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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 1970 - 30th SEPTEMBER 1970

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ACTING DIVISION CHIEF – MR. W. GEMMELL

CONTENTS

1. INTRODUCTION

Several of the senior staff have assisted in the assessment of the tenders for the proposed Jervis Bay power station. This has involved studies on light water moderated reactor systems where our experience has been limited. Several of the questions raised by the tenders are considered important and effort on these topics will continue when the assessment is complete.

Major effort, other than for the Jervis Bay Project, has been devoted to the improvement of facilities and the construction of the critical facility. Studies relevant to an improved understanding of MOATA have continued to support the proposed power uprating to 100 kW.

The increasing number of shielding (neutron and gamma) problems referred to the Division has resulted in the procurement of several specialised codes and data libraries. These are now operational on our IBM 360 computer, and several problems are being investigated.

2. EXPERIMENTAL REACTOR PHYSICS (A/Head: D.B. McCulloch)

2.1 Reactor Neutron Measurements

2.1.1 Proportional counter spectrometry (A. Rose)

The spherical proportional counter and its associated electronics were tested and found to work satisfactorily with mixtures of H_2, N_2 and CH_4 as the counter gas.

2.1.2 Time of flight spectrometry (A.W. Dalton)

A study has begun to establish the equipment required to determine the maximum safe speed of the existing chopper rotors, and to improve the performance of the associated electronics to give optimum spectral resolution from these rotors.

2.1.3 Neutron streaming (D.B. McCulloch, G. Durance)

All the aluminium plates have now been delivered and some trial 'dry' plate assemblies successfully built and dismantled. The necessary modifications to the ancillary equipment to allow the experimental assemblies to be mounted on MOATA were completed.

The automatic foil comparator was repaired and is now operating satisfactorily. The paralysis times, operating conditions, etc., for its three scintillator counting channels have been determined, and an intercalibration of some two hundred manganese foils needed for the experimental programme successfully completed. An apparent discrepancy between our observed manganese decay rates and the published 'best' half life (Sher and Pate, 1968 Nucl. Phys. A112, 85) of 2.585 $\pm$ 0.001 h may require some further investigation.

A preliminary MOATA irradiation has been made on one assembly of 1 inch thick plates to establish suitable reactor power etc. A few further preliminary experiments will be necessary before starting the actual programme to finalise techniques and to enable the irradiation schedule to be optimised.

2.2 MOATA

2.2.1 Operations (J.P. Sawyer)

	Days	%
Operation	85	65
Defect loss	4	3
Experiment assembly	20	15
Modifications and maintenance	22	17
	131	100

Total integrated power 3308 kWh

2.2.2 Modifications and new equipment

The reactor was shut down for a three week period to permit extensive modification of the process system and associated pipework. This involved many welds in aluminium pipework to fabricate complex pipe runs, and the work was done jointly by staff of Physics Division and the Main Workshops. The principal features were as follows:

1. The existing 10 kW primary coolant pump was re-located on the opposite side of the process pit adjacent to the dump tank.

2. A larger capacity pump capable of circulating up to 50 Imp. gal/min through the core tanks was installed. This high flow circuit is essentially in parallel with the low flow circuit, with isolation achieved by appropriate valving and electrical switching.

3. A flow meter was installed in the inlet line to the reactor core tanks, and indicates coolant flow to within ± 2%. This, combined with accurate core coolant temperature difference monitors, can be used for the determination of thermal power.

To facilitate the total removal of 100 kW of heat generated in the reactor core, a large stainless steel heat exchanger with a closed circuit secondary coolant loop was mounted in the duct adjacent to the process pit. This secondary coolant circuit utilises an evaporative cooling tower located at the western end of Building 22, and is brought into operation by a pump controlled from the reactor console.

2.2.3 Experiments (J. Connolly)

Some further investigations were made of the characteristics of large fission chambers with fast pulse rise times.

Preparation of a revised safety document for the reactor, embracing the up-rating to 100 kW was continued. For this work further measurements of a variety of reactor parameters have been made, including void and temperature reactivity coefficients, flux tilting with unequal core tank fuel loadings, and a recalibration of control elements.

A detailed investigation was made of anomalies observed among previous determinations of reactor power. This established that the power sharing between the core tanks is very sensitive to the individual multiplication constant of each.

Equal power contributions are achieved only when the west tank has a higher fuel loading than the east tank. This is attributed to the west reflector being rather thinner than the east one.

The calculational model set up for the reactor gives good agreement with most of the above measurements. The exception is the temperature coefficient of reactivity which is calculated to be about 3 times higher than the value measured. This appears to arise from the complex interactions of the graphite and water reflector temperature coefficient with that of the core, and the difficulty of establishing the precise temperature conditions applicable to the measurements.

The radiation levels in the process pit due to ^{16}N activity in the coolant were measured for a variety of reactor power and coolant flow conditions. It was deduced that at a flow of 40 gal/min the maximum dose-rate at 100 kW would be 500 mR/h at the position where the coolant return line enters the process pit. Suitable improvements to the shielding are being investigated.

2.2.4 General

During the long shutdown of HIFAR, MOATA was used to produce a wide range of radioactive isotopes for Isotope Division and other users. These included the regular weekly production runs of ^{24}Na and ^{198}Au for medical use in scheduled hospitals.

A training programme to qualify further reactor physicists has been in progress through much of the period.

2.3 Heavy Water Reactor Physics (D.B. McCulloch)

2.3.1 Fast fission ratios (A. Rose)

Completion of this project requires only resolution between ourselves and Bhabha Atomic Research Centre of the ^{235}U content of the depleted uranium foils used in the experiments. Extensive measurements at Lucas Heights by irradiation and mass spectrometer have convinced us that the enrichments of the different foil production batches are indistinguishable and close to 400 p.p.m. ^{235}U. Further measurements are being made at Lucas Heights to attempt to resolve the significant difference between two batches ($\sim$ 366 p.p.m. and 419 p.p.m. ^{235}U) found in an irradiation measurement at BARC.

2.3.2 Conversion ratios (P. Duerden)

The collaborative series of measurements in the ZERLINA reactor at BARC, Trombay, was completed in mid-July.

A test section comprising nine UO_2 rod cluster fuel elements on 19 cm square pitch was used at the centre of the ZERLINA reactor. The central cluster in which the measurements were made was 125 cm long, while the surrounding eight were of the same geometry and composition, but of full reactor height (248 cm).

Six cluster geometries were studied in this type of test region, and for each one 'coolants' of air, D_2O, H_2O and polystyrene (to simulate reduced density steam/water two-phase boiling coolant) were used in the cluster housing tubes. The experiment consists of irradiating UO_2 foil (which must be machined to match the fuel rod dimensions to extremely close tolerances) in all representative rods of a cluster, and subsequently counting the fission product and ^{239}Np radioactivities. It is also necessary to 'calibrate' the counting experiments by carrying out identical irradiations in a known thermal neutron flux spectrum. This was done by removing fuel elements from one edge of the ZERLINA can to form a thermal column.

Analysis of the experimental data is now in progress. Completion of this phase of the project, the analysis of corresponding Indian Atomic Energy Commission data taken using different counting techniques, and the comparison of the results with theoretical models will proceed with the co-operation of Mr. Gubbi of BARC who will be attached to Lucas Heights for this purpose.

2.4 HIFAR (D. Wilson, T. Wall)

The Division's major contribution to studies of HIFAR during this period has concerned the X-170 irradiation experiment. A number of calculations were made to check the effect of changing various items and parameters associated with the rig. In addition, preparations were made to measure the absolute fission rate in a 7.5% enriched UO_2 fuel pin in the actual rig and location in HIFAR at low power, during the October / November shutdown. Preliminary work was carried out by irradiating an enriched fuel pin in the internal reflector and in the thermal column of MOATA. Subsequently, the fission rate during the irradiation was estimated by solid state fission track counting in mica, and by gamma-counting of the ^{140}La fission product activity. Inhomogeneities in the UO_2 pellets due to enrichment blending prevented an absolute fission rate per uranium atom being obtained from the fission track data, although a good estimate of the flux depression (centre/edge = 0.57) across a pellet diameter was possible. Further measurements with 7.5% enriched uranium metal foil in contact with the mica should overcome this problem. The two techniques agreed to within 10% for the absolute fission rate of a 92% enriched uranium metal foil irradiated in the MOATA thermal column.

2.5 Critical Facility (W. Gemmell, D.B. McCulloch)

Construction of the cell and ancillary building continued. Work on the cell walls was complicated by non-availability of the bulkhead door and its frame. This necessitated 'blocking out' and changes in formwork to enable its later installation. Nevertheless, the cell walls, with the exception of the door section, have now been poured to about half their final above-ground height.

The ancillary building ground floor, and the concrete support columns for the first floor, were completed. Formwork, steel and electrical ducts installation, etc., for the first floor slab were near completion, and pouring of this section was about to start.

Good progress was made on the development of inflatable seals for the bulkhead door. Leak-testing of door, frame and seals as an integral assembly, was in progress at M.R. Hornibrook's Enfield works, and early delivery of the unit to site was expected.

Work in France appeared to be progressing according to schedule and first assembly of major components was to commence in early December.

Studies were made in the Division on a range of problems related to the design and future use of the facility, including reactivity transients and the problems of leak-testing the complete cell structure.

2.6 Reactivity Transients (D. Culley)

Studies continued of reactivity transients resulting from fuel loading errors on the basis of a simple point reactor model and the results were prepared for publication. Prompt neutron lifetimes, ℓ^* , from 5×10^{-3} to 10^{-8} seconds have been included in the study. Because of the wide range of lifetimes digital rather than analogue techniques were used.

The studies were in three sections :

(1) Thermal systems fuelled with ^{235}U with ℓ^* varying from 5×10^{-3} to 10^{-4} seconds.

(2) Epithermal systems fuelled with ^{233}U with ℓ^* varying from 5×10^{-4} to 10^{-5} seconds.

(3) Fast systems fuelled with ^{239}Pu with ℓ^* varying from 10^{-6} to 10^{-8} seconds.

The results show that provided the assumed fuel loading error does not cause criticality until the tables are in the final (7.5 cm) slow speed range, it is unlikely that fuel melting will occur except for very fast (ℓ^* about 10^{-8} seconds) ^{239}Pu fuelled systems.

If criticality occurs in the intermediate speed range, operation of safety rods worth 1% reactivity will be sufficient to prevent damage to both thermal and epithermal systems, but this operation comes too late to prevent damage to the fast systems.

2.7 Explosive Energy Release in Criticality Accidents (J. Connolly, K. Maher)

No progress was made on the MELT code owing to staff commitments to other projects.

2.8 Cell Leakage Measurements (R. Knott)

A study was made of the problems experienced elsewhere in measuring the overall leakage rate of large containment structures similar to the facility cell. This enabled selection of the techniques likely to be most accurate for our own application, and indicated the type and quantity of equipment required.

2.9 Pulsed Neutron Studies (I. Ritchie)

2.9.1 Pulsed thorium assembly (M. Rainbow, S. Moo)

The experimental rig was completed, and preliminary experiments started, to investigate the problems of room return and other sources of background. These experiments showed that :

(1) Although various shielding configurations reduce the proportion of room return, neutrons still present a considerable problem.

(2) Higher mass components from the accelerator ion source, having different flight times to the neutron producing target, produce a time dependent background which confuses the time dependent reaction rate measurements.

(3) There is almost certainly a d.c. level on the beam pulse which masks the tail of the time dependent reaction rates.

Problems (2) and (3) should be overcome by a fast post acceleration deflection unit now on order. The further investigation of room return neutrons will be considerably assisted by the use of the count down system recently installed on the

3 MeV Van de Graaff accelerator. To date the beam pulse width has been limited to ~30 ns at a repetition rate of 1 MHz neither of which is really suitable for the present investigations. In particular, the count down system will permit the use of longer periods between pulses, thus allowing a better estimate to be made of the effects of room return.

2.9.2 Neutron waves in BeO at high frequency (S. Whittlestone, K. Maher)

The amplitude and phase of neutron waves at frequencies of 500 Hz, 714 Hz, 952 Hz and 1428 Hz were measured in a block of BeO 60.96 x 60.96 x 55.88 cm with statistical errors reduced by about a factor of five compared with preliminary experiments. Analysis confirms the findings of the earlier experiments that there is no discrete propagation constant in this frequency region. For example at 1428 Hz the 'attenuation constant' decreases by about 10 per cent and the 'phase shift constant' increases by about 15 per cent over the range 7 to 37 cm from the source. This is consistent with the concept of a sub-Bragg contribution to the discrete mode (Duderstadt, Nucl. Sci. Eng. 33: 119, 1968).

No pronounced interference effects were noted between the supposed sub-Bragg component and the discrete mode. Some of the high frequency runs will be repeated with a liquid nitrogen cooled polythene moderator in an attempt to enhance the sub-Bragg component of the source and hence increase the likelihood of noting any interference effects.

During the wave experiments, drifts of up to 10 per cent were noted in the count rates from the 1/4 in. BF_3 detectors when drifts due to gain, EHT, counter positioning, machine voltage and machine current changes should have accounted for only about one per cent change. This problem is being investigated in more detail.

2.10 Neutron Source Project (G. Hogg, J. Tendys)

The coaxial plasma gun assembly was completed and preliminary investigations were made of the system operating at voltages of 17-25 keV and a hydrogen gas filling of 0.1-10 torr. The interference encountered on the voltage and current waveforms measured at the gun proved difficult to eradicate. The signal cable screening system from the screened room was re-designed. The interference has been reduced to a more tolerable level and has permitted detection of the plasma power. The glass insulator separating the inner and outer electrodes was replaced with one of more uniform glass thickness. This insulator should improve the quality of the focus and hence the neutron output owing to more even breakdown along the insulator at the commencement of formation of the current sheath.

X-ray photographs show the existence of a small X-ray flux. The construction of a dual pin-hole camera and absorption system will permit determination of the X-ray flux and energy. A new gun which will operate with a positive central electrode is under construction.

A program will be obtained from Imperial College, London, which models certain aspects of the plasma focus. It is hoped to use this program to further the understanding of the discharge and neutron emission from the focus. A review is also being prepared of the work done on the plasma focus at other centres.

3. NEUTRON PHYSICS SECTION (Head: J.R. Bird)

3.1 Fission Physics

3.1.1 Dependence of $\bar{\nu}$ on incident neutron energy (J. Boldeman, R. Walsh)

Measurements were completed of the variation of $\bar{\nu}$ with incident neutron energy between thermal and 2 MeV in the neutron fission of ^{239}Pu (Figure 1). The experimental data can be accurately represented by two straight lines with the change in slope occurring at the pairing energy. The $\bar{\nu}$ (E_n) dependence for ^{239}Pu is similar to that measured for ^{235}U and fits the explanation previously given for that isotope.

3.1.2 Delayed fission gamma rays (N.N. Ajitanand, J. Boldeman)

Delayed fission gamma rays from the decay of isomeric states produced in the spontaneous fission of ^{252}Cf were observed in two separate experiments. The first, using a high resolution Li drifted germanium detector concentrated on those isomeric states with half lives less than 4 μsec and with decay gamma ray energies less than 400 keV. Table 1 summarises the decay energies, half lives and yields per fission for 11 lines and gives a comparison with a previous experiment (Guy 1970, UCRL 50810).

The second experiment used a NaI detector and concentrated on isomeric states whose decay might contribute to the neutron count rate in liquid scintillator measurements of $\bar{\nu}$ absolute for ^{252}Cf, i.e. total cascade energies greater than ≈ 1 MeV. The four isomeric states previously observed by Sund and Walton (1969 - Nucl. Inst. Meth., 68) for neutron fission of ^{235}U and ^{239}Pu were observed among the ^{252}Cf spontaneous fission products. The yields per fission in Table 2 were estimated assuming the half-lives measured by Sund and Walton. The present data were not sufficiently accurate to yield both half-lives and yields per fission, although the data are consistent to within 50 per cent with the half-lives of Sund and Walton (1969).

3.1.3 Neutron emission versus fragment mass (J. Boldeman)

Measurements were made of the average number of neutrons per fragment emitted from fragments of specific mass as a function of the total fragment kinetic energy in the thermal neutron fission of ^{235}U. The complete data set of 2 x 10^7 fission events has now been analysed. Figure 2 shows the mean neutron emission per fragment as a function of the fragment mass for six ranges of the total fragment kinetic energy. The most interesting feature of the data is the dramatic way in which the neutron emission from fragments with A > 140 decreases with increasing total kinetic energy. Figure 3 shows the variation of total neutron emission with total fragment kinetic energy. The slope of the curve

$$\frac{dE_T}{d\nu}$$

is - 16.7 MeV/neutron. With the use of the Myers-Swiatecki mass formula (Nucl. Phys. 81, 1, 1966) this variation can be converted into that with total fragment excitation (E^*). The value obtained for

$$\frac{dE^*}{d\nu}$$

i.e. 9.5 MeV/neutron is much larger than usual estimates of the energy required for the emission of a neutron. The data, therefore, support the proposal of gamma ray emission as a competing fragment de-excitation process with neutron evaporation.

3.2 Neutron Capture

3.2.1 keV neutron capture for H = 90 - 140 (N.J. Pattenden, M.J. Kenny, J.R. Bird)

Measurements were completed and preliminary analysis carried out of keV neutron capture gamma ray spectra from Zr, Mo, Cd, Sn, Te and Ba targets. The number of isotopes in these elements produces quite complex gamma ray spectra, but strong transitions are seen which are presumed to arise from the strong p-wave neutron interactions which are known to occur for nuclei in this mass region.

3.2.2 keV neutron capture in iron (M.J. Kenny)

Using a constant fraction timing system with the 45 cm^3 Ge(Li) detector, and the klystron bunched accelerator beam, timing resolution of 5 ns was achieved. Measurements with a 1/8 in. iron target at a flight path length of 50 cm (in cone geometry) give much more detailed information on γ-ray spectra for individual resonances than had previously been achieved. Figure 4 shows a time spectrum for the two high energy γ-rays from capture in ^{56}Fe.

3.2.3 keV neutron capture: NaI measurements (G.J. Broomhall, M.J. Kenny)

An 8 in. x 6 in. NaI detector with 8% pulse height resolution at 0.67 MeV was used in keV neutron capture experiments. Special shielding reduces background gamma rays which arise chiefly from capture in the iodine in the detector and in iron in surrounding material.

Using constant fraction timing equipment, measurements were made with a one metre flight path and a time resolution of 3 - 4 ns. Most known resonances in ^{58}Ni, ^{48}Ti and ^{207}Pb are observed in partial capture cross sections in the energy range from 15 - 60 keV.

3.2.4 Resonance averaging methods (J.R. Bird, A.R. de L. Musgrove)

Measurements of gamma ray intensities from neutron capture at keV energies involve s, p and possibly d-wave resonances. Thus when the measurements involve averaging over many resonances it is necessary to consider a number of neutron angular momenta as well as gamma ray multipolarities in the interpretation of the results. Expressions were derived for averaged gamma ray intensities for both thin and thick targets and plots prepared showing the expected behaviour of intensity ratios for pairs of final states with different spin and parity.

3.2.5 Compilation (J.R. Bird)

A number of papers have been published containing results of experiments on keV neutron capture carried out at O.R.N.L. (U.S.A.) during the years 1960 - 63. However, a significant number of gamma ray spectra observed in this work have remained unpublished. A compilation of gamma ray spectra has been prepared jointly with I. Bergqvist of Lund Institute of Technology, Sweden, and J.A. Biggerstaff, J.H. Gibbons and W.M. Good of O.R.N.L., U.S.A. This compilation is to be used together with results from AAEC/E200 to prepare a complete compilation of gamma ray spectra from keV neutron capture.

3.2.6 Thermal capture (F. Hille)

The detector geometry in the angular correlation equipment at HIFAR has been changed to place the detectors closer to the target (particularly the 10 cm^3 Ge(Li) detector). Improved shielding reduced the effects of the 478 keV gamma ray from ^{10}B. These changes improved both the coincidence count rate (10 per minute) and the true to random ratio.

3.3 Nuclear Analysis

3.3.1 Oxygen analysis (B.L. Campbell, L.H. Russell)

Measurements were made of the oxygen concentration in a number of Zr-ZrO_2 dispersions using the ^{18}O (p,α)^{15}N reaction. Standard ZrO_2 samples were used for comparison and thick targets of boron, nitrogen and fluorine were used to determine the shape of pulse height spectra to be expected from competing reactions. Improvements were made in electron suppression and target alignment in the very simple target chamber used.

3.3.2 Deuterium analysis (M.D. Scott)

A ^{24}Na source was used to test the method for deuterium analysis based on the photonuclear reaction $^{2}D(\gamma,n)^{1}H$. A simple arrangement of source and neutron detector ($^{10}BF_3$) in a beaker of water gave 3 counts per second from the natural levels of deuterium in the water.

3.4 Experimental Facilities

3.4.1 3 MeV accelerator performance and development (A. van Heugten, H.G. Broe, J. Copland, L.H. Russel, A.I.M. Ritchie)

Accelerator operating time was 2624 hours, distributed as shown in Table 3. With 1282 hours used for maintenance and modifications this shows a high efficiency in usage of available time. Approximately half the down-time was used to install a count-down facility in the top terminal. At the same time the change to slosyn motors was completed for all terminal controls and a third light pipe system installed so that a 1 MHz signal for the nanosecond oscillators could be provided from outside the accelerator.

The circuits for the count down system were designed and built by Instrumentation and Control Division and provide a 1 kV square pulse applied to one of the auxiliary deflection plates in the terminal deflection chamber. The square pulse is triggered on and off via light pulses from outside the accelerator and can be used either for 'microsecond pulsing' with variable duty cycle or in synchronism with fast pulsing and bunching to provide 2 ns pulses with variable repetition rate. The rise and fall times of the square pulse are $\sim$200 ns giving beam pulses of 70 ns width or greater. The only difficulty experienced during commissioning of this system was failure of the gallium arsenide light sources. Although mounted at the tank base they were destroyed by tank sparks until they and their leads were heavily shielded with copper braid.

A new outlet manifold for the target area switch magnet provides more beam tubes (10 instead of 7), water cooling to withstand the full beam of the accelerator (400 μA) and improved vacuum ($2 - 4 \times 10^{-6}$ torr). A turbo-molecular pump mounted on top of the magnet is connected directly through a 6 in. elbow to the outlet manifold. This gives much improved vacuum in the beam lines, low maintenance and quick automatic recovery after vacuum excursions or mains failures. Two of the beam tubes were extended to a shielded target area for low background experiments.

Because of the close spacing of the new beam lines a new stabilising slit system was designed to be much more compact and with easy-to-clean water cooling channels. New target facilities include a second mechanical wobbler and a dual magnetic beam deflection system for high current targets. A zener stabilised degauss supply was installed on the analyser magnet giving increased range and improved resolution for adjusting the 'straight through' beam.

3.4.2 Special equipment (P.D. Lloyd)

A diffractometer gear box assembly was adapted to carry a detector for angular distribution experiments. The 2θ arm is fitted to carry a detector such as a

Ge(Li) gamma ray detector and an engraved scale with optical periscope allows setting of this arm to ± 1 minute of arc. A solenoid clutch locks the mechanism at any desired angle and a second gear box, driven by a slosyn motor, is available for computer controlled scanning or indexing.

A target changing mechanism has been constructed using two wires moving over a system of pulleys. A slosyn motor drive gives 230 steps of 0.017 in. per second and can be driven by the PDP7 computer. The total length of traverse is 35 in. and a number of light weight targets can be spaced at desired intervals along the wires.

3.4.3 45 cm^3 Ge(Li) detector (M.D. Scott, H.G. Broe)

A true coaxial type Ge(Li) detector manufactured by Instrumentation and Control Division was installed in a long horizontal arm type cryostat which is pumped continuously with a small vac-ion pump. A soft aluminium detector cradle was used for improved detector cooling. Initial performance of the detector showed a resolution of 4.2 keV at 1.33 MeV and a photopeak efficiency of approximately 4% per incident gamma ray.

4. THEORETICAL PHYSICS SECTION

4.1 Nuclear Data Group

4.1.1 Fission product data analysis (J. Cook)

The preparation is almost complete of data for 184 fission product nuclides in the formats of the Winfrith data library and of the GYMEA group cross section library. The optical model code COMPOST was used to calculate data in the fast region and where experimental data was not available a statistical theory was used to generate and interpret the data in the unresolved resonance region. For the thermal and resolved resonance regions the data were calculated using the GUNYA code. Editing programmes were written to handle the large number of data points and to check the data for consistency.

4.1.2 Multilevel analysis (J. Cook)

Analysis of an equiphase hypothesis which simplifies the expressions for multilevel fission cross sections has continued. At present it appears that an effective single level formation can be derived which is easily Doppler-broadened and permits an exact least squares analysis of the cross section in the form of the reaction matrix. It is proposed that the fissile nuclides be analysed with this new formalism.

4.1.3 Resonance statistics (A.R. de L. Musgrove)

Interpolative formulae for total radiation width and nuclear average level spacing were found and cross section calculations in the kilovolt region made for nuclei important in reactor calculations and in theories of nucleosynthesis.

Resonance parameter fits were made to all available measured kilovolt capture cross sections and values of the p- and d-wave neutron strength function were extracted.

4.1.4 Overseas data (E. Clayton, H. Ferguson)

Routine data preparation of GYMEA libraries from the Winfrith data file continued and all major nuclides are now translated and in use.

Conversion of the ENDF/B data tapes and processing programmes to suit the A.A.E.C. computer has begun.

4.1.5 The inverse scattering problem (E. Clayton, J. Cook)

An analysis of the inverse scattering problem has reached the stage where potentials can be calculated without the need for matrix inversions, which previously limited the analysis. To test the validity of the method, the pion-nucleon interaction was selected for study because the phase shifts for this reaction are so well known.

A computer programme ZEUS was written which uses calculated resonance parameters to generate values for the pion-nucleon interaction. Numerical integration of the source equation is then carried out to evaluate phase shifts which are compared with experimental values. The agreement is within experimental accuracy. Computing times, on an IBM 360/50 computer, are of the order of a few minutes per energy point.

The solution method is to be extended to cope with reactions with nuclei and it is hoped that further information about the nuclear potential will be obtained.

4.1.6 Gamma ray spectra (W. Bertram)

A theory was developed for gamma ray de-excitation in nuclei. It was used to calculate the isomeric production ratios and the associated gamma ray spectra for several radiative capture reactions. The calculated values of these quantities were found to be in reasonable agreement with experiment. On this basis, the theory is being generalised to investigate the more important problem of gamma ray competition in neutron scattering and (n,2n) reactions.

4.2 Reactor Physics Group

4.2.1 Collision probability method (G. Doherty)

Work continued on the axial leakage problem in cylindrical geometry. An improved radial boundary condition was derived for this problem and is being tested. Approximations were derived for the time consuming integrals which appear in the collision probability formulation of this problem. The extension of the collision probability method to the case of anisotropic scattering will begin as soon as commitments to the Jervis Bay tender assessment cease.

4.2.2 Transport theory studies (I. Donnelly)

The approximation used in the diffusion equation to define the neutron current is the first term of a series expression which can be derived from transport theory. By retaining all terms in this series one obtains a flux-dependent diffusion coefficient of the form

$$D = \sum_{n=1}^{\infty} a_n \nabla^{2n} \phi / \nabla^2 \phi .$$

Use of this diffusion coefficient makes diffusion theory exact for large homogeneous systems which may contain neutron sources that vary slowly with position. A numerical solution of the modified diffusion equation requires that the flux dependence of the diffusion coefficient be simplified. One method of doing this, which is exact for fluxes of exponential form, is to take

$$D = \sum_{n=1}^{\infty} a_n [\nabla^2 \phi / \phi]^n / [\nabla \phi / \phi] .$$

Preliminary investigations indicate that this modified diffusion theory is better than conventional diffusion theory, especially for systems which have a large absorption cross section.

4.3 Reactor Codes Group

4.3.1 GYMEA - data preparation code (B. Harrington)

Work is in hand on the theory of mixing fission products in order to produce data for pseudo fission products. At present 127 group data are being prepared (Nuclear Data Group) for about 180 fission products. A working library is to be prepared containing about 50 of the original fission products and a few pseudo fission products. The data for the pseudo fission products are chosen so that about the same reactivity loss results for typical burnup calculations as would result from using the full 100 nuclide library. This is generally only possible by fully retaining the important fission product chains.

Further work was done on comparison of resonance reaction rate calculations between PEARLS (exact) and GYMEA (approximate). No substantial improvement in GYMEA resulted when the broad 6.68 eV ^{238}U resonance was assumed to fall entirely into one group.

4.3.2 Shielding calculations (B. McGregor)

The following shielding codes are now operational on the site computer:

AMC Monte Carlo code utilising albedo approach for calculating neutron and capture gamma ray distributions in rectangular ducts. Ref. ORNL-3964.

AMC has run its test problem and has also given an alternative solution to a duct calculation for the critical facility. The library at present only includes albedo data for concrete although other materials have a similar distribution.

SABINE A one dimensional bulk shielding program developed by EURATROM. Ref. EUR-3636e.

SABINE uses the removal-diffusion model to calculate the transmission of neutrons through large shields. The program includes a neutron library of 26 energy groups and a gamma library for 7 energy groups. Calculations may be undertaken for quantities such as neutron fluxes, neutron dose rates, gamma fluxes and gamma heating and dose rates. Gamma sources are from:

(a) equilibrium fission and fission products

(b) neutron captures, and

(c) inelastic neutron scattering.

Four types of geometry are allowed: slab, finite or infinite cylinder, sphere and disk.

The program has run its test problems and has also produced reasonable results for a number of other problems. Calculations have been made as part of the Jervis Bay Reactor tender assessments.

ANISN A one dimensional discrete ordinates transport code. Ref. K-1693.

ANISN is the latest in the series of 1D codes which started with DSN written in FLOCO at Los Alamos. It is the result of a number of years of experience with this type of code and includes most of the features which have been found to be worth while. The problem size is limited only by the machine size.

Much of the nuclear data has been prepared in ANISN format. We have obtained two sets with the appropriate data preparation codes.

DLC-2 99-group neutron cross section data based on ENDF/8. -28 elements with up to P_8 scattering matrices.

DLC-9 122-group coupled neutron and gamma ray cross section data, 104 neutron, 18 gamma groups. -9 elements with up to P_8 scattering matrices.

Calculations have been made using ANISN as part of the Jervis Bay Reactor tender assessment.

An abortive attempt was made to make MAC operational. The code would not run its own test problem and further information is being sought from Oak Ridge.

4.3.3 JOSHUA-XYZ, 2 group diffusion code with coupled hydraulics (G. Robinson)

The JOSHUA code has been one of the main tools used in assessing the core performance of the Jervis Bay Reactor tenders. The code has been continually modified to enable the various situations which have arisen to be successfully treated.

5. PUBLICATIONS

5.1 Papers

Ajitanand, N.N. and Boldeman, J.W. (1970).- Precise measurements of the average kinetic energy of fragments in the fission of ^{235}U by fast neutrons. Nucl. Physics, 144:1.

Boldeman, J.W. and Walsh, R.L. (1970).- The energy dependence of $\bar{\nu}$p for neutron induced fission of ^{235}U below 2.0 MeV. J. of Nucl. Energy, 24:191.

5.2 Reports

Bertram, W.K. (1970).- The calculation of (n,2n) cross sections using the Hauser-Feshbach theory. AAEC/TM542.

Bertram, W.K. (1970).- The use of Hauser-Feshbach theory for predicting inelastic scattering of neutrons by nuclei. AAEC/TM545.

Clayton, E. (1970).- Multilevel R-matrix analysis of neutron elastic scattering from ^{238}U, ^{197}Au and ^{23}Na. AAEC/TM546.

Cook, J.L. (1970).- Fission product cross sections. AAEC/TM549.

Cook, J.L. (1970).- Solutions to the relativistic two body problem. AAEC/TM560.

Cook, J.L. (1970).- The inverse reaction problem. AAEC/TM561.

Dangerfield, G.R. and Walsh, R.L. (1970).- BOPTIC, a beam transport program in Fortran IV. AAEC/TM544.

Donnelly, I.J. (1970).- On the application of variational methods to neutron transport in slabs. AAEC/TM544.

McGregor, B. (1970).- Monte Carlo shielding calculations. AAEC/TM531.

Wall, T. (1970).- Measurement of the fission track recording efficiency of mica. AAEC/TM541.

5.3 Conference Papers

Broe, H.G. and van Heugten, A. (1970).- Description and operation of a turbo-molecular pump. 2nd A.I.P. Vacuum Symposium, Sydney, August 1970.

6. RESEARCH CONTRACTS

Title: Neutron Capture Cross Section Measurements on the Melbourne Betatron

Reference No.: 70/D/29
Period: 12/5/70 - 30/9/70
Supervisor: Professor B.M. Spicer
University: School of Physics, University of Melbourne
Liaison Officer: J.R. Bird

Objective: To improve the accuracy of measurements of the radiation width of the 132 eV resonance in cobalt and to investigate the upper limit to neutron energy which can be used for radiation width measurements including considerations of the 330 and 1098 eV resonances in manganese.

Status: New measurements with improved shielding have been made for cobalt and the results are being analysed. Interference from the fast contracter on the Betatron has been substantially reduced and measurements on copper show the 2 keV resonance clearly with a relatively low background.

Title: Study of Single Particle Wave Functions

Reference No.: 70/E/1
Period: 7/5/70 - 30/9/70
Supervisor: Professor I.E. McCarthy
University: School of Physical Science, Flinders University
Liaison Officer: J.R. Bird

Objective: To calculate single particle wave functions using optical model computer codes and to compare the results with experimental data, including information obtained from neutron capture studies.

Status: Calculations have been carried out on the position of 1s and 2p single neutron states as a function of mass number. A reasonable fit can be made to neutron capture data, but the nuclear radii required for these fits are different for the different states and do not agree with information on nuclear radii from other work. Possible explanations for these discrepancies are being investigated as well as comparisons with other experimental data.

TABLE 1

DELAYED GAMMA RAY DATA
FINAL RESULTS FOR AVERAGE OF FOUR RUNS

S.No.	E_γ (keV)		$T_{1/2}$ (nsec)		Yield per 10^4 fission	
	Present	Guy	Present	Guy	Present	Guy
1	66.2	66.2	< 200	140 ± 14	-	60 ± 6
2	96.7	96.2	600 ± 20	550 ± 40	74 ± 4	80 ± 7
3	115.2	115.0	< 250	162 ± 12	-	61 ± 4
4	122.4	121.4	2240 ± 700	360 ± 36	12 ± 5	48 ± 5
5	131.1	129.8	370 ± 30	340 ± 50	29 ± 3	29 ± 4
6	142.2	141.7	690 ± 130	1400 ± 140	3 ± 1	9 ± 1
7	172.1	170.5	1570 ± 250	1100 ± 220	8 ± 1	20 ± 4
8	192.9	191.6	1800 ± 210	850 ± 140	13 ± 2	14 ± 3
9	205.5	204.0	> 4000	~3000	-	-
10	326.7	324.5	630 ± 50	570 ± 50	25 ± 2	31 ± 3
11	383.5	380.7	3380 ± 350	3400 ± 270	39 ± 9	73 ± 6

TABLE 2

DELAYED GAMMA RAY DATA

Cascade	E_γ (keV)	T 1/2 (μ sec)	Yield per Fission %
1	1330 390 205	3.4	0.3
2	990 720	26.7	0.19
3	850 260	54.0	0.24
4	1250 460	80.0	0.32

TABLE 3

ACCELERATOR TIME ALLOCATION

Topic	Expt No.	Title	Personnel	Origin	Running Time (hours) 1/4/70 - 30/9/70
Fission	11	Nubar	Boldeman, Walsh	Physics	690
Transport	25	Sine Wave Modulation	Whittlestone	Physics	452
	45	Time, Energy Spectra	Ritchie	Physics	20
	55	Thorium Assemblies	Rainbow, Ritchie, Moo	Physics, Tasmania	246
Neutron Capture	17	keV Spectra	Bird, Kenny	Physics	38
	27	Resonance Shapes	Broomhall	Melbourne	101
	37	Cross Sections	Stroud	Melbourne	60
	47	keV Fast Timing	Kenny	Physics	87
	57	p-wave Capture	Pattenden, Bird		370
Radiation Damage	16	Crystals	French	U.N.S.W.	34
	26	Cells	Davy	Health Physics	95
Nuclear Analysis	28	^{18}O Activation	Lauder	Queensland	63
	38	^{18}O Concentration	Campbell	Isotope	58
	68	O_2 in Zirconium	Russell, Campbell	Physics, Isotope	
Charged Particle Reactions	59	(p,γ) Reactions	Lasich	Queensland	19
	69	" "	Boydell	Melbourne	78
Atomic Physics	44	Proton Channelling	Price	U.N.S.W.	38
Isotope Production	22	^{13}N Tracing	Nicholas	Adelaide	12
	32	^{11}C Tracing	Moorby	Macquarie	12

Tests: 71 hours
Total Operating Time: 2624 hours
Maintenance: 1282 hours

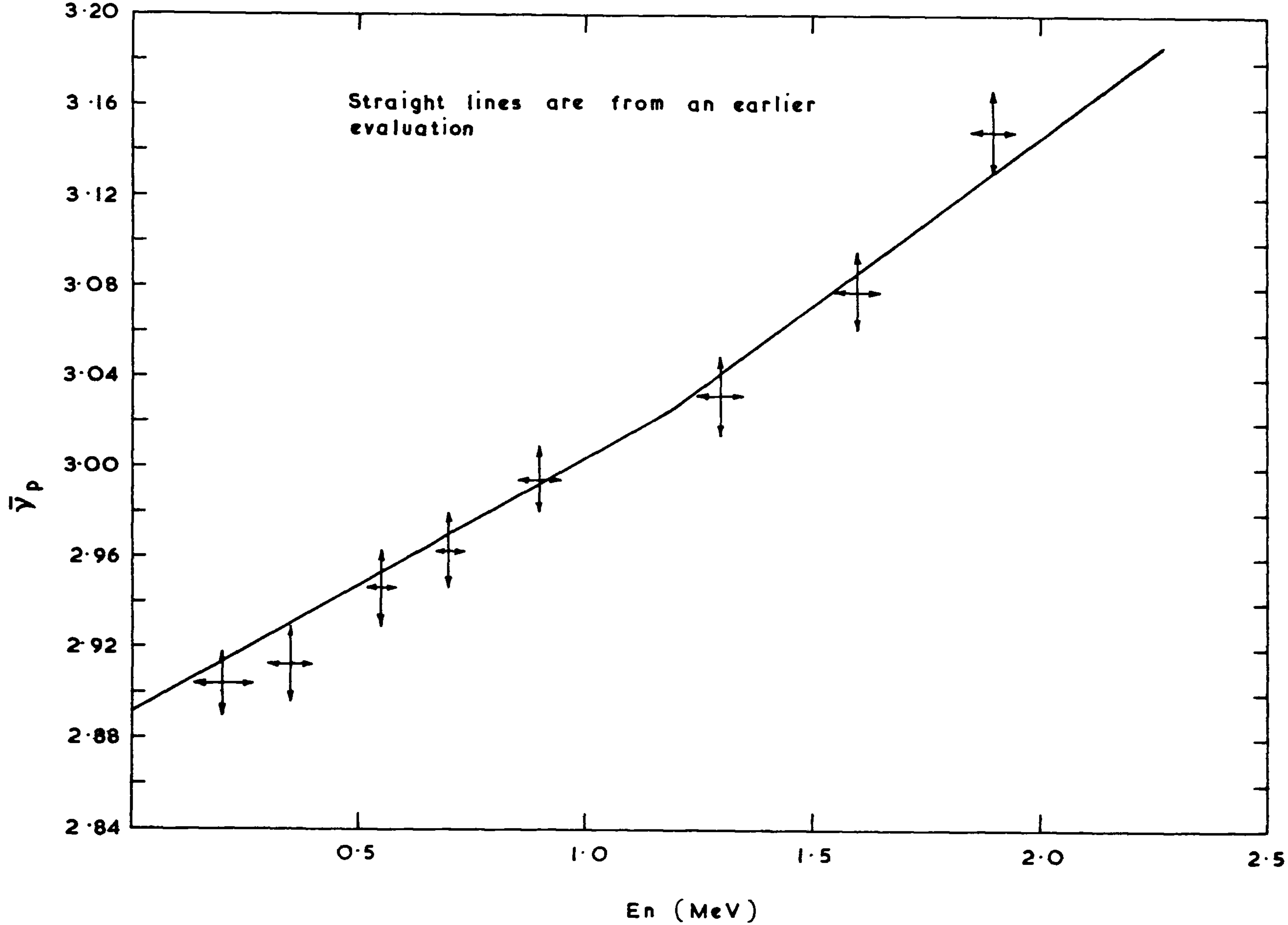

FIGURE 1. ENERGY DEPENDENCE OF $\bar{\nu}_p$ FOR NEUTRON FISSION OF ^{239}Pu

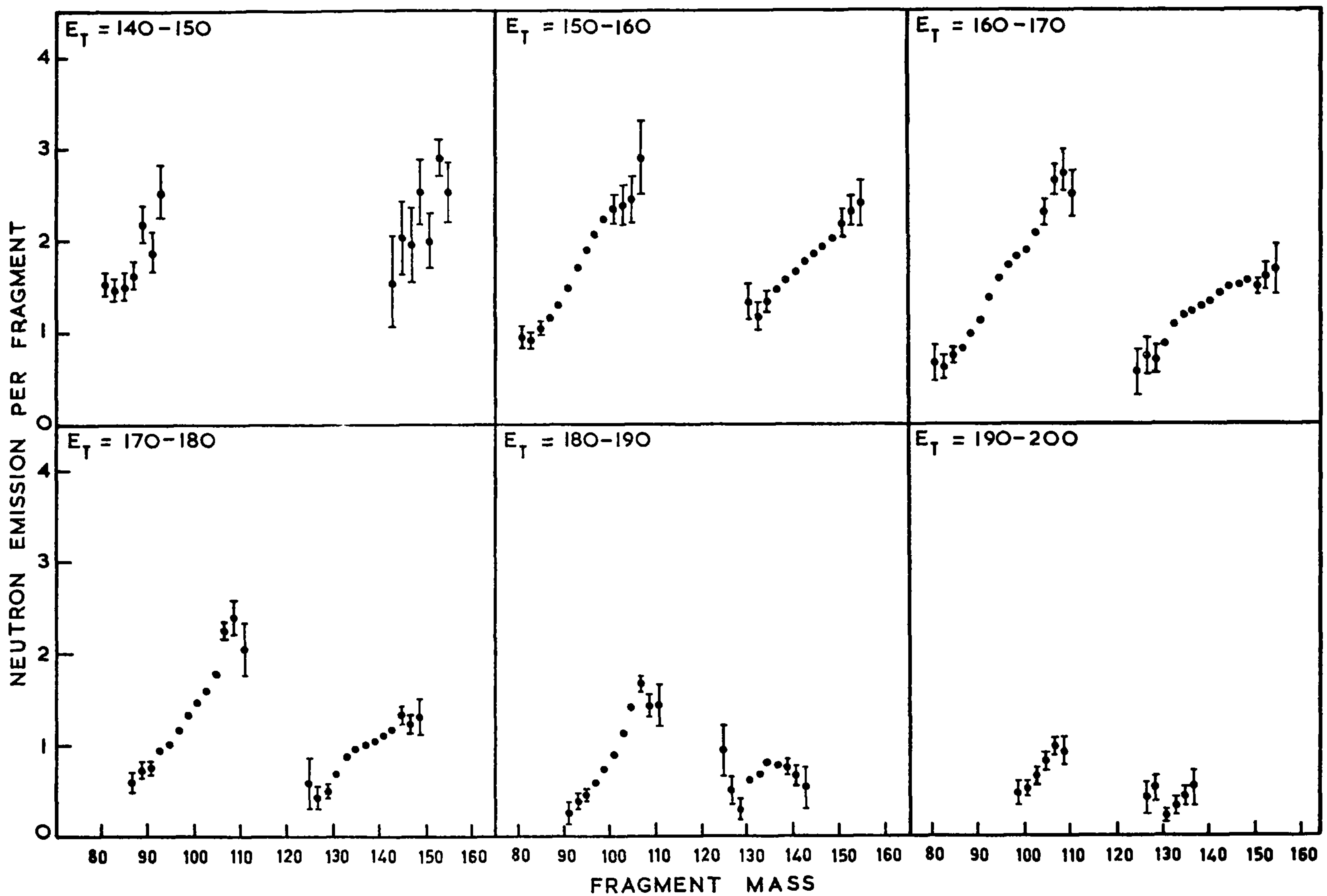

FIGURE 2. NEUTRON EMISSION PER FRAGMENT v. FRAGMENT MASS FOR SIX RANGES OF TOTAL FRAGMENT KINETIC ENERGY

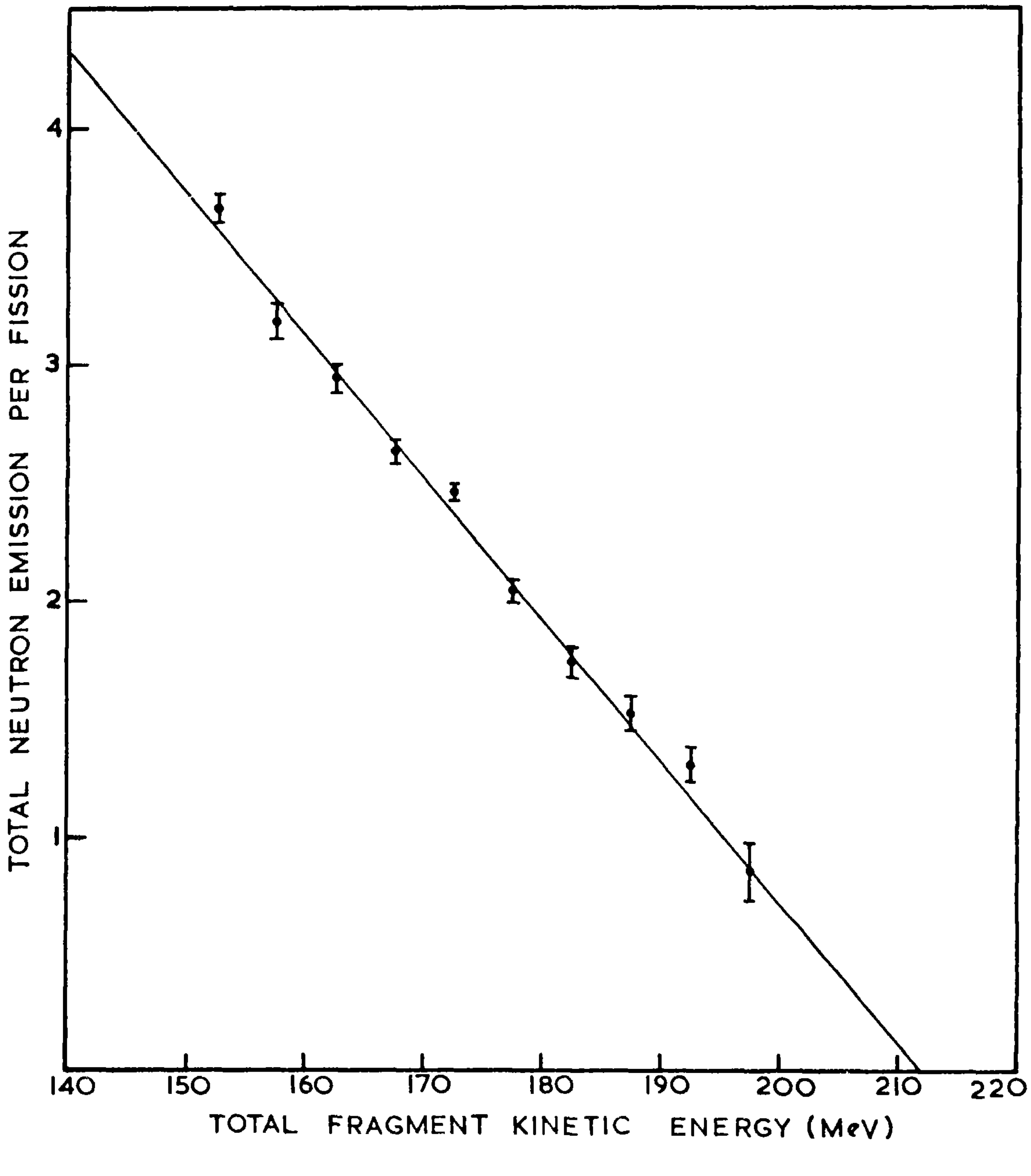

FIGURE 3. TOTAL NEUTRON EMISSION v. TOTAL FRAGMENT KINETIC ENERGY

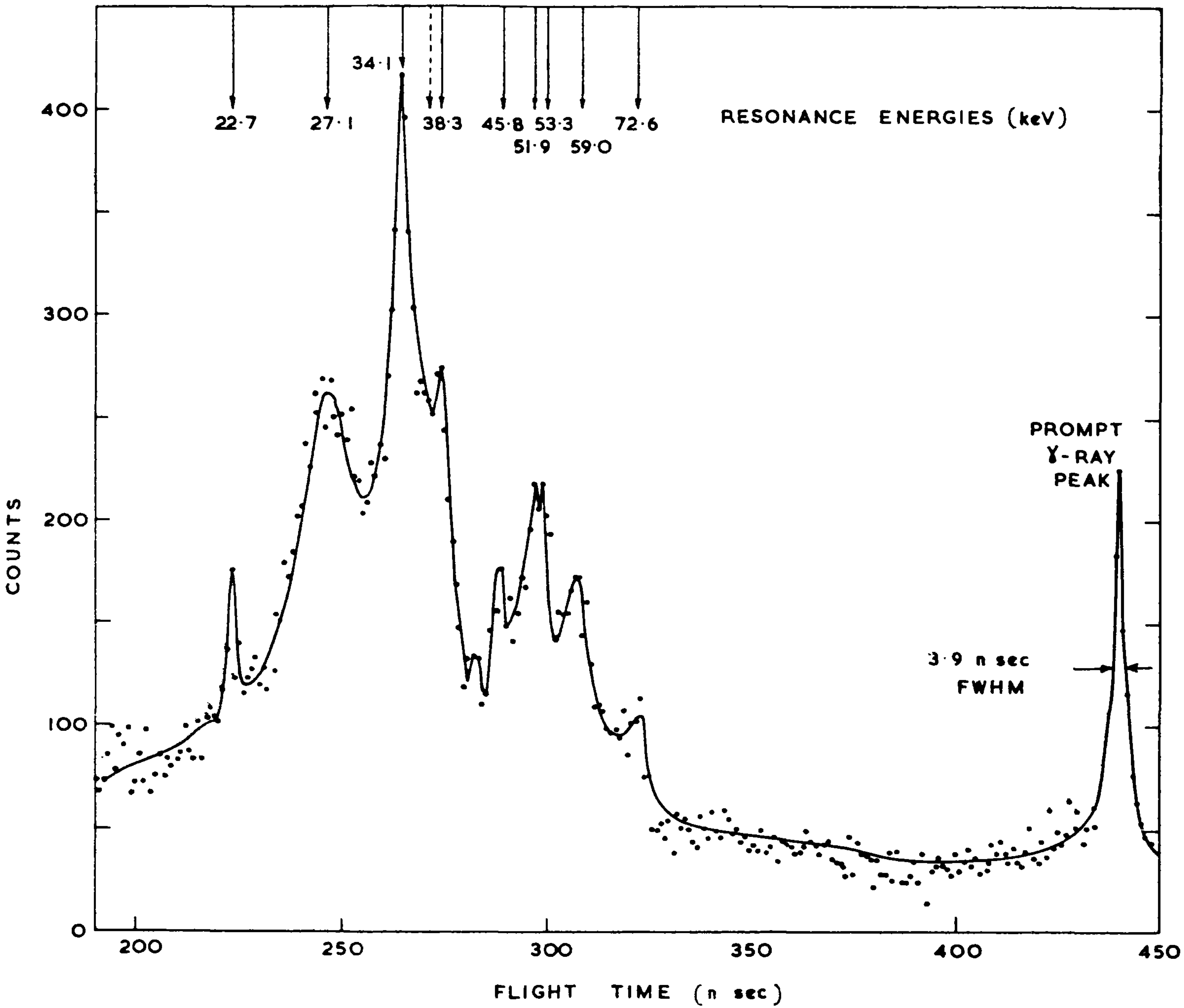

FIGURE 4. NEUTRON RESONANCES FOR HIGH ENERGY γ-RAYS FROM ^{56}Fe CAPTURE

APPENDIX (PHYSICS)

STAFF

ACTING DIVISION CHIEF : Mr. W. Gemmell

EXPERIMENTAL REACTOR PHYSICS SECTION (A/HEAD: Mr. D.B. McCulloch)

General Reactor Physics Group		Technical Staff	
RS:	J. Connolly A. Marks (O) A.W. Dalton P. Duerden	TO/TA:	G.K. Brown
EO:	T. Wall R. Knott		
Heavy Water Group			
RS:	W.J. Turner	TO/TA:	R. Jones D. Stevenson J. Bursell
EO:	A. Rose G. Durance D. Culley		
Pulsed Neutron Group			
RS:	A.I.M. Ritchie	TO/TA:	K. McMaster (C)
SO:	M. Rainbow		
EO:	S. Whittlestone		
Special Duties			
EO:	D.J. Wilson P. Cripps (O)	TO/TA:	J.P. Sawyer D. Hyde R. Farmer

NEUTRON PHYSICS SECTION (HEAD: Dr. J.R. Bird)

Neutron Capture Group			
RS:	M.J. Kenny B.J. Allen (O) G. Upex (R)		
Fission Physics Group			
RS:	J. Boldeman		
EO:	R. Walsh		
		TO/TA:	A. van Heugten J. Copland H. Broe L. Russell
		OA:	R.C. Hannan (C)

APPENDIX (cont'd)

THEORETICAL PHYSICS SECTION (HEAD: Mr. B. Clancy)

Nuclear Physics Group

RS: G. Derrick (C)
W. Bertram

Nuclear Data Group

RS: J. Cook
A. Musgrove

EO: H. Ferguson
E. Clayton

Reactor Physics Group

RS: D.A. Newmarch
I. Donnelly

EO: G. Doherty
K. Maher
E. Rose

Reactor Codes Group

RS: J. Pollard

EO: B. McGregor
G. Robinson
B. Harrington

TO/TA: G. Trimble
R. Mullins
J. D'Souza

ATTACHED STAFF

N.N. Ajitanand	(B.A.R.C., India)
S.G. Boydell	(University of Melbourne)
G.J. Broomhall	(University of Melbourne)
D.M.H. Chan	(University of Melbourne)
F. Hille	(Cook University, Townsville)
P.D. Lloyd	(A.I.N.S.E.)
J. Mathur	(University College, Wollongong)
P.W. Martin	(University of British Columbia, Canada)
N.J. Pattenden	(A.E.R.E., England)
B.B.V. Raju	(University of Melbourne)
D.B. Stroud	(University of Melbourne)

(C) Commenced
(R) Resigned
(O) Overseas

AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

PROGRESS REPORT FOR APPLIED MATHEMATICS AND COMPUTING SECTION

1st April 1970 – 30th September 1970

HEAD OF SECTION – MR. D. J. RICHARDSON

CONTENTS

1. INTRODUCTION

The assessment of Jervis Bay tenders resulted in a big increase in the section's computing load during the latter half of the period, and computer usage is now approaching the limit of the present operating system's capacity.

Multiprogramming (MVT) will be introduced towards the end of 1970, and will allow maximum use of the present computer's facilities for small to medium sized programs. Large nuclear codes may still require the present type of sequential operating system, and this will be retained.

An assembler for the PDP11 computer was completed. Users of the various small computers on the site may now compile their assembler programs on the central facility for running on their own computers.

Research staff from other divisions continue to call on the specialist knowledge of this section, and combined projects with other divisions continue to form a large part of the section's work.

2. COMPUTER UTILISATION AND RESEARCH GROUP (Leader: Dr. P.L. Sanger)

2.1 ACL-NOVA - A Conversational Language for the NOVA Computer (P.L. Sanger)

A simplified version of ACL-NOVA was written and tested thoroughly. This version allowed simple arithmetic expressions from any one of five teletypes attached to the NOVA computer to be syntax checked and evaluated.

Work on the final version of ACL-NOVA will soon be completed.

2.2 NOVA Assembler (P.L. Sanger)

The NOVA assembler, NOVASM, was modified so that work space for the symbol table and cross-reference list was allocated dynamically. This feature allows the user to control the amount of core storage required to run the assembler and will be valuable in a multiprogramming environment. The amount of work space allocated is printed at the start of the assembly output.

The punched card output from the assembler has been changed from a column binary format to an EBCDIC format to avoid difficulties that would occur in an OS/MVT environment.

2.3 PDP11 Assembler (G.W. Cox)

A preliminary version of an assembler for the PDP11 computer was written in IBM 360 assembler language, and is now available for use. This assembler includes all but a few minor features of the PAL11A language and provides much more diagnostics and checking facilities.

2.4 Paper-tape Programs (G.W. Cox)

The assemblers for small computers which run on the IBM 360 have in the past produced paper-tape object programs from column binary object card images passed to the PDP9L paper-tape punch via the IBM 360 to PDP9L Link. With the introduction of MVT, column binary cards will no longer be supported, and these assemblers have been changed to produce EBCDIC object cards in a standard format. New programs have been written for the PDP9L to accept these new card images and produce paper-tape object programs for the PDP8, PDP9L, PDP11 and NOVA computers.

2.5 PDP9L Hardware Problems (G.W. Cox)

Some hardware faults in the Analex line printer and PDP9L Automatic Priority Interrupt system caused a considerable amount of down-time with the PDP9L computer. Programming techniques to characterise these faults were developed, and after collaboration with D.E.C. engineers, these problems appear to have been overcome.

3. APPLIED MATHEMATICS GROUP (Leader: J.M. Barry)

3.1 Program Development

A number of programs were written to assist projects for other sections and divisions. These are:

3.1.1 Determinant evaluation (S.G. Johnson)

Determinants arising in the analysis of linear control systems are characterised by the presence of linear polynomial terms in some of the diagonal elements. An algorithm to evaluate such determinants efficiently was devised and is employed in the LINCAN programming package used by the Reactor Control Group.

3.1.2 PDPGENER (R.P. Backstrom)

A new version of PDPGENER was written to handle object decks that are punched in EBCDIC format. This was necessary because there is no straightforward method in which column binary cards can be read by the IBM 360 computer when transition to the multiprogramming system (MVT) occurs. PDPGENER allows small computer users to build up program libraries on the IBM 360 discs for later transmission to their own computer over the Dataway.

3.1.3 QNPRINT - An alternative printer facility for IBM 360 users (R.P. Backstrom)

Output previously directed to the IBM 360 1403 printer may now be passed to the PDP9L computer by means of the link. QNPRINT, a PDP9L program will list this on the Analex printer, while permitting the buffered tape system to accept plotting and punching information from the IBM 360. Besides making a second printer available to IBM 360 users, large quantities of output may be dispatched more quickly by the IBM 360 computer and higher quality listings produced for reports.

3.1.4 Critical facility studies (J.M. Barry)

Further work has been done in conjunction with D. Culley (Physics) involving the reactivity transient studies for the A.A.E.C. critical facility. Investigations culminated in the production of the code BHORU to simulate this system.

3.1.5 Contour plotting (J.M. Barry)

To produce accurate contour graphs for data that is rectangularly spaced, a method of surface representation employing bicubic spline functions was tested. The program CONT is now capable of producing high quality plots.

3.1.6 FORTRAN program debugging aids (S.G. Johnson)

Investigations into IHCDEBUG, the facility provided with the IBM G FORTRAN compiler, are being made in an attempt to produce a more satisfactory and efficient debugging aid for FORTRAN programmers.

3.2 Assistance to Commission Staff

A main function of the Applied Mathematics Group continued to be the provision of programming and mathematical advice and assistance to computer users. Areas in which assistance was provided include:

(i) Data transformation from a one hundred channel multiscalar and statistical analysis. (D.J. Wilson [Reactor Operations], S.G. Johnson.)

(ii) Modifications to existing polynomial regression packages to include confidence interval calculations (J. Woolfrey [Ceramics], G. Lowenthal [Applied Physics], S.G. Johnson.)

(iii) Modifications to existing packages to provide users with a means of solving systems of first order differential equations by Milne's Method (D. Mercer [Mechanical Development], S.G. Johnson.)

(iv) Production of nomograms for charged particle scattering (B. Campbell [Isotope], S.G. Johnson.)

(v) Completion of the information retrieval system for nuclear standards (S. Quaass [Nuclear Power Assessment], J.B. Barry, unpublished report AM/CP 18).

(vi) Alterations to some of the MATMAN (element and isotope distribution) programs (D. Hocking [Nuclear Materials], R.P. Backstrom).

(vii) Programs to facilitate the manipulation of data for seven track tape units attached to the PDP9L (H. Ferguson [Physics], R.P. Backstrom).

(viii) Evaluation of multiple integrals (C. Howard [Solid State Physics], S.G. Johnson).

3.3 Education

A FORTRAN programming course was conducted during July.

4. PROGRAMMING SYSTEM GROUP (Leader: C.B. Mason)

Recruitment to this group continues to be difficult. This is a result of the current shortage of suitably experienced programmers and the consequent demand for their services. Members of other groups within the section have assisted where necessary and in particular, Dr. G.W. Cox will be taking an active part in the implementation of MVT (multiprogramming) later this year.

4.1 Language and Operating System Facilities (C.B. Mason)

This aspect of the work of the group is a continuous process aimed at improving the facilities provided for users. Some highlights include the implementation of a new programming language SNOBOL, which is very powerful in the areas of string manipulation and pattern matching.

A new version of the FORTRAN compiler (Release 18) has been added, overcoming a number of bugs in previous versions. PL/1 Version 5 has recently been implemented and it is claimed that this compiler is faster and produces a more efficient object code.

A number of P.T.F.'s (Program Temporary Fixes) have been included in the

Operating System correcting many of the known bugs. The most significant of these corrections resulted in the elimination of many 'WAIT STATE' halts on the computer, allowing it to run more smoothly.

It is now possible for a computer user to have access to systems information bulletins by means of the 'USERNOTE' facility. He can now be kept informed of the latest developments in the operating system and their possible effect on him.

Some assistance is being given to the University of New South Wales in the implementation of the SIMSCRIPT simulation language on their computer.

4.2 Assemblers and Utilities (C.B. Mason)

A number of improvements have been made to AEMOVE (M. Davids, AAEC/TM519, 1969), a facility for the manipulation of unloaded data sets on magnetic tape. A copy of this routine is being sent to an institute in Karlsruhe, Germany.

Further modifications have been made to the PDP9L Assembler (PDP9LASM) to improve its flexibility and performance, making it suitable for use with other 360 or PDP9L computer configurations. Work on other locally written assemblers is reported elsewhere.

4.3 Multiprogramming

Discussions are being held between members of the section and Mr. T. Wilkes of IBM on the subject of the multiprogramming system MVT. Mr. Wilkes, who has had considerable experience in MVT in the United States, will assist us with its implementation later in the year.

Release 19 of the Operating System is due to arrive in October and initially the sequential (PCP) system will be implemented. A period of investigation and experimentation with Release 19 MVT will then follow before it becomes the standard system.

5. COMPUTER OPERATIONS GROUP (A/Leader: R.S. Dunne)

5.1 Computer Usage

Usage figures for the IBM 360/50I computer are shown in the following table. All figures are in hours.

Month	A.A.E.C. Usage	IBM Programming	Universities, A.I.N.S.E.	Outside Users	Total Usage
April	374	9	2		385
May	397	1	13		411
June	440	1	9		450
July	427		20		447
August	413	1	10	1	425
September	452	1	1		454
Total	2,503	13	55	1	2,572
Previous Six Months	2,025	17	23		2,065

Of the 2,503 hours of A.A.E.C. usage, significant proportions were:

Solid State Physics (6.6%), Experimental Physics (12.9%), Theoretical Physics (22.9%), Administration (10.0%), Applied Mathematics and Computing (9.6%) and the Jervis Bay Project (20.2%).

5.2 Equipment

No changes to installed equipment were made.

5.3 Operations

The average monthly usage was 429 hours, an increase of 24.6% compared to the previous period. Jobs processed totalled 23,633 with an average job time of 6.5 minutes.

5.4 Programming Support

Programming support included a utility program for checking the sequential numbering of object decks, an audit program, the conversion of the vocabulary of stores to use magnetic tape instead of punched cards, a program for the calculation of various heat transfer systems and modifications to the payroll programs to obviate the need for different carriage-control tapes for the special stationery which is used.

6. PUBLICATIONS

Backstrom, R.P. (1970).- PDPGENER - An IBM 360 program to reconstruct symbolic source listings from PDP9L object code. AAEC/E210 (in press).

Sanger, P.J. (1970).- Special programs (IPLTEXT and AEBOOTØ1) written to facilitate the development and use of stand-alone programs for the IBM 360 computer. AAEC/E209 (in press).

APPENDIX

APPLIED MATHEMATICS AND COMPUTING SECTION STAFF

SECTION HEAD : Mr. D.J. Richardson

COMPUTER UTILISATION AND RESEARCH GROUP

RS: P.L. Sanger (Leader)
G.W. Cox

EO: R.E. Davids (R)

APPLIED MATHEMATICS GROUP

EO: J.M. Barry (Leader)
R.P. Backstrom
A. Isaacs (R)
Mrs. S.G. Johnson

PROGRAMMING SYSTEMS GROUP

EO: C.B. Mason (Leader)

COMPUTER OPERATIONS GROUP

TO: R.S. Dunne (A/Leader)
P.D. Williams

TA: Mrs. H.B. Bannister
D.P. Belbin
J. Bills (C)
W.J. Blundy
Mrs. J.F. Bransgrove (R)

TA: K. McGregor (C)
Mrs. M.M. Moore
S. Morey (C)
A.J. Walker

(C) COMMENCED

(R) RESIGNED

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64	R.K. Warner
65	A.D. Thomas
66	R. Crivelli
67	E.A. Palmer (AINSE)
68 - 70	Safety Review Committee
71	Reactor Shift Superintendents
72 - 97	J.L. Symonds for INDC and Bilateral Agreement Correspondents
98	J. Connolly
99	I. Ritchie
100	D.B. McCulloch
101	J. Boldeman
102	G. Hogg
103	J. Cook
104	J. Pollard
105	M. Kenny
106	D.A. Newmarch
107	W. Bertram
108	D.J. Richardson
109	P. Sanger
110	G. Cox
111	J. Barry
112	C.B. Mason
113	R.P. Backstrom
114	S.G. Johnson
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139	S. Kapoor (B.A.R.C. India)
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