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AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

PROGRESS REPORT OF PHYSICS DIVISION

including

APPLIED MATHEMATICS AND COMPUTING SECTION

1st OCTOBER 1970 - 31st MARCH 1971

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ACTING DIVISION CHIEF – MR. W. GEMMELL

CONTENTS

1. INTRODUCTION

Each nation has developed, often for historical reasons, its own approach to nuclear design calculations and particularly those concerned with core neutron behaviour. Following the Jervis Bay tender, comparative investigations into the methods used continued. The differences between tenderers and ourselves proved educational in regard to the nuclear data used, the degree of detail used in the representation and the code methods used. The scope for developing a more sophisticated approach to the problems associated with loss of flow transients led to the establishment of a small study program of our own.

The initial MOATA safety assessment was based on data and calculations available before the advent of multigroup diffusion theory codes in two dimensions. That assessment is being revised and extended to gain approval for 100 kW operation. The more detailed representation obtained in the new calculations has resulted in a much better understanding of the physics of this reactor. The properties of the reactor are determined to a large extent by neutron leakage from the rather thin core tanks. In particular the effect of leakage on the coupling between the core tanks and on reactivity coefficients has been clarified and quantified.

In neutron data studies, the theoretical fission product library was revised, checked against any experimental values and distributed to interested overseas centres. Some further nubar work was done with much better neutron energy resolution, and confirmed our earlier measurements. A promising formulation of R matrix theory of nuclear interaction is expected to lead to simpler multilevel resonance parameter description.

With large amounts of digital data being collected, displayed and used by theoreticians and experimentalists, more attention was given to visual interactive computer displays. This interest is generating constructive proposals for use of the dataway now being installed between the Division and the IBM 360/50 computer.

The study of gamma rays following the capture of keV neutrons continues to reveal new and interesting features of the physical processes involved. A detailed international compilation of the gamma rays emitted and their intensities is in progress. The work on nickel-58, amongst others, has enabled a partial capture cross section to be generated from the gamma ray parameters obtained by experiment. Much work still remains to be done, possibly at other establishments with more extensive facilities.

The electrical and mechanical components of our new zero power split table machine for reactor physics assemblies - the Critical Facility - have been assembled in France, where they are undergoing pre-shipment tests. No major problems have been reported. Civil engineering work on the cell to house the machine is well advanced and should be complete before the equipment arrives in August.

A number of nuclear techniques are being considered for problems related to raw materials. These include photonuclear determination of heavy water, alpha backscattering determination of heavy minerals and the delayed neutron determination of fissile materials.

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

2.1 Reactor Neutron Measurements

2.1.1 Proportional counter spectrometry (P. Cripps)

Two further counters of cylindrical geometry were received and tested. A program was written to analyse single and two-parameter data obtained using these counters.

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

Further investigation was made of the apparent ^{56}Mn decay period discrepancy noted in AAEC/PR33-P. 196 foils were each counted over a period of 11 hours to yield a mean half-life of 2.576±0.003 hours. Excluding Sher and Pate's (Nuc. Phys. A112, 85, 1968) value of 2.585±0.001 hours the weighted mean value of 9 separate determinations from the published literature dating back to 1938 (Nuc. Data Sheets B3-3, 4-64, 1970) was found to be 2.577±0.0013, in excellent agreement with our own result. Sher and Pate's paper gives no detail of their determination, which claims an accuracy better by a factor of 3 than that of any other published value found, and was in any case only a check made incidentally to the determination of nuclear energy levels. We therefore concluded that our data were not discrepant with accepted values and that it would be appropriate to use our value as 'best data' for analysis of these particular experiments.

A thorough investigation was made of possible sources of systematic error in determining foil intercalibration factors, as a result of which we are confident that these are known to an accuracy of better than ±0.3%.

The assembly of 1 inch thick aluminium plates separated by 1/4 inch gaps selected for the first studies immediately showed difficulties with asymmetrical flux distributions and serious higher harmonic contamination of the fundamental modes. These problems are being tackled by detailed systematic attention to minor differences in the cadmium boundaries on various sides of the stack, and by modifications to the construction of the reactor thermal column to provide a more nearly fundamental mode source into the assembly. Considerable improvements were made, and investigations are continuing to determine whether the situation is now such that the main experimental program can proceed or whether further modifications will be necessary.

2.2 MOATA

2.2.1 Operations (J. P. Sawyer)

	Days	%
Operation	74	61
Defect loss	Nil	Nil
Experiment Assembly	37	30
Modifications and Maintenance	11	9
	122	100

Total integrated power 2119 kWh

Two further MOATA physicsts were appointed after completing a course and a period of training and operating experience.

2.2.2 Modifications and new equipment

A radiation monitor for ^{16}N activity was fitted to the Dump Tank return line. A warning is relayed to the control room when preset levels are exceeded. Calibration runs on the equipment were carried out.

A new core-tank high moderator level scram device utilising a float and photoelectric detector was fitted to the moderator level sight glass.

An additional contractor was fitted in the process pit to control the high capacity primary pump, P2. It prevents starting of P2 unless the moderator is already at operating height.

2.2.3 Experiments (J. W. Connolly, T. Wall)

Measurements were made to establish the correct core fuel loading ratio to balance the flux levels in the two reactor core tanks. The required configuration was loaded, and a new calibration of ion chamber current vs reactor thermal power and neutron fluxes carried out.

2.2.4 Reactor up-rating (J. W. Connolly)

Four group diffusion theory calculation (CRAM) was performed on a simplified representation of MOATA to gain a basic understanding of the system. Both flux and adjoint solutions were obtained and used in a perturbation analysis of some important reactivity coefficients. Figures 1 and 2 are CRAM flux solutions for groups 1 (fast) and 4 (thermal) in a vertical plane through the reactor centre line. Void coefficients quoted for UTR reactors, based on total voiding of one coolant channel were shown to be almost a factor of two higher than those obtained for partial voiding. This is attributed to neutron streaming in the one cm wide coolant channels.

The SPERT series of transient experiments was studied to obtain an estimate of the maximum step input of reactivity that the MOATA core can safely tolerate. A draft of a revised safety document, covering 100 kW operation, is nearing completion.

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

2.3.1 Fast fission ratios (A. Rose)

All outstanding problems related to ^{235}U content of the depleted uranium detector foils were satisfactorily resolved. A mean value of 0.0399 atom per cent ^{235}U resulted and was agreed with B.A.R.C.* All the fast fission ratio experimental data were re-analysed in the light of the revised enrichment figure, and the results as calibrated by the double fission chamber and ^{140}La 1.6 MeV γ-ray counting techniques now agree within the error of the measurements.

A re-drafted report was prepared and will be submitted to B.A.R.C. for their agreement prior to publication.

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*Bhabha Atomic Research Centre

2.3.2 Initial conversion ratios (P. Duerden, G. K. Gubbi*)

The Li-Ge detector data were analysed and final ratios of ^{239}Np to fission product count-rates were derived for each experimental cluster. Further work is needed to analyse the thermal column data, and to assess experimental errors.

Considerable difficulty was encountered in analysing the data obtained using the sodium iodide detector. It is clear that severe drifts in gain sometimes occurred during the measurements and the usefulness of the data is being assessed.

Preliminary work began for comparison of the experimental results with WIMS and METHUSELAH calculations.

2.4 HIFAR (D. Wilson, T. Wall, D. Culley)

Low power measurements were made in a mock-up of the X-170 rig in HIFAR to determine the absolute fission rate in the X-170 fuel pin. Fission product gamma-counting and mica foil track-counting techniques were used. Axial and radial fine structure were measured by copper foil activations. Calibration to full power was made by copper and gold activations at a range of reactor power levels.

A model in cylindrical geometry was set up to represent the X-170 rig and the influence on it of the HIFAR core. GYMEA data were then used in WDSN calculations for the system to give fission rates, fine-structure, etc. The fine-structure flux calculated was in excellent agreement with that measured by the copper foil activations. Further calculations were then made to correct the measured absolute rod fission rates (scaled to full reactor power) for actual hot operation in the final X-170 rig geometry, and to assess the variation in rod power with fuel enrichment.

At 10 MW thermal power in a 3.2 kg ^{235}U HIFAR core it is estimated that the (peak) linear heat rating of the 7.5 per cent by weight ^{235}U UO_2 X-170 pin at core mid height will be 790 ± 50 watts per cm length. This corresponds to $\int k d\theta$ of 54 ± 6 Wcm^{-1}.

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

The final concrete placements for the cell were made, and preparations for leak-testing began. The exhaust stack was assembled and erected.

The ancillary building construction work was completed, with the exception of some portions of the plant room cladding. Interior painting and finishing work, etc. are still to be done.

Good progress was made on installation of the air conditioning and ventilation plant and equipment, but the work is not yet complete.

The machine was assembled at the Graffenstaden works of Alcatel, and a program of preliminary testing begun. All control rod mechanisms were

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*On attachment from B.A.R.C., India.

completed, and a number successfully completed their test schedules.

A survey was made of potential accident mechanisms and the likely magnitudes of their consequences.

Equipment was assembled and checked ready for installation in the cell as soon as it is available for pressurising and leak-testing.

2.6 Reactivity Transients (D. Culley)

Investigation of the results of the previously reported point model reactivity transient calculations for the Critical Facility revealed some problems arising from the numerical techniques in the short lifetime cores.

The AIREK III (AMTD 131) code was converted for the IBM 360/50, and a new study undertaken for Pu, ^{233}U and ^{235}U systems with ℓ^* varying from 10^{-3} to 10^{-8} seconds for input reactivity ramps of 1.1, 2.2 and 5.5 x 10^{-4} $\Delta k/k$ sec^{-1}. These ramps correspond to 1, 2 and 5% $\Delta k/k$ per cm of gap respectively at the final range closure speed of the tables. More information is being sought on the response times of the period meter units to ramp reactivity inputs.

2.7 Thermal Reactor Experiments in the Critical Facility (R. Knott)

Calculations were begun to evaluate possible core arrangements for 'PCTR-type' studies of heavy water moderated and light water moderated reactor lattice cells in the Critical Facility. The calculations will be used to establish the most favourable driver lattice arrangements, and to investigate such safety aspects as reactivity changes or loss of liquid moderator.

2.8 Uranium Analysis (A. Rose, K. Brown)

Preliminary measurements were made to test the feasibility of uranium ore assays by delayed neutron counting following short irradiations in MOATA. The tests showed that adequate count-rates will be obtained from samples containing less than 1 mg U after a few minutes irradiation at 10 kW reactor power. A suitable pneumatic sample transfer system and constant geometry efficient neutron detector assembly are being designed.

2.9 Reactor Dynamics (W. J. Turner)

The code OWEN was implemented on the site 360/50 computer. An initial steady state routine was written, which greatly simplifies the running of the code. Major modification of the code to allow slip between the stream and water phases was completed. Unfortunately these changes introduced numerical instability into the calculations. A detailed study of the stability of finite difference schemes is under way in an effort to understand and correct this problem.

2.10 Pulsed Neutron Studies (I. Ritchie)

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

The installation of the count down system on the 3 MeV Van de Graaff

accelerator permitted the use of more suitable pulse length and repetition rates. In the latest series of measurements pulse lengths were typically 200 ns with pulsing periods in the range 5-10 μs. A 2 kV fast post acceleration deflection unit was also installed. This unit

(i) reduces the off pulse level in the pulsed beam reaching the target, and

(ii) removes the higher mass components in the beam which have different flight times, provided the beam pulse is not much greater than 300 ns.

Figure 3 shows the response of a ^{239}Pu detector 12 cm from the edge of the thorium assembly with and without the post acceleration unit operating. It demonstrates that the unit is quite effective in removing the higher mass components. The diagram also shows that the 'background' level at long times (1.5 μs after the pulse) is reduced by a factor of two. This is much less than the off pulse level of the beam which was reduced by a factor of at least 200.

Figure 4 shows the effect of surrounding the thorium assembly with 1/4 inch boral plate. It can be seen that the boral markedly reduces the 'background' which must be predominantly low energy neutrons scattered back from the floor which is only some 106 cm below the bottom of the thorium assembly. The curves also show that the decay of the assembly with the boral in position is somewhat slower during the first 400 ns or so after the pulse than the decay of the assembly without boral. This effect was noted with several shields and did not differ very much from position to position in the thorium assembly.

The preliminary measurements indicate that useful measurements with an unshielded assembly can probably be done in the first 400 ns or so after the pulse. There still remains the possibility that neutrons sent back from the floor affect the decay during this period. Room return can be moderately reduced at later times at the expense of changing slightly the decay of the assembly. A greater separation between the bottom of the assembly and the floor would be advantageous.

The code TENDS was modified to accept pulse shapes other than square. This was done by summing the effect of a number of square pulses of different lengths, amplitudes, and time of occurrence, and by using this in the initial condition to predict the decay in the off pulse period. The actual beam pulse shape is approximated by the sum of the individual square pulses.

2.10.2 Neutron waves in BeO at high frequencies (S. Whittlestone)

Measurements were carried out at a frequency of 952.4 Hz with the polythene moderator of the source cooled to 70°K. This was expected to increase the number of neutrons with energies below the Bragg cut-off in BeO and lead to more pronounced interference effects, or at least interference effects close to the source. No major effects on the propagation of the neutron waves was noted.

Experiments to verify the effects already noted at high frequencies are almost complete. The frequency range of interest is between 500 Hz and 1500 Hz.

2.10.3 Theory of neutron wave propagation (K. Maher)

A multigroup one-dimensional diffusion program was written which describes the propagation into a heterogeneous stack of wave-like disturbances of the neutron population arising from an exterior sinusoidal source. Previous numerical calculations described in the literature have considered only homogeneous semi-infinite media. An explicit finite difference representation of the spatial dependence of the flux has been avoided, although it is implicit in the form of the exponentiated complex matrix operators used in the theory.

An equivalence can readily be established between this theory and the eigenfunction expansion methods more commonly found in the literature. Hence spectral analysis after the style of Duderstadt (Nucl. Sci. Eng., July 1968) is applicable and some detailed explorations were made of the spectral K-plane using a cross-section model somewhat more realistic than that which he describes. This spectral analysis should result in an appreciation of the influence of Bragg Scattering effects on neutron wave propagation in polycrystalline media, thus easing the task of interpreting the output of the abovementioned diffusion code.

The mathematical details of a multigroup Sn code that will do comparable transport calculations have been defined but not yet programmed.

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

A series of measurements were performed on the coaxial plasma gun with a hydrogen gas filling, a negative inner electrode and the capacitor bank voltage in the range 16-25 kW. The initial voltage and current measurements indicated that either no plasma focus occurred or that it was small and not observable. The voltage pulse contained considerable ringing during the first micro-second which indicated the existence of a mismatch in the system. Measurements of the velocity of the front of the current sheath were performed using photodiodes to detect the visible light of the front. The diode response indicated that a well defined front was formed, but the velocities measured tended to be below the value predicted by the two dimensional snow plough theory (Rosenbluth, M., Garwin R. and Rosenbluth, N., LA-1850 1956).

The above results led to a photographic study of the focus and the uniformity of breakdown using the A.I.N.S.E. Abtronics Image Converter camera. The results obtained showed that the initial breakdown along the insulator was quite uniform and that it remains uniform until the sheath reaches the end of the inner electrode. The collapse of the sheath appeared symmetrical and a well defined focus was formed. However several arcs were observed at the insulator after the inverse pinch and these arcs do not allow the maximum energy input to the plasma, hence the very small focus. It was thought that the voltage oscillations, nearly twice the steady state voltage, were the cause of the arcing.

To overcome this problem a series of terminations were used on the gun and a circuit analysis of the gun during the initial stages of breakdown was made. This led to several modifications and rewiring of the energy storage system and preliminary measurements show that the voltage oscillation problem has been overcome.

A computer code was obtained from Imperial College, London, to model

the plasma focus gun. It is being converted to operate on the IBM 360 computer with modifications relevant to our experimental set up.

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

3.1 Fission Physics (J. Boldeman, R. Walsh)

3.1.1. Nubar measurements

The variation of $\bar{\nu}_p$ for ^{235}U with individual neutron energy is being re-measured with better neutron energy resolution (± 7 keV). Preliminary data confirm the lack of fine structure noted in the earlier measurements.

A method of measuring $\bar{\nu}_p$ absolute for the spontaneous fission of ^{252}Cf using (n,p) scattering was investigated and detailed measurements are now planned. In preparation for this, all photomultiplier tubes on the large liquid scintillator were replaced and the tank recharged with fresh scintillator.

3.1.2 Total fragment kinetic energy measurements

The variation with incident neutron energy of the average total fission fragment kinetic energy ($\bar{E}_K$) of ^{233}U is being measured. The data obtained so far show that the $\bar{E}_K(E_n)$ dependence complements the previously measured $\bar{\nu}_p(E_n)$ dependence for ^{233}U.

3.1.3 Neutron emission from specific fission fragments

Some K X-ray spectra were recorded in coincidence with ^{252}Cf spontaneous fission. The well known even odd effect in the heavy fragment X-ray yield was observed. The X-ray detection system is being improved as the available resolution (900 eV for 59.36 keV γ-ray from ^{241}Am) is not considered satisfactory.

3.2 Neutron Capture

3.2.1 Resonance keV neutron capture (G.J. Broomhall, M. J. Kenny, P. W. Martin, J. A. Biggerstaff)

Resolved resonance spectra were obtained for thin samples of titanium, nickel and iron at a 1 metre flight path using a 20 x 15 cm shielded NaI detector. Partial capture yields for ^{58}Ni, ^{48}Ti and ^{56}Fe were analysed to give values of $\sigma_o \Gamma_{\gamma i}$ and in some cases $\Gamma_{\gamma i}$. Figure 5 shows the capture cross sections obtained using a natural nickel target for various γ-ray energy regions. Timing resolution for these data was 3.5 nsec/metre.

For titanium, target thicknesses of 0.5 and 1.0 mm were used to allow multiple scattering corrections to be made. The yield for the fifth excited state of ^{49}Ti was analysed using a multi-level interference cross section. Results for the ground state transition in ^{49}Ti confirm the presence of a d-wave resonance at 39.1 keV.

3.2.2 Averaged keV neutron capture in molybdenum (M. J. Kenny, J. R. Bird, P. W. Martin, J. Furness)

Capture spectra have been obtained for small samples (~15g) of the separated isotopes ^{94}Mo and ^{96}Mo. The NaI detector was used at a 25 cm

flight path and time of flight was used merely to separate keV capture events from time dependent background. The resulting spectra after allowing for time independent background show the averaged keV capture spectrum.

3.2.3 Averaged keV neutron capture in zinc (J. R. Bird, M. J. Kenny, A. R. deL. Musgrove)

Gamma ray transition strengths in ^{65}Zn and ^{67}Zn following neutron capture were analysed and the results compared with calculations based on resonance parameters and a statistical neutron capture mechanism. Estimates of p- and d-wave strength functions were obtained. Because of the substantial deviation from statistical behaviour of averaged transition strengths, it is concluded that configuration effects are important in partial neutron capture cross sections.

3.2.4 keV neutron capture for A=90-140 (J. R. Bird, J. Furness)

Analysis of results for averaged capture in Zr, Mo, Cd, Sn, Te and Ba targets continued using newly developed IBM 360 analysis programs. Gamma ray intensities were derived and more evidence was obtained for p-wave capture in this region.

3.2.5 Capture cross sections (D. B. Stroud, D. M. H. Chan)

Using two Moxon Rae detectors, 30 keV averaged capture cross sections were measured for small samples of Co, Ta, Ag, ^{94}Mo, ^{96}Mo, with respect to gold. The targets are mounted on an automated changer and the whole experiment is computer controlled.

3.2.6 Thermal capture (F. Hille)

Directional correlations of γ-rays from the reaction $^{63}Cu(n,\gamma)^{69}Cu$ were measured.

In a separate experiment the energy spectra of γ-rays following the capture of thermal neutrons in the separated isotopes ^{94}Mo and ^{96}Mo were obtained.

3.3 Experimental Facilities

3.3.1 3 MeV accelerator (A. van Heugten, H. G. Broe, J. Copland, L. H. Russell)

Of the total time in this period, 916 hours or 21% was taken up by maintenance and modifications. Of the remaining 3,452 hours, 3,003 were actually used for experimental running, which is 87% of the available time and this was distributed as shown in Table 1. The time required for maintenance and modifications included:

(a) Teething troubles and modifications to the new count-down system in the terminal. Throughout most of the period this system has been operated in the 'microsecond' mode in which both the pulse width and repetition rate are variable. The beam pulses in this mode have a rise time of ~20ns and a full time ~30ns with a jitter on the pulse width of some ±10ns. In the count-down mode, where a nominally 10ns pulse is produced with a variable repetition

rate, considerable modulation of the pulse height was noted. The reasons for this are not clear.

The major maintenance problem to date has been the comparatively rapid deterioration in the output from the photomultiplier which transmits the 1 MHz signal to the main deflection and auxiliary deflection amplifiers. This problem should be overcome by installing a further amplifier after the photomultiplier.

(b) Vacuum leaks in the terminal.

(c) Installation of a new fast 2 kV post acceleration unit. The unit was designed to have a rise and fall time of less than 150 ns when driving a 25 pF load. These figures were not achieved in practice because of the high capacity (~100 pF) of the deflection plates in use. This high capacity, which is mainly due to stray capacity from the plates to the flight tube wall, should be proportional to the deflection plate length. The use of a 7 kV unit will allow the plate length to be decreased by about a factor of three and somewhat better design of the plates should reduce the capacitance to an acceptable level.

Rearrangement of the centre beam line, with the quadrupole lens relocated at its optimum position brings the second viewer in the centre line to a position 15 feet further from the cell wall and facilitates much higher accuracy in lining up the accelerator. One of the two low background facilities in the extended target area is now completed and in use for proton channelling experiments. The beam lines are about 40 feet long, measured from the switching magnet.

Since its installation, extensive modifications have been carried out on the accelerator and its electronics. So many alterations and extensions were made to the original circuit drawings that a new set of drawings was completed with help from the drawing office.

3.3.2 Duoplasmatron ion source (M. J. Kenny, J. A. Biggerstaff)

Extensive beam current measurements were made in the test rig using the duoplasmatron ion source and a H.V.E.C. deflection chamber. Peak currents of up to eight hundred microamps were obtained through the chamber. The R.F. ion source in the accelerator will deliver up to fifteen hundred microamps through the deflection chamber and it appears that the duoplasmatron source will not better this without extensive development of the deflection chamber.

3.3.3 Data acquisition facilities (J. A. Biggerstaff, M. O. Scott, R. Cawley)

A PDP-15/10 computer with 8k core storage was acquired and a Nuclear Data Corp. ND 2200 (4k) ADC was interfaced in a mode suitable for single parameter analysis. A buffer mode display interface with overlay capabilities was constructed; this interface drives a modified BWD 506 oscilloscope which was mounted on the computer teletype to provide a mobile control console. A concise binary-format punch routine was written to enhance the printed output capabilities of the system (presently limited to 10 bytes/second).

The conceptual design of a unique link between the PDP-15 and the older PDP-7 was completed and hardware based on this design is being constructed by I. & C. Division. The unique feature is that data transmission will be almost completely controlled by the PDP-7, requiring no resident program in the PDP-15 to effect transmission in either direction. Although, with appropriate software, either computer will have access to the other's peripheral equipment, the link will permit loading of the PDP-15 from the PDP-7 (which presently has much faster input/output equipment) without first loading a program into the PDP-15. Further, it will be possible for the PDP-7 to use the entire memory of the PDP-15 for data storage without reserving space in the PDP-15 for program storage.

All data acquisition programs currently being used on the PDP-7 and the PDP-15 have been reassembled using the IBM 360 PDP9L Assembler. Thus full documentation of these programs is available and modifications do not require assembly time on the PDP-7.

4. THEORETICAL PHYSICS SECTION (Head: B. Clancy)

4.1 Nuclear Data Group

4.1.1 Fission product data (J. Cook, E. Rose)

The calculations for the basic library of 184 fission product nuclides were completed and the data assembled in the formats of the UKAEA data file and the GYMEA group cross section libraries. Absorption and total cross section plots were prepared and the data now agree with all latest measurements available. Preliminary versions were communicated to the IAEA and Brookhaven data centres and the final corrections to these can now be circulated.

4.1.2 Multilevel analysis (W. Bertram, J. Cook)

A revised formulation of R-matrix theory was developed. This formulation leads to a multilevel multichannel resonance theory which is much simpler than that obtained by the conventional level matrix expansion technique. The main advantage of the new theory is the relative ease with which analysis of fission and capture cross sections can be made for fissile nuclei. For this purpose a computer program was written and is being tested.

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

Progress was made in fitting phase shifts to reaction matrix parameters and in improving the accuracy of the calculated potentials. Two independent checks on the potentials yielded accurately reproduced phase shifts. Programs for plotting the data were written and are now functional. Investigation of the pion-nucleon interaction using this formalism is now almost complete.

4.1.4 Fission physics (A. Musgrove)

To obtain information about the dynamic state of a fissioning nucleus at the moment of scission, calculations can be made of the trajectories of the various fragments from fissions which emit low mass particles. Trends in the initial dynamic state were studied by performing such calculations for ^{252}Cf ternary fission accompanied by ^{1}H, ^{2}H, ^{3}H, ^{4}He, ^{6}He and ^{8}He particles.

The heavy fragment separation distance is found to increase as the mass of the third particle decreases. Calculations were also carried out for the energy required to limit each of the particles considered in ternary fission.

4.1.5 Cross section data display system (H. Ferguson)

A program is being developed for the IBM 360 and Calcomp 565 plotter to display all the major cross section data available, i.e. GYMEA group cross sections, UKAEA and ENDF/B point cross sections and cross sections from resolved resonance data as well as cross sections from other miscellaneous sources. A feature of this will be its flexibility which, in particular, will allow cross sections from different sources to be superimposed for comparison. It is expected that this program will form the basis of an eventual interactive video display.

4.2 Reactor Physics Group

4.2.1 Collision probability method (G. Doherty)

An extensive investigation of collision probability theory was completed. Codes using this theory are available for the solution of problems in slabs, spheres, cylinders and clusters. A rapid approximate routine is available for each geometry and its performance on typical problems was compared with slower, more accurate collision probability routines and with Sn codes where the latter are applicable. P_1 scattering is available for slabs, spheres and cylinders, and an axial streaming approximation was also coded for cylinders.

4.2.2 Resonance absorption studies (G. Doherty)

As a necessary step in the development of a general geometry resonance equivalence relation, a Monte Carlo resonance absorption code is being written. This code will provide exact results for cluster geometry and is complementary to the PEARLS code which performs the same function for the simpler geometries. The same data tapes will be used by the two programs.

4.2.3 Processing of multiple magnetic tapes (H. Ferguson)

A Fortran accessible subroutine was developed which enables multiple magnetic tapes to be processed on the IBM 360 using only one data definition statement for the entire tape instead of one per file.

4.2.4 Fast reactor calculations (I. Donnelly)

The accuracy of the GYMEA high-energy cross section library for fertile and fissile isotopes is being evaluated by using these data for the calculation of critical parameters of several critical assemblies such as LADY GODIVA and JEZEBEL, and comparing results with the known experimental values. Preliminary results indicate that the recently modified ^{239}Pu data are quite accurate as they give good agreement for neutron flux and leakage spectra and a value of k_{eff} correct to 0.1% for the JEZEBEL assembly.

4.2.5 Heterogeneous method (I. Donnelly)

The preparation of input parameters for the heterogeneous reactor code SOS-1 is being studied. The fuel-moderator boundary conditions for the neutron flux in the moderator must be specified for this code for both the monopole and dipole flux components and although the preparation of the exact monopole boundary conditions is reasonably straightforward, this is not so for the dipole case. The accuracy of several approximation methods is therefore being examined.

4.2.6 The subroutine library PHYS.FORTLIB (B. Clancy, G. Trimble)

A number of subroutines already written within Physics Division have been collected together and are now available at link edit time to all programmers. To complement these a general purpose X-Y plotting system was developed which enables users to construct Calcomp plotting routines for their own purpose. All these routines are described in an internal report being prepared.

4.3 Reactor Code Group

4.3.1 Pseudo fission product data (J. Pollard, B. Harrington)

Extensive calculations were undertaken to replace 154 fission product dregs by a pseudo fission product. The aim of the replacement is to produce multigroup cross sections for the pseudo fission product which, for a variety of reactor systems, results in the same reactor lifetime average neutron loss in fission products. In practice agreement is not exact, although for the systems studied (typical SGHW and AGR reactors) the error incurred when using 41 main fission products and a pseudo fission compared with using the full set of 192 fission products is less than 0.03% in k_{eff}. This agreement is well within possible errors due to data uncertainties. Reports are in preparation.

4.3.2 The GYMEA system (J. Pollard)

The Sn code, ANISN, is now coupled to the GYMEA system although at present we only have a limited number of P_1 scattering matrices (and higher order) in our main library.

Following a recent visit to overseas establishments to discuss latest trends in reactor code development (including modular coding) many new aspects were revealed which need to be investigated before we develop a system to replace GYMEA. Considering the amount of effort used overseas in producing a reactor codes system (usually of the order of 10-50 man years) we need to study other systems carefully before we tackle any new system ourselves.

4.3.3 Shielding codes (B. McGregor)

Further checks were made on the accuracy and efficiency of the large borrower codes ANISN and SABINE which will be used as basic shielding assessment codes.

Gamma ray shielding data were obtained for use with the ANISN code.

5. PUBLICATIONS

5.1 Papers

Bertram, W. K. (1971) - A statistical theory for gamma ray de-excitation of nuclei - Aust. J. Phys. 24, 7.

Bird, J. R. (1971) - Measurements of γ-radiation following keV neutron capture in Zinc - Aust. J. Phys. (in press).

Musgrove, A. (1971) - Trajectory calculations for α-particle accompanied spontaneous fission - Aust. J. Phys. 24, 29.

5.2 Reports

Ajitanand, N. N. (1971) - Delayed gamma ray emission in the spontaneous fission of ^{252}Cf - AAEC/TM577.

Allen, B. J. (1970) - Review of gamma ray transition from keV neutron capture - AAEC/TM565.

Allen, B. J. and Musgrove, A. R. deL. (1971) - keV neutron capture in Zinc - AAEC/TM573.

Bertram, W. K. and Cook, J. L. (1971) - Solution of the inverse reaction problem for complex potentials - AAEC/TM586.

Bertram, W. K., Clayton, E., Cook, J. L., Ferguson, H., Musgrove, A. and Rose, E. (1971) - Fission product group cross section library - AAEC/E214.

Bertram, W. K. and Cook, J. L. (1971) - Compound nucleus formulation of reaction matrix theory - AAEC/TM (in press).

Boldeman, J. W., Musgrove, A. R. deL. and Walsh, R. L. (1971) - Prompt neutrons from ^{236}U fission fragments - AAEC/TM581.

Musgrove, A. (1970) - Resonance parameters for measured keV neutron capture cross section - AAEC/E198 Supplement No. 1.

Musgrove, A. (1970) - Interpolation formulae for average nuclear level spacing and total radiation width - AAEC/E211.

Turner, W. J. (1970) - A finite difference method for transient two-phase compressible flow - AAEC/TM558.

Walsh, R. L. and Boldeman, J. W. (1971) - The energy dependence of $\bar{\nu}_p$ for ^{233}U, ^{235}U and ^{239}Pu below 5.0 MeV - AAEC/TM574.

5.3 Conference Papers

Bird, J. R., Kenny, M. J., Musgrove, A. R. deL. and Allen, B. J. (1971) - Averaged keV neutron capture in Zinc. - Proc. 3rd Conf. Neutron Cross Sections and Technology, Knoxville, U.S.A.

6. RESEARCH CONTRACTS

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: A best nonlocal potential was selected and calculations of single neutron state energies give satisfactory agreement with experiment for spherical nuclei. However, for strongly deformed nuclei allowance will be necessary for the effects of the deformation to obtain a satisfactory theoretical description of single particle wave functions.

Title: Development of Nuclear Analysis Methods for Light Elements

Reference No: 70/D/32
Period: 1/10/70-30/3/71
Supervisor: Dr. J. L. Rouse
University: School of Physics, University of Melbourne
Liaison Officer: J. R. Bird

Objective: To develop new methods using nuclear reactions for the quantitative estimation of deuterium and other isotopes of light elements (particularly carbon, nitrogen and oxygen).

Status: Initial tests were carried out and equipment designed to assess the sensitivity and accuracy of deuterium estimation by detection of photoneutrons.

TABLE 1

ACCELERATOR TIME ALLOCATION

Topic	Expt. No.	Title	Personnel	Origin	Running Time (hours)
Fission	11	Nubar	Boldeman, Walsh	Physics	248
	21	Isomeric fission	Boldeman, Martin, Walsh	Physics	71
	31	^{233}U kinetic energy	Boldeman, Walsh	Physics	371
Capture	17	keV Spectra	Bird, Kenny	Physics	427
	27	Resonance Shape	Broomhall	Melbourne	183
	37	Cross Sections	Stroud	Melbourne	28
	47	keV Fast Timing	Kenny	Physics	172
Transport	25	Sine Wave Modulation	Whittlestone	Physics	295
	45	Time, Energy Spectra	Ritchie	Physics	328
	55	Thorium assemblies	Rainbow, Ritchie, Moo	Physics Tasmania	208
Radiation Damage	16	Crystals	French	U.N.S.W.	8
	26	Cells	Davy	Health Physics	148
Nuclear Analysis	38	^{18}O Concentration	Campbell	Isotopes)	58
	68	O_2 in Zirconium	Russell, Campbell	Physics, Isotopes)	
Charged Particle Reactions	49	(p,γ) Reactions	Din	A.N.U.	9
	59	(p,γ) "	Lasich	Queensland	8
	69	(p,γ) "	Boydell	Melbourne	106
	79	(p,γ) "	Sargood	Melbourne	79
Atomic Physics	44	Proton Channelling	Price	U.N.S.W.	209
Isotope Production	22	^{13}N Tracing	Nicholas	Adelaide)	34
		^{11}C Tracing	Moorby	Macquarie)	
Charged Particle Reaction	60	(p,n,γ) Reactions	Carlson	A.N.U.	13

Tests: 54 hours
Total Operating Time: 3003 hours
Maintenance: 916 hours

APPENDIX (PHYSICS)

STAFF

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

General Reactor Physics Group

RS: J. Connolly
A. Marks (O)
A. W. Dalton
P. Duerden

EO: T. Wall
R. Knott

Technical Staff

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Heavy Water Group

RS: W. J. Turner
J. Harries

EO: A. Rose
G. Durance
D. Culley

TO/TA: R. Jones
D. Stevenson

Pulsed Neutron Group

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SO: M. Rainbow

EO: S. Whittlestone

TO/TA: K. McMaster

Special Duties

EO: D. J. Wilson

TO/TA: J. P. Sawyer (O)
R. Farmer

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

Neutron Capture Group

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B. J. Allen (O)

EO: G. J. Broomhall

Fission Physics Group

RS: J. Boldeman

EO: R. Walsh
P. Martin

Technical Group

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H. Broe
L. Russell
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OA: R. C. Hannan (C)

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RS: G. Hogg
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TO/TA: J. Fredericks

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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)
J. Caruano	(University College, Wollongong)
D. B. Stroud	(University of Melbourne)

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W. Bertram

Nuclear Data Group

RS: J. Cook
A. Musgrove

EO: H. Ferguson
E. Clayton

Reactor Physics Group

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I. Donnelly

EO: G. Doherty
K. Maher
E. Rose

Reactor Codes Group

RS: J. Pollard

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G. Robinson
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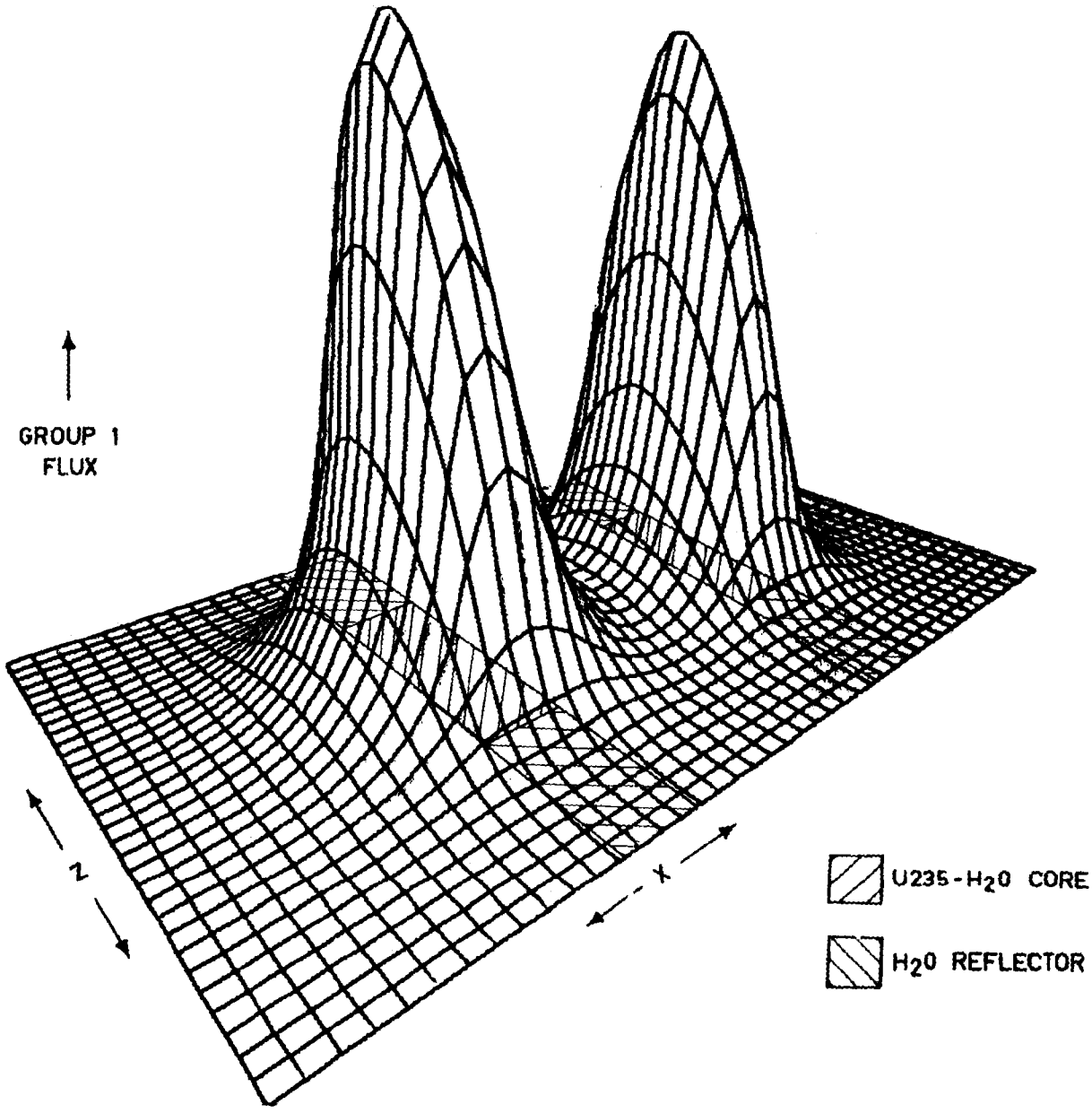

FIGURE 1. MOATA - GROUP 1 FLUX (10 MeV - 0.8 MeV)

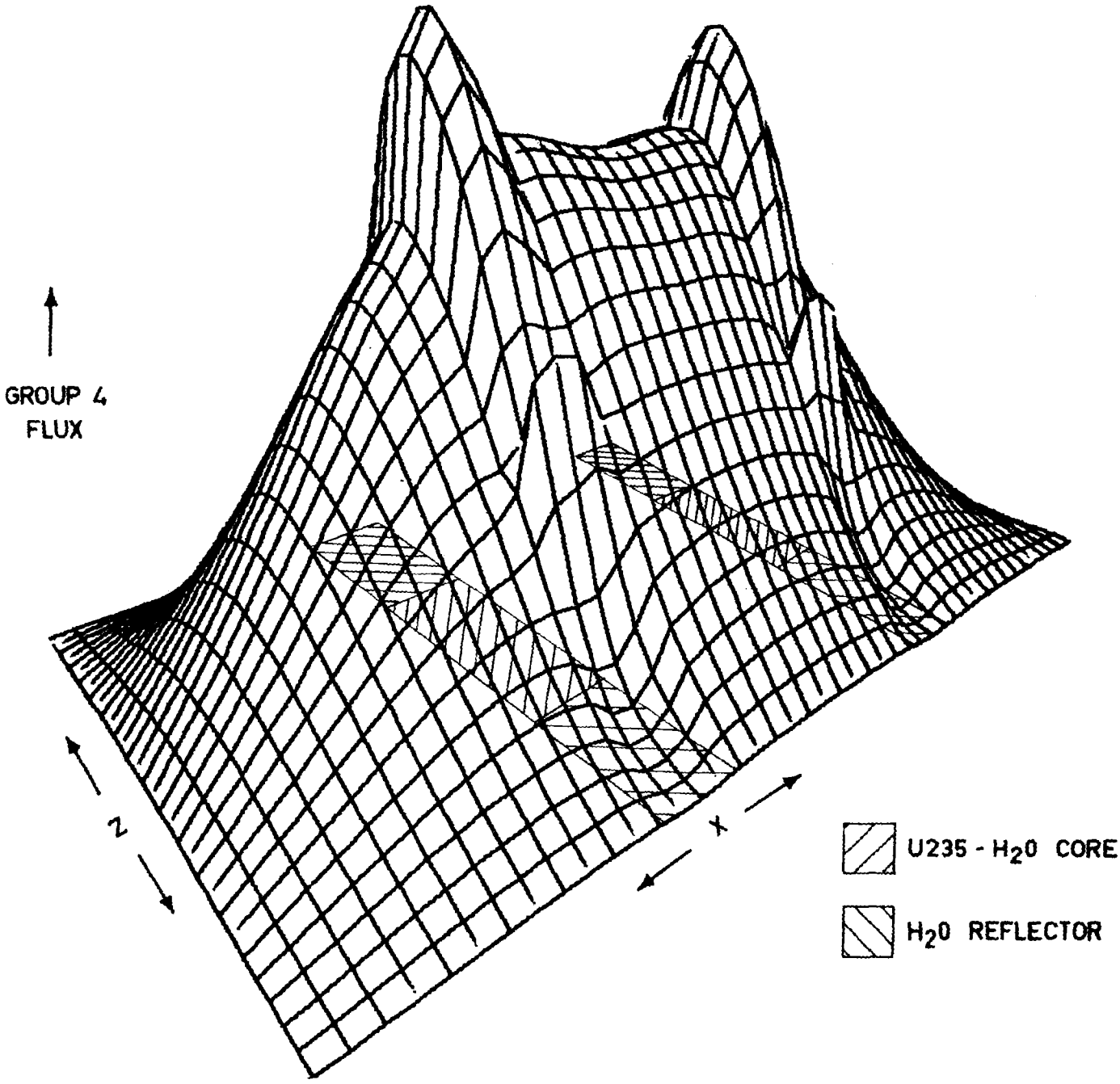

FIGURE 2. MOATA - GROUP 4 FLUX (0.4 eV - ZERO)

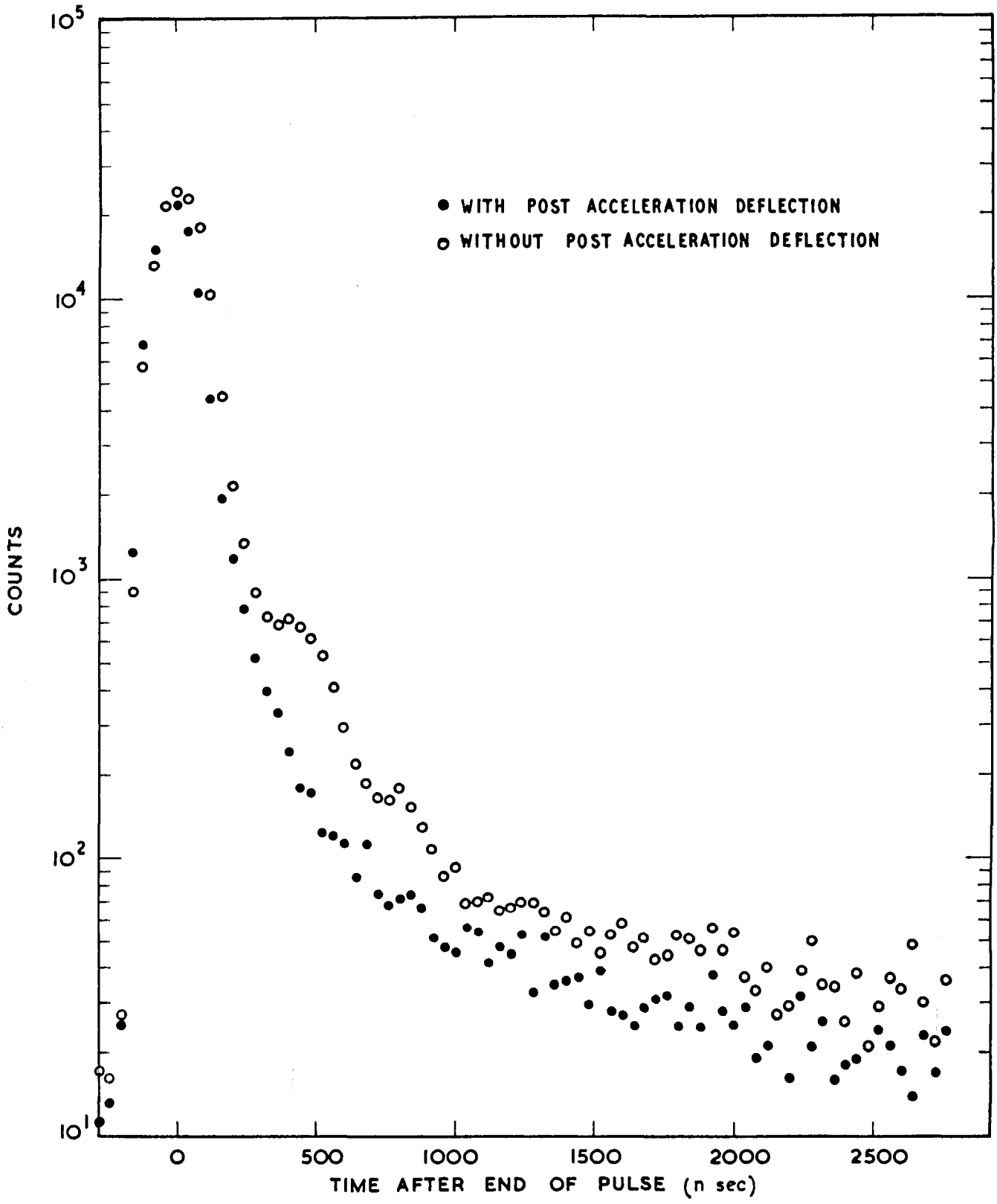

FIGURE 3. EFFECT ON ^{239}Pu DETECTOR RESPONSE OF POST ACCELERATION DEFLECTION

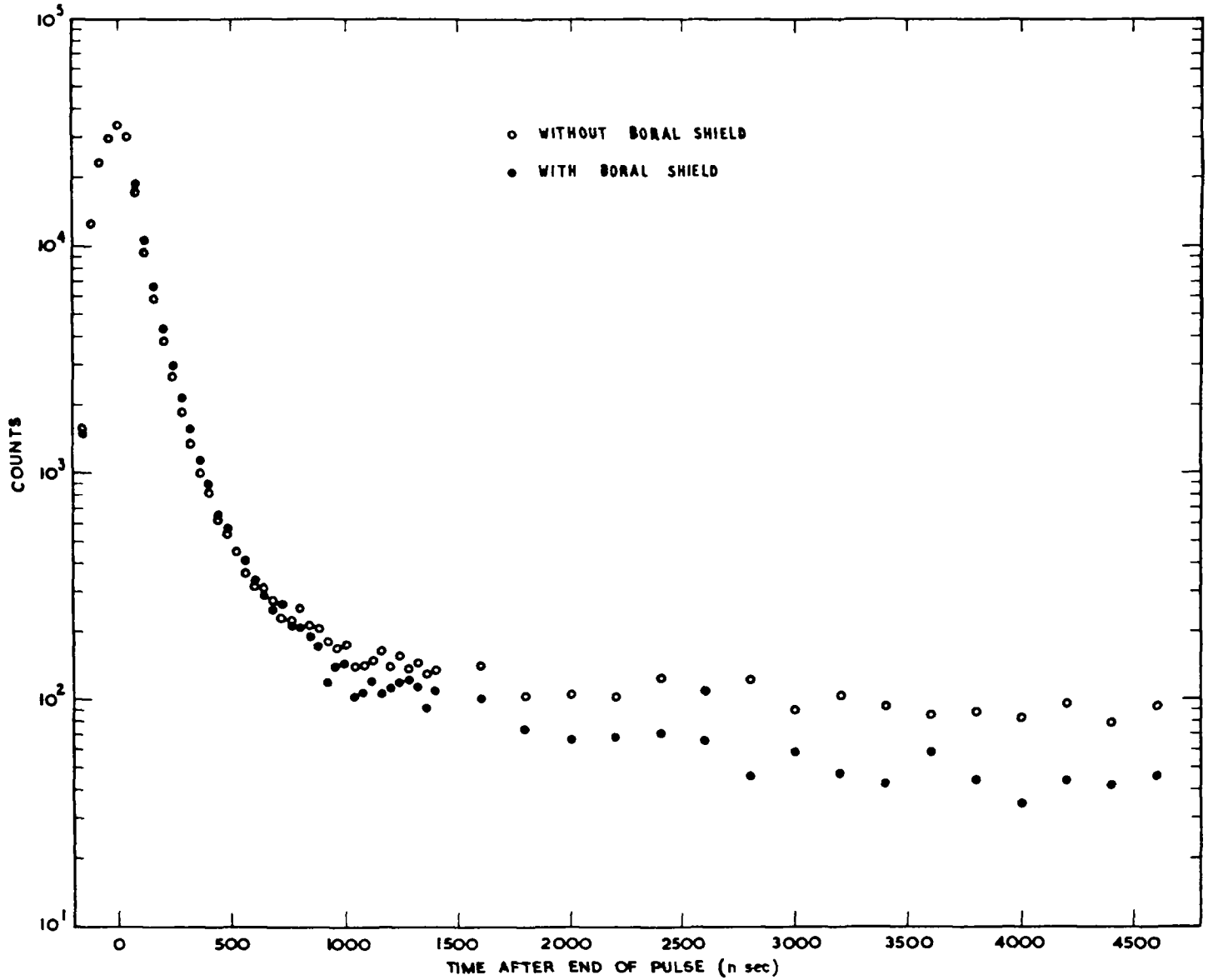

FIGURE 4. EFFECT ON ^{239}Pu DETECTOR RESPONSE OF BORAL SHIELDS AROUND ASSEMBLY

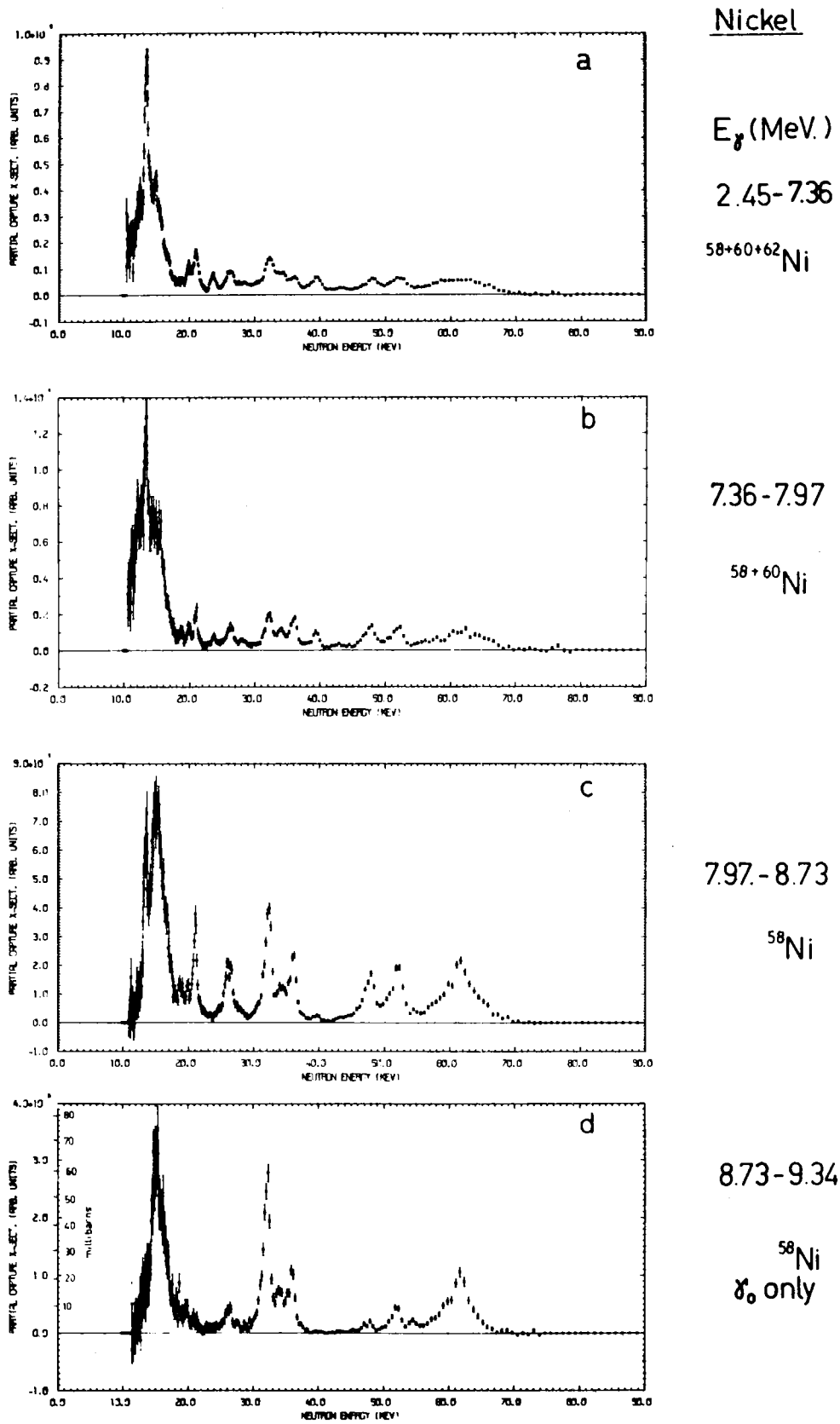

FIGURE 5. CAPTURE CROSS SECTIONS IN NICKEL FOR VARIOUS γ-RAY ENERGY REGIONS

AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

PROGRESS REPORT FOR APPLIED MATHEMATICS AND COMPUTING SECTION

1st OCTOBER 1970 – 31st MARCH 1971

HEAD OF SECTION – DR. D. J. RICHARDSON

Note: Applied Mathematics and Computing Section
is responsible to Deputy Director

CONTENTS

1. INTRODUCTION

This period saw a much needed increase in the number of professional staff attached to the Programming Systems Group. Mr. I. J. Hayes started as a vacation student in November and jointed the Section permanently in February. Dr. W. A. Angus, formerly with IBM in England, also joined the Section in February.

The ACL-NOVA conversational computer language for the Commission's NOVA computer was completed and is undergoing extensive field trials. Outside organizations have shown considerable interest in this project, and it is expected that ACL-NOVA will become a source of revenue for the Commission.

The linking of the various separate Research Establishment computers into a computer network is nearing completion. This will greatly enhance the usefulness of the central computing installation by making the central computer's power available wherever locally needed in the Research Establishment.

Release 19.6 of the operating system for the IBM360 computer was implemented. A number of faults in this system were found and corrected. A multi-programming operating system (MVT) was also prepared under release 19.6, and is now undergoing tests. New computer accounting procedures are being designed and it is planned to implement these and change over to full multi-programming on 1st July, 1971.

A pre-checking facility for Fortran programs was designed and implemented on the PDP9L. This facility checks the syntax of users' Fortran programs during listing, thus enabling many errors to be found and corrected before running on the central computer.

Mathematical and programming assistance to the staff of other divisions and sections has continued to be an important part of this Section's work.

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

2.1 ACL-NOVA (P. L. Sanger)

ACL-NOVA, a multi-user conversational interpreter for the NOVA computer, is now available for general use. The system currently supports five teletypewriter terminals attached to the NOVA computer.

2.2 PDP11 Assembler (G. W. Cox)

An assembler for the PDP11 computer was written for use on the IBM360 computer. The assembler is being used by Instrumentation and Control Division to develop software for the Chemistry Division's PDP11 computer.

2.3 Polarized Neutron Spectrometer (G. W. Cox)

Software for the PDP9L - controlled polarized neutron spectrometer in HIFAR was designed, written and partly tested. The spectrometer should be operational in May, 1971.

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

3.1 Program Development

3.1.1 QNPRINT (R. P. Backstrom)

An improved version of the PDP9L program was devised which allows IBM360 output to be printed on the Anelex printer attached to the PDP9L. Information to be printed may now be blocked (to a maximum of 800 bytes) increasing the efficiency of output bound IBM360 jobs by a factor of six.

3.1.2 AEDUMP - A stand alone IBM360 dump routine (R. P. Backstrom)

A method to produce a selective print-out of core memory for any IBM360/370 computer with complete restoration of the existing program was designed and implemented. AEDUMP will accept commands from a console typewriter and will direct output to either a magnetic tape or a line printer.

3.1.3 HDT - Hexadecimal debug technique for the NOVA computer (R. P. Backstrom)

A comprehensive debug program was developed for the NOVA computer. It incorporates syntax checking of keyboard or paper tape input, including provision for printing ranges of locations and protecting areas of program against inadvertent entry. This program was written for the Computer Utilization and Research Group in connection with the ACL-NOVA project.

3.1.4 FORTRAN type assembler macros (S. G. Johnson)

Assembler language macros to simulate the FORTRAN I/O commands READ,WRITE,BACKSPACE,REWIND,END FILE have been written. These macros generate the same code as the FORTRAN H compiler and call on the FORTRAN library routine IHCECOMH to implement the operations. They are intended primarily for use by FORTRAN programmers who find it necessary to write some assembler routines and for this reason the macro statements follow the same syntax rules as the analogous FORTRAN statement.

3.1.5 Plotting (S. G. Johnson)

A plotting package is being developed to plot perspective projections of 3-dimensional figures.

3.1.6 FORTRAN syntax analysis (J. M. Barry)

A PDP9L program has been implemented to analyse FORTRAN programs for correct syntax. This program occupies a partition in the PDP9L memory and interfaces with the link monitor, plotting and paper tape punching routines.

3.1.7 FORMAC (J. M. Barry, P. C. Herald*)

The IBM symbolic manipulator FORMAC was implemented. This has allowed derivatives for the BMDX85 non-linear least squares program to be generated automatically.

---

*Vacation student

3.2 Assistance to Commission Staff

The applied mathematics group continues to provide mathematical advice and specialist assistance to computer users. Areas in which assistance was provided include:

(i) Modifications to the plotting subroutine GPCONT so that correct systems of closed contours are generated. (S. G. Johnson)

(ii) Modifications to the line printer plotting program PLOT to increase its efficiency. (S. G. Johnson)

(iii) Least squares analysis of data for various members of staff including B. G. Olrian, D. A. Johnson, Dr. G. C. Lowenthal, G. A. Tingate, Dr. J. G. Clouston. (J. M. Barry, S. G. Johnson)

(iv) Development of a further stress analysis program for S. Quaass. (J. M. Barry)

(v) An analysis program to handle experimental data for Dr. A. D. Tucker. (J. M. Barry, J. W. Bills)

(vi) Conversions of FORTRAN programs received from London University on 7 track tapes to a form suitable for running on the IBM360 for Physics Division. (R. P. Backstrom)

(vii) Assistance to the library with the recovery of information from INIS library tapes. (J. M. Barry)

3.3 Education

Two courses were conducted for computer users:

(i) FORTRAN programming course (R. P. Backstrom)

(ii) Job Control language and systems features (J. M. Barry, G. W. Cox, C. B. Mason)

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

4.1 IBM360 Operating Systems Facilities

The major activity of the group centred on the implementation of Release 19 of the operating system. Some of the advantages of this release are:

(i) Support of devices to be connected shortly to the DATAWAY, including the provision of a Conversational Remote Job Entry (CRJE) option.

(ii) Extended System Management Facilities (SMF) providing for automatic data collection and accounting under the multiprogramming system MVT.

(iii) A 6:1 speed improvement in the IEBCOPY partition data set utility with facility for compressing inefficient data sets.

(iv) In-stream catalogued procedures, reducing the need for private procedure libraries and facilitating the testing of procedures.

(v) New versions of the FORTRAN G and H compilers implementing a number of SHARE proposals. The backspace record problems have been resolved.

(vi) Improvement in flexibility and function of the MVT multi-programming system soon to be introduced on site.

The implementation of Release 19 gave rise to an unusually large number of problems with the result that a number of system generations were attempted before a reliable system was obtained. Major stages in the process were:

4.1.1 Primary control program - Release 19.3 (G. W. Cox, S. G. Johnson)

The first attempts to generate Release 19 began in November with the then current version, 19.3. It was soon apparent that there were many bugs in the system including some due to the interaction of the IBM system with locally written accounting routines. Despite the application of numerous P.T.F.s (Product Temporary Fixes), the generated system was still unreliable. IBM notified us that a further seventy corrections were either necessary or desirable to the operating system. This was quite unacceptable.

Early February saw the arrival of Release 19.6, an updated version of Release 19 with about 130 P.T.F.s applied, in house.

4.1.2 Primary control program - Release 19.6 (W. Angus, S. G. Johnson, C. B. Mason)

A Release 19.6 system was generated in February. Unfortunately many of the 19.3 bugs were still present. Further problems arose with the running of some nuclear codes, notably GYMEA, under Release 19.

Correction of these problems occupied a further five weeks before Release 19.6 was finally brought into service as the standard operating system.

4.1.3 Multiprogramming with a variable number of tasks (MVT) - Release 19.6 (W. Angus, C. B. Mason)

A release 19.6 MVT system was generated in March. It is hoped to change over to this MVT system at the start of the financial year, after a program of operator and user education.

4.2 Assemblers and Compilers

4.2.1 PDP9L assembler (C. B. Mason)

Major alterations and improvements were made to the PDP9L assembler. Notable among these were the inclusion of a multiplication arithmetic operator and a facility for using literals. The latter feature provided a simple method of referencing data constants while retaining the cross-referencing advantages of normal symbols.

The inclusion of both new features enabled Physics Division to assemble PDP7 computer programs received from overseas. The PDP9L computer is sufficiently similar to the PDP7, and the assembler sufficiently flexible to allow for the assembly of these programs.

4.2.2 AEFORT - High speed batch processing FORTRAN compiler (I. J. Hayes)

The 'AEFORT' FORTRAN compiler is at present being developed to replace the current 'ABACUS' FORTRAN compiler which will become obsolete with the introduction of MVT. The compiler will 'batch process' many jobs in sequence, thus removing high system overheads and allowing a greater throughput of jobs. AEFORT is designed to follow ASA standard FORTRAN completely in its full error checking in both compile and execution phases. The reduction in both compile time and system overheads should be quite considerable especially on short FORTRAN jobs. Under IBM FORTRAN these jobs have a system overhead of some 18 seconds. Under AEFORT the expected overhead is of the order of one millisecond.

4.3 Computer User Support

Considerable time is spent assisting computer users with their many problems and queries, especially those relating to systems programming and operating system features.

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

5.1 Computer Usage

Usage figures for the IBM360/50I computer are set out in the following table. Totals for the previous six months are shown in brackets.

Computer Usage* (hours)

Month	AAEC Usage	Universities AINSE	Outside Users	Total Usage
October	410	8	1	419
November	423	8	-	431
December	271	-	-	271
January	379	8	2	389
February	420	6	3	429
March	473	3	2	478
Total	2,376 (2,503)	33 (55)	8 (1)	2,417 (2,572)

*IBM programming for this period - nil, for previous period 13 hours

The average monthly computer usage was 403 hours. Jobs processed totalled 23,688 with an average job time of 6.5 minutes. Of the 2,376 hours of AAEC usage, significant proportions were:

Theoretical Physics (19.3%), Experimental Physics (16.8%), Applied Mathematics and Computing (12.5%), Administration (11.3%) and the Jervis Bay project (15.8%).

5.2 Equipment

A new 029 card punch was installed to cope with the increasing card punch work-load.

5.3 Programming Support

Programming has been done for HIFAR and Neutron Diffraction staff. The Vocabulary of Stores has now been converted to operate entirely on the IBM360 computer. Operations group staff assisted in the implementation of Release 19.6 of the IBM360 operating system.

6. PUBLICATIONS

Cox, G. W. et al. (1971) - Programs for the management and processing of neutron diffraction data. AAEC/TM578.

Richardson, D. J. (1970) - The A.A.E.C. computer network. AAEC/TM576.

Sanger, P. L. (1970) - NOVASM and NOVASIM - an assembler and a simulator for the NOVA and SUPERNOVA computers written to run on an IBM360 computer. AAEC/TM566.

APPENDIX

APPLIED MATHEMATICS AND COMPUTING SECTION STAFF

SECTION HEAD: Dr. D. J. Richardson

Computer Utilization and Research Group

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

Applied Mathematics Group

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

Programming Systems Group

EO: C. B. Mason (Leader)
W. A. Angus (C)
I. J. Hayes (C)

Computer Operations Group

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

TA: Mrs. H. B. Banister
D. P. Belbin
Mrs. J. W. Best (C)
J. W. Bills
W. J. Blundy
G. J. Fisher
K. J. McGregor
Mrs. M. M. Moore
S. Morey (R)
A. J. Walker

(C) Commenced

(R) Resigned

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