. Trimble
Mrs. J. D'Souza
Mr. D. Mullins (C)

**Consultants**

Professor A. Keane
Professor J.L. Griffiths

C : Commenced
O : On overseas attachment

# APPLIED MATHEMATICS AND COMPUTING SECTION

## PROGRESS REPORT : 1ST APRIL 1969 - 30TH SEPTEMBER 1969

## HEAD OF SECTION : MR. D.J. RICHARDSON

## INDEX

## 1. INTRODUCTION

This half year has been an exceptionally busy one for the Section.

A PDP9L system, with two 7-track magnetic tapes and a graph plotter, was installed in June. All necessary software for the system was written by the section. A PDP9L generator, PDPGENER, was written for the IBM 360. This enables the user to pass from object code back to source decks. This facility is most useful when only object decks are available originally.

The link between the PDP9L and IBM 360 computers is due for delivery in October. This link, designed in this Section, is now being produced commercially in the United States. Software for the link is being written within the section, and this work is well advanced.

A NOVA digital computer, with four teletype terminals, has been ordered for delivery later in the year. ACL-NOVA, an extension of the ACTIV-8 language used with the PDP8 computer, is being designed to enable modern conversational Fortran-type facilities to be available at the terminals, which will be installed at various points around the Site.

A Fortran course for on-site users was held in June 1969.

## 2. COMPUTER UTILISATION AND RESEARCH GROUP (P.L. Sanger)

### 2.1 NOVA Computer

With delivery of the NOVA digital computer and four teletype terminals expected during October, the major effort of this group has been concentrated on the design of a multi-terminal conversational compiler for use on this system. A new language, ACL-NOVA, is being designed to allow communication between the NOVA computer and the various remote teletype terminals. This language will make use of some of the better features of existing conversational languages such as APL.

To enable testing of these concepts before the delivery of the NOVA system, an Assembler and Simulator for the NOVA have been written to run on the IBM 360 computer.

### 2.2 Computer Network

A special version IPLTEXT and a stand-alone program AEBOOT01 were written to allow special purpose stand-alone programs stored on disk to be loaded into core storage and executed. These programs will play an important role in the development of facilities to be used with the forthcoming PDP9L to IBM 360 link.

### 2.3 2314 Disk System

As a result of the resignations of a number of experienced members of the Computer Operations Group, some time has been spent in assisting in the generation of two IBM 360 OS systems* to handle the changeover from the 2311 to the 2314 disk systems.

Opportunity was taken to incorporate software handling facilities necessary for the use of the proposed computer network as an extension of normal OS facilities. These software handling facilities will enable users of the central computer system to communicate in a simple manner with all parts of the

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* Davids, R.E. (1969). - A.A.E.C. modifications to Release 14 of the IBM 360 Operating System. A.A.E.C. interr-l report AM/TN4.

proposed computer network.

## 3. APPLIED MATHEMATICS GROUP

### 3.1 High Precision Arithmetic Package (R. Backstrom)

AAEARITH, an IBM 360 assembler language subroutine package, has been written to enable multiple-precision floating point arithmetic calculations to be performed with thirty-digit accuracy. It is expected that this package will enable reference calculations to be made when it is desired to evaluate the accuracy of proposed computational methods.

A subroutine to find the zeros of polynomials of up to 40th order has been written, employing AAEARITH. This subroutine will be available to Fortran users.

### 3.2 PDP9L Program Generator (R. Backstrom)

PDPGENER, a utility program for the PDP9L digital computer was written for use on the IBM 360 computer. This program allows the reading of paper tape programs by simulating the instructions in the loader supplied on the front of most object paper tapes. The initial aim was to produce card object decks from object paper tape programs supplied by Digital Equipment Corporation. A paper tape program which would have taken the PDP9L 15 minutes to load, can now be read in through the card reader in 40 seconds. PDPGENER can also be used to reconstruct source decks and sequentially labelled source listings complete with cross reference tables from either object decks or object tapes.

### 3.3 Curve Fitting (A. Isaacs)

A program has been written to optimise the fitting of straight line segments to arbitrary curve functions. Investigations into the use of spline functions in graph plotting routines were carried out, and a number of routines were developed.

### 3.4 Education

A Fortran course for on-site users was held during the second week in June.

## 4. PROGRAMMING SYSTEMS GROUP

This group was set up to investigate and develop systems software suitable for the needs of the Research Establishment.

### 4.1 PDP9L Assembler (C. Mason)

An assembler for the PDP9L computer was written for use on the IBM 360 computer. This assembler produces object card decks, suitable for loading into the PDP9L computer, together with source and label cross reference listings.

A novel feature of this assembler is the use of a PDP9L 'pseudo core' within the IBM 360 to represent the bit patterns of PDP9L instructions and data. This pseudo core concept has also been used within the PDP9L generator PDPGENER, and within the PDP9L simulator.

### 4.2 PDP9L Simulator (P. Bakalor)

A simulator to enable PDP9L programs to be run on the IBM 360 computer has been written. This simulator runs in conjunction with the PDP9L assembler,

using the pseudo core concept.

### 4.3 Graph Plotting Routines (K. van Klink, J. Carey)

A set of standard routines has been written to enable Fortran users to prepare information for plotting on the Calcomp drum plotter attached to the PDP9L. When the PDP9L-IBM 360 link is installed, this information will be fed directly to the PDP9L from the IBM 360. As an interim measure, cards are punched by the IBM 360 and read in through the PDP9L card reader.

Appropriate PDP9L plotting software was written to handle this plotting information.

## 5. COMPUTER OPERATIONS GROUP

### 5.1 Computer Usage

Usage figures for the IBM System 360 computer are shown in Table 1; all figures are in hours.

TABLE 1

| Month | A.A.E.C. Usage | IBM Programming | Universities A.I.N.S.E. | Outside Users | Total Usage |
|---|---|---|---|---|---|
| April | 348 | 1 | 1 | - | 350 |
| May | 344 | 9 | 5 | 2 | 360 |
| June | 343 | 5 | 1 | 1 | 350 |
| July | 371 | 7 | 2 | - | 380 |
| August | 339 | 1 | 3 | - | 343 |
| September | 352 | 1 | 10 | - | 363 |
| Total | 2,097 | 24 | 22 | 3 | 2,146 |
| Previous 6 months | 1,785 | 23 | 20 | 2 | 1,830 |

In the 2,097 hours of A.A.E.C. usage, the sectional users of more than a few percent of the time are Solid State Physics (3.2%), Theoretical and Experimental Physics (45.8%), Applied Mathematics and Computing (16.5%), Engineering Research (13.1%), and Administration (7.1%).

### 5.2 Equipment

The DIGITAL PDP9L computer system, comprising a digital PDP9L computer, 2 magnetic tape drives, drum plotter and teletype, were installed and are operating on experimental runs in relation to the drum plotter.

The Link to connect the PDP9L and the IBM 360 has not arrived but the software connected with this computer linkage is almost complete.

The Anelex line printer and Burroughs card reader listing facility has now been connected to the PDP9L. This has released the PDP8 for full-time use as a fast iterative calculator with full memory facilities using ACTIV-8, a Fortran-type stored program.

5.3 Operations

The average monthly usage was 358 hours, an increase of 61 hours compared with the previous six months.

This represents an increase in computer usage of 20.5% over the previous six months with a significant increase in the number of jobs carried out during the period.

5.4 Programming Support

All available members of the Computer Operations Group were engaged on the programming for the PDP9L-IBM 360 linked system which should be in operation before the end of the year.

5.5 Administration Programs

The Payroll programs are in the advanced state of final checkout under parallel running conditions and should be available for final audit checking before the end of the year.

The Staff Records programming is well under way but there are many months of work still to be carried out before this project is completed.

6. CONFERENCES

Mr. D.J. Richardson, Mr. N.W. Bennett, Dr. P.L. Sanger and Mr. C.B. Mason attended the Fourth Australian Computer Conference held in Adelaide from 11-15th August, 1969. A paper entitled 'AELINK - A Dynamic Programming System' was presented at this conference by C.B. Mason and D.J. Richardson.

Dr. P.L. Sanger and Mr. R.P. Backstrom attended a special lecture on, and practical demonstration of, the C.S.I.R.O. 'VISPLAY' display system in the Division of Computing Research, C.S.I.R.O., Canberra on 30th September, 1969.

Mr. J.M. Barry attended the SHARE computer conference in Boston, U.S.A. in August, 1969.

7. PUBLICATIONS

Davids, Mrs. M. (1969). - AEMOVE - A utility program to manipulate unloaded partitioned data sets on magnetic tape for the IBM 360. AAEC/TM519.

## APPENDIX (A.M.&C.)

## STAFF

### Computer Utilisation and Research Group

RS: Dr. P.L. Sanger (Leader)
Mr. N.W. Bennett (R)
EO: Mr. R.E. Davids (L.A.)

### Applied Mathematics Group

EO: Mr. J.M. Barry (Leader) (L.A.)
Mr. R.P. Backstrom
Mr. A. Isaacs (C)
TA: Mr. K.H. Van Klink (R)

### Programming Systems Group

TO: Mr. C.B. Mason (Leader)

### Computer Operations Group

TO: Mr. E.A. Kemp (Leader)
Mr. R.S. Dunne
Mr. P.D. Williams
TA: Mr. P.D. Bakalor (R)
Mrs. H. Bannister
Mrs. J.F. Bransgrove
Mr. B.P. Bussell
Mr. J.H. Carey
Mrs. M. Davids (R)
Mrs. D.L. Frith (R)
Mr. I.R. Gardiner (C)
Mr. P.M. Kalms
Mr. A.J. Walker

C : Commenced
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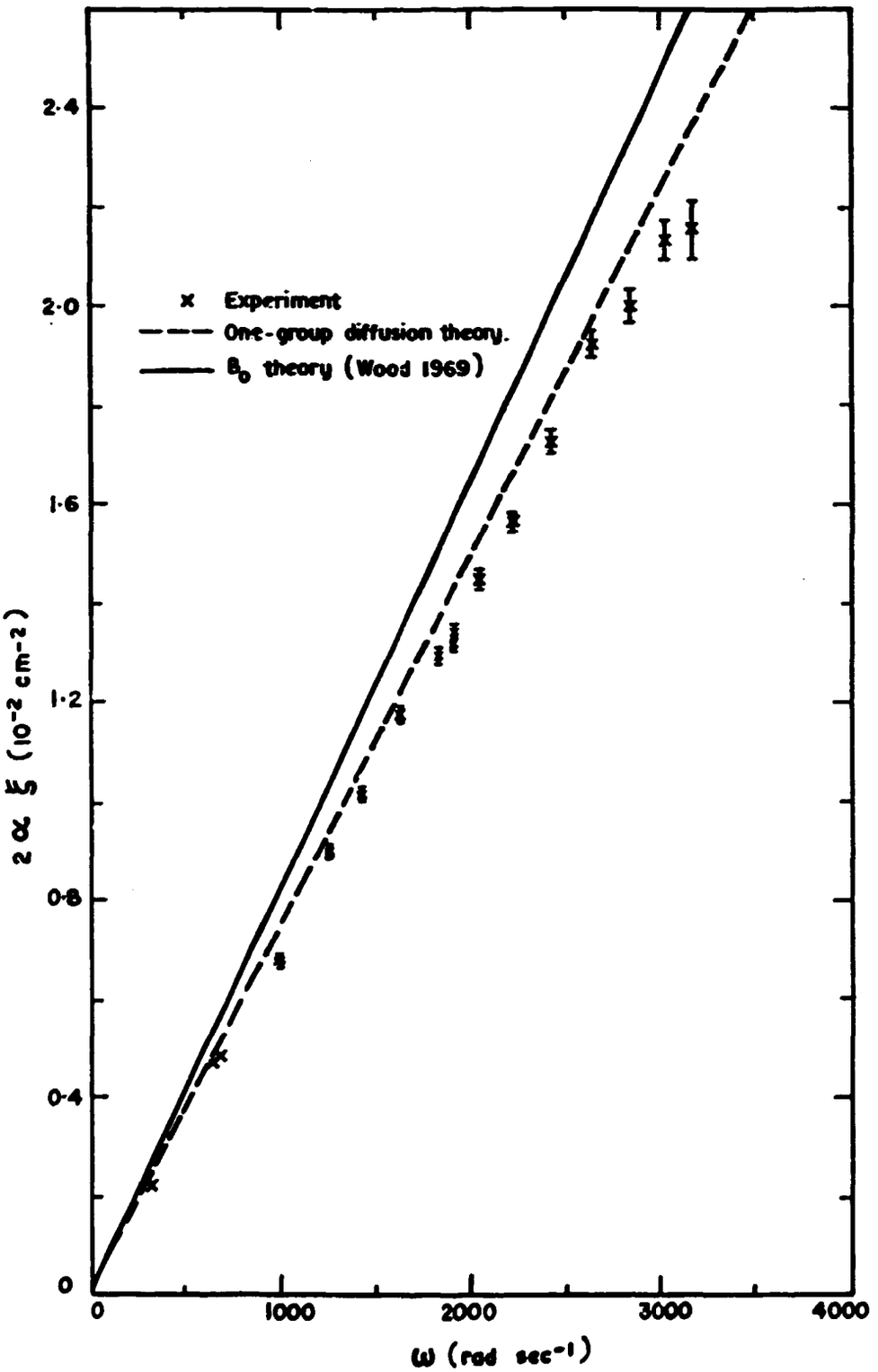


FIGURE 1. $2\alpha\xi$ VERSUS $\omega$ FOR BeO NORMALISED TO 2.96 g cm$^{-3}$ AND 22°C

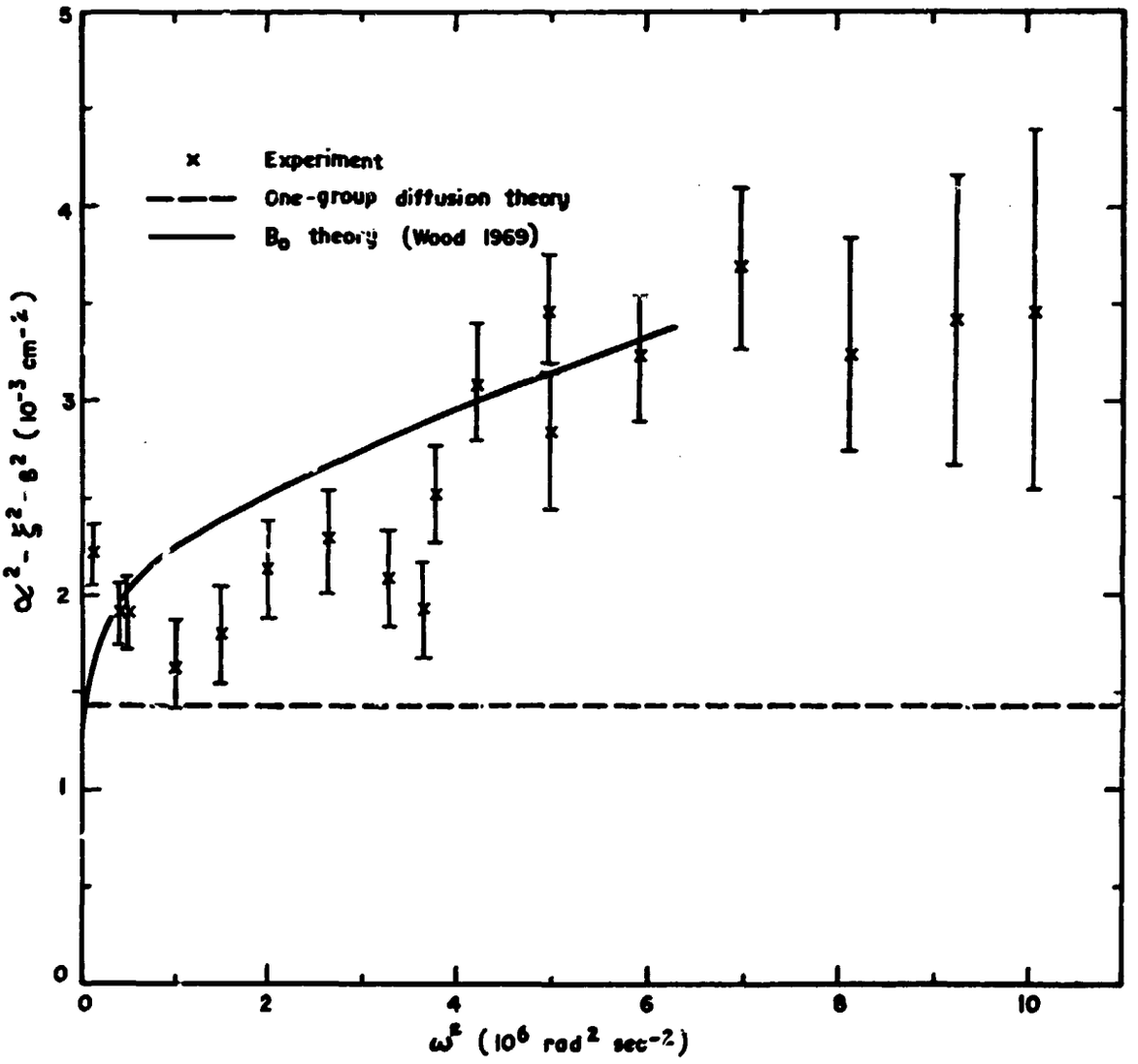


FIGURE 2. $\alpha^2 - \xi^2 - B^2$ VERSUS $\omega^2$ FOR BeO NORMALISED TO 2.96 g cm$^{-3}$ AND 22°C

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