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AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

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PROGRESS REPORT OF PHYSICS DIVISION

1st APRIL 1972 - 30th SEPTEMBER 1972

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ACTING DIVISION CHIEF – MR. W. GEMMELL

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CONTENTS (cont'd)

1. INTRODUCTION

The building housing the zero power split table machine for reactor physics studies was officially opened by the Prime Minister, the Right Honourable William McMahon, on 19th June, 1972. Preparation of the Safety Document for the machine continued and the collection began of components for the first reactor assembly which will use fuel already available. An order was placed with CERCA (Compagnie pour l'Étude et la Réalisation de Combustibles Atomiques) for delivery of 15 kg ^{235}U during the first quarter of 1973.

Major effort continued to be devoted to the safety analysis of the Commission's other reactors. MOATA was prepared for 100 kW operation, with increased interest in its use for neutron beam work in physics and metallurgy fields. A convenient pneumatic transfer unit is now operational for analysis of uranium ores by delayed neutron analysis and levels down to 0.001 per cent have been detected with reasonable accuracy. A major review of nuclear reactions in the analysis of materials was prepared.

Installation commenced on a system of switching and focussing magnets to provide protons and hence neutrons at a point 4 m above the floor and equidistant from the walls and roof of the building. This should reduce scattered neutron return problems with the neutron capture gamma ray studies and the fast neutron transport experiment in thorium metal.

Analysis continued at a more intense level on the neutron capture cross section measurements from Oak Ridge National Laboratory. This analysis forms an important aspect of our work as long as our major equipment is unable to compete with the excellent Oak Ridge National Laboratory Electron Linear Accelerator. Collaboration takes the form of material assistance in the analysis of the abundance of information supplied by this facility to which we hope to provide a few confirmatory checkpoints.

The advent of the zero power split table machine provided the impetus for a critical examination of the adequacy of our data library, methods of manipulating the data and codes for using it, particularly in the area of fast reactors. Development continued with the AUS modular scheme and a range of ZPR III fast zero power assemblies was studied.

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

2.1 Reactor Neutron Measurements

2.1.1 Neutron streaming (D. B. McCulloch, D. J. Wilson)

The scheduled experiments on neutron migration anisotropy in Al-H_2O slab lattices were concluded on completion of the series using 12.7 mm water gaps. No further experimental work is anticipated on this project.

2.1.2 Fission yields of ^{140}Ba (A. Rose)

Experimental work was completed for the double fission chamber/foil γ-counting determination of the relative yields of the $^{140}Ba/^{140}La$ chain in ^{235}U and ^{238}U fission. A calibrated ^{140}La source counting experiment was also carried out over an extended period in an attempt to make the yield data absolute. The results now await analysis.

2.2 MOATA

2.2.1 Operations (T. Wall)

	Days	%
Operation	86	68.3
Defect loss	1	0.8
Experimental assembly	2	1.6
Modifications and maintenance	13	10.3
No operation	24	19.0
	126	100.0

Total integrated power 2951.8 kWh

The use of the reactor has included the following experiments:

- Neutron activation analysis
- Capture gamma ray spectroscopy
- Fission yield measurements
- Neutron radiography
- Proton recoil, primary emission and ion chamber calibrations
- Fast neutron damage in transistors
- Noise measurements
- Anisotropic scattering

In addition, two trainee operators are currently concluding their period of training and instruction in operation of the reactor.

Further to the 100 kW uprating program, a motorised valve has been installed in the primary coolant line to permit console control of the moderator-coolant flow rate. An electric motor has been installed to allow control of source movements from the operating console. Console modifications to make these items fully functional and to take account of other requirements of 100 kW operation have been designed and will be installed shortly.

2.2.2 Uprated reactor safety assessment (J. W. Connolly)

The MOATA Safety Document was approved by the Reactor Safety Committee subject to some amplification of the transient analysis presented. The amplification sought an estimate of the worth of the uncertainties to the maximum step reactivity addition which can be permitted without the onset of fuel melting. This has necessitated further examination of the SPERT experimental correlations. In addition, the code ZAP has been used in attempts to calculate observed power behaviour in the SPERT P12/25 core. Although satisfactory burst shapes are obtained with the feedback coefficient suggested by the previously reported SPERT correlation, peak powers are over-estimated by a factor of two when the heat conduction option of ZAP is used to compute region weighted feedback. Since ZAP will be used in safety studies for other reactor cores, there is an additional reason for attempting to obtain reasonable agreement with SPERT results. SPERT provides a good set of bench-mark experiments against which the code may be tested. Further efforts to discover the cause of the above noted discrepancy will therefore be made.

2.2.3 Reactor measurements (J. R. Harries, R. B. Knott)

The kinetic behaviour of MOATA is being investigated using neutron noise techniques. The cross correlation between the neutron fluctuations in the two core tanks provides information about the prompt neutron generation time and the coupling coefficient between the core tanks of the critical reactor.

BF_3 proportional counters were positioned adjacent to each core tank and the fluctuations in the countrate from each counter were recorded on magnetic tape. Subsequently, the data were analysed on the correlator and spectrum analyser of the Noise Analysis Laboratory, Engineering Research Division.

The data are being compared with cross correlations and cross-power spectral densities predicted by a two mode model of the reactor.

2.3 HIFAR

2.3.1 HIFAR safety assessment (D. J. Wilson)

Further contributions were made to this project through collation and analysis of accumulated experimental physics data from a range of recent HIFAR cores, and through additional PACE analogue computer studies of the reactor power response to step and ramp reactivity additions and to the loss of a coarse control arm.

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

Commissioning tests of the facility were completed satisfactorily and a certificate of practical completion was issued in April. The facility was officially opened by the Prime Minister, The Right Honourable William McMahon, on 19th June, 1972.

The major effort has been concentrated on preparation of a comprehensive safety assessment for the facility, embodying a detailed description of the plant, its siting including climatology, seismology, etc., followed by a comprehensive analysis of potential accident mechanisms for a broad range of reactor assemblies. The descriptive part of this safety document has been completed and submitted for consideration by the Reactor Safety Committee. Much of the hazards analysis and operational procedures part of the document has been drafted, but calculational support work in a number of key areas is still in progress and further substantial effort will be involved before the document can be finalised.

The first experiment, an all-solid moderator mock up of the MOATA reactor, has been designed and mounted on the tables. A separate safety submission (to be read in conjunction with the plant description) is in preparation to cover this experiment alone and fuel will be loaded into the experiment on receipt of favourable advice from the Reactor Safety Committee.

2.4.1 Reactivity transients (D. Culley, J. R. Harries)

The response of the period meters in both current and pulse input channel situations has been measured using the PACE analogue computer.

The output voltage as a function of time was recorded for input periods of 5 to 0.1 sec, and starting levels of 1, 10, 100 and 1000 pulses per second or 10^{-11}, 10^{-10}, 10^{-9} and 10^{-8} amp. These data have enabled a conservative model of the period meter response to be formulated for use in startup reactivity accident studies.

A reassessment has been made of shutdown flux levels and detector outputs for a wide range of reactor types. In conjunction with the new period meter response data, this has enabled the power transients which would result from accidental fuel overload followed by various electronic unit failures to be calculated using the AIREK III code. The results will form part of the over-all safety assessment for the facility.

2.4.2 Neutronics and control modifications (J. R. Harries, J. P. Sawyer)

A number of modifications have been formulated to improve safety margins and operational convenience of the facility. The proposals have been independently checked by Instrumentation and Control Division, and a number of them are being implemented.

One of the most important modifications was to the rod drive selection procedures for safety or control modes of operation. Previously, the interlock arrangements were such that selection could not be made until after the rods were latched, necessitating reselection at every startup, thus unnecessarily risking incorrect selection. The interlock logic for each rod drive has now been modified in such a way that the key operated function selection can be set at the beginning of each new assembly and will not require any subsequent reselection unless a change of function is essential to the execution of some particular experimental measurement.

A noise level and long term stability check is being made on the neutronics current operated channels with a view to lowering their effective minimum usable input current by half a decade or so, thus improving the available overlap range between pulse and current operated channels.

2.4.3 Safety assessment (A. W. Dalton, D. B. McCulloch, J. R. Harries, D. J. Wilson, T. Wall, W. J. Turner, A. Rose)

Part I of the Critical Facility Safety Document - Summary and Plant Description, was completed and submitted in mid-September for consideration by the Reactor Safety Committee.

Part II of the document - Operational Procedures and Hazards Analysis - is intended to cover operation of the entire envisaged range of experimental reactor assemblies containing up to 100 kg Pu and 20 kg ^{235}U. A considerable volume of calculation is required in support of the hazards analysis; many of these calculations require input data which can only be determined by direct measurements on the machine, e.g. the time and distance required for the movable table to stop and then to reverse by action of a drive motor after a SCRAM signal is initiated.

This program is continuing in parallel with drafting of sections covering normal operational procedures, fuel handling and control, emergency procedures, etc.

2.4.4 Experiments (J. W. Connolly)

A mockup of the MOATA reactor has been built on the machine tables. The graphite reflector has been constructed from machined graphite blocks already held by the Division. These have been stacked to give a 2050 x 800 x 1400 mm assembly on each table. The plane of separation has been made orthogonal to the length of the core slabs to keep the multiplication of each single table assembly low. The core slab region is contained in square section aluminium tubing fitted into cavities in the graphite structure. Each tube contains ten slabs of polythene, machined to accept the fuel plates and of such a thickness to approximate the H/U5 ratio of the MOATA core. Completely loaded, the core slabs would contain 2.86 kg of ^{235}U fuel. The calculated critical mass is 2.7 kg.

Horizontal holes in the graphite have been provided for the passage of one control rod and two safety rods on each table. All rods are identical, the absorbing section being a cadmium cylinder wound on an aluminium former. The individual worth of a rod has been measured in MOATA and from this is estimated to control 450×10^{-5} $\delta k/k$ in the mockup core.

2.5 Uranium Analysis (A. Rose, G. K. Brown)

A reliable and repeatable pneumatic transfer rig is now operational. The reproducibility of the delayed neutron activity has been studied as a function of irradiation time and counting period. It appears that a single in-core irradiation of 45 sec followed by a 40 sec count of the sample's neutron activity would allow 2 g samples containing more than 0.001 weight per cent natural uranium to be assessed with an accuracy of a few per cent. Routine through-puts of 20 or more samples per hour should be possible.

Technical problems associated with transit time stability, background reduction and the $^{17}O(n,p)^{17}N$ reaction are being studied to establish the minimum concentration amenable to reasonable assay. This is expected to be better than 10 ppm.

Preliminary analyses of six ore samples of 1 to 3 g each are compared with their direct chemical analysis in Table 1. The calibrating sample for the delayed neutron analysis was a 2.5 mg sliver of natural uranium metal centralised in a sample container identical to those used for the ore samples.

2.6 Neutron Radiography (T. Wall)

Neutron radiography is a potentially powerful method for studying hydriding of zirconium specimens. Some preliminary work was done in conjunction with Materials Division.

A detector foil (e.g. indium) is placed behind the specimen in the neutron beam. Neutrons transmitted by the specimen activate the indium and the image so formed is transferred to a photographic film. High beta (β^-) activities are necessary for adequate film contrast. The neutron beam intensities available from MOATA appear to be adequate for this purpose and work is in progress to determine film response characteristics.

2.7 Reactor Dynamics (W. J. Turner)

Details of the heater used in the CISE experiments (A. Premoli 1969, Energia Nucleare 16, 626) have been obtained and are being used in the analysis of the inlet blockage blowdown experiments.

Another type of experiment carried out by Premoli is blowdown at the feeder outlet without an inlet blockage. Premoli stated in his paper that the inlet flow was kept constant during these experiments. A comparison of the experimental and calculated results is shown in Figure 1. The calculations indicate that some of the coolant flashes to steam at the inlet to the test section. This suggests that in fact it was the flow at the pump which was kept constant rather than the flow at the channel inlet as stated.

Details of CISE test loop several years before Premoli's experiment were obtained (N. Adorni et al. 1962, CISE R62) and a calculation done for the part of the rig between the pump outlet and the test section outlet, keeping the flow at the pump outlet constant. The results are plotted in Figures 2 and 3 and show an increase of over one hundred per cent in the flow at the test section inlet. Two factors contributed to this: firstly, flashing of coolant to steam upstream of the test section (initial contents 86 g); secondly, the drop in pressure in the damper (volume 120 litres) allowing the water to expand, forcing about 40 g of coolant out of the damper. Information since obtained from Premoli has confirmed that the flow at the pump and not the inlet flow to the test section was kept constant, and that the loop used by Premoli was actually as described by Adorni in the above reference.

2.8 Pulsed Neutron Studies and Spectra (A. I. M. Ritchie)

2.8.1 Pulsed measurements in thorium (M. Rainbow, S. Moo)

Work has continued in comparing the experimentally measured, fundamental spatial mode fission rates of ^{237}Np, ^{235}U and ^{239}Pu with those calculated theoretically. The problem of choosing the most appropriate extrapolation length to use in both the Fourier analysis of the experimental results and in calculating the buckling used in the zero dimensional diffusion theory code has been solved.

It would also appear that a proper comparison of experimental and theoretical time dependent reaction rates requires the time scale of the measured time distribution to be normalised to the start of the neutron source in the assembly. This normalisation is not known precisely for the present series of measurements, but the magnitude of the systematic error introduced is small because of the very narrow (~10 nsec) neutron pulses used in the experiment. In experiments where long pulses (~100 nsec) are used, this effect could be important.

Some preliminary experiments have been carried out using neutrons from the Li(p,n) reaction at a proton energy of 2.3 MeV. This gives a source spectrum having a high energy cut off at ~500 keV which is significantly softer than the spectrum from the Be(d,n) reaction used previously.

The version of the code SUPERTOG available for processing data from the ENDF/B file was not capable of handling the elastic cross section data for ^{232}Th in the form in which it was presented on the file. Previously, ^{232}Th data from the file had been processed by a rather circuitous route involving other data processing codes. This deficiency in SUPERTOG has now been corrected.

2.8.2 Measurement of the Be(d,n) neutron energy spectrum (S. Whittlestone)

Information in the literature on the energy spectrum of neutrons from the Be(d,n) reaction is sparse, particularly at energies below 1 MeV. A time of flight experiment has been mounted to measure the energy spectrum from a thick target as a function of angle, paying special attention to the low energy spectrum. Time of flight spectra have been measured and the detector efficiency below 1 MeV determined using neutrons from the Li(p,n) reaction. The neutron energy spectra have yet to be evaluated from the time of flight distributions.

2.8.3 Proton recoil detectors (A. Rose)

The resolution of a 20th Century Electronics spherical detector filled with CH_4 has been examined using monoenergetic neutrons from the 3 MeV Van de Graaff accelerator. The SPEC IV code was used to reduce the measured pulse height spectra to energy spectra.

An improved gas filling system incorporating a hydrogen diffusion unit has been commissioned and successful fillings of H_2 with 2.5 per cent N_2 have been carried out. Counter resolutions of 8 per cent have been obtained for gas pressures of 2 and 3 atmospheres. Work is progressing with a gamma ray discriminator unit.

2.9 Neutron Source Project (G. R. Hogg, J. Tendys, J. A. Daniel)

The positive centre electrode coaxial gun has been operated with deuterium gas fillings and further measurements of the neutron and X-ray emissions have been obtained. The operation of the gun, in terms of neutron output, has not been repeatable and it is suspected that this results from impurities in the glass vacuum vessel, the surface of which has been considerably damaged by the hot expanding plasma. A stainless steel vacuum vessel is being assembled and tested to improve system cleanliness and hence neutron output repeatability.

A closed cycle vacuum system, utilising activated charcoal sorption pumps has been constructed and fully tested. This will enable the operation of the coaxial gun with deuterium-tritium gas fillings. The larger cross section for the D-T reaction will result in an increase in neutron yield by a factor of 80 compared with the D-D neutron output.

A new electrically screened room with filtered mains power supply and double screened input cables has been completed. This arrangement has considerably reduced the interference noise on the signal lines and measurements of signals of millivolt levels are now possible. This is of importance for the semiconductor detector X-ray measurement system.

Several magnetic probes have been constructed and a series of measurements of the magnetic field between the coaxial electrodes has been made; these will be correlated to the two dimensional numerical fluid model. Various screening configurations have been investigated as the probes are in a very high interference field and it is important to exclude this interference.

3. NEUTRON PHYSICS SECTION

3.1 Neutron Data Measurements

3.1.1 Nubar absolute for ^{252}Cf (J. W. Boldeman)

An absolute measurement of the average number of neutrons emitted in the spontaneous fission of ^{252}Cf has been carried out using a large liquid scintillator. The final value is 3.735 ± 0.014.

3.1.2 Fast neutron capture cross sections (B. J. Allen, J. W. Boldeman, R. J. Cawley, D. M. H. Chan, M. J. Kenny, A. R. Musgrove, R. L. Walsh)

Analysis has continued of high resolution capture cross section data measured at the Oak Ridge Electron Linear Accelerator. An IBM360 program library is in operation for background estimation, Breit-Wigner fitting and iterative Monte Carlo calculations of resonance yields. Extensions and modifications to the library are nearing completion. Data from measured widths of a large number of resonances in several isotopes have been used to prepare experimental resolution curves for beam pulse widths of 5 and 40 nsec.

Analysis is well advanced for results for natural silicon (2.5 to 1500 keV), ^{134}Ba (3 to 50 keV), ^{136}Ba (3 to 50 keV), ^{138}Ba (3 to 280 keV) and for isotopes of Ca and Zr.

The average level spacings for the Ba isotopes show a dramatic decrease when moving away from the N=82 closed neutron shell. Initial estimates of level spacings are: ^{138}Ba - 3 keV; ^{136}Ba - 0.5 keV; ^{134}Ba - 0.15 keV.

Analysis of the capture cross section of ^{206}Pb has shown that the reported doorway state in ^{206}Pb is not present in the photon channel. Observed originally by the Duke group in the s-wave neutron channel (Γ_n^o), the doorway was confirmed in the ground state gamma ray channel ($\Gamma_{\gamma o}$) by the Livermore group. However, the ORELA capture data, with its improved resolution, cannot confirm the reported correlation between Γ_n^o and $\Gamma_{\gamma o}$ because of the disagreement in energies and neutron widths with the s-wave resonances in the Duke data.

3.2 Neutron Reactions

3.2.2 Neutron emission from specific fission fragments from ^{252}Cf (R. L. Walsh, A. Emery)

An initial series of measurements has been completed using a 90 kΩ cm

Si X-ray detector with a resolution of 450 eV (FWHM) for the 26.36 keV ^{241}Am line. Because of low count rates, only data for single fission fragment - X-ray coincidences have been recorded, rather than for two fragment - X-ray coincidences. This 'singles' rate was about 3 per minute. Figure 4 shows a raw K X-ray energy spectrum for one series of runs. The expected positions of the $K\alpha_1$ peaks for a number of fragments are indicated.

It is proposed to increase the count rate by inserting large area (4 cm^2) fragment detectors in the system. Also the number of channels on the X-ray pulse height line will be increased from 220 to 1024.

3.2.2 Resonance neutron capture in F and Si (M. J. Kenny, L. C. Carlson, B. J. Allen)

In order to clarify a number of features in the resonance capture of neutrons in F and Ca, new measurements have been made using a larger Ge(Li) detector (17 per cent efficiency relative to 7.5 x 7.5 cm NaI). The gamma ray spectra from silicon have been compared with capture cross section data to determine the isotopic allocation of some of the resonances below 100 keV. Analysis of spectra from individual resonances is in progress.

3.2.3 Resonance neutron capture in Cl (A. Barus, D. M. H. Chan, M. J. Kenny, J. R. Bird)

New measurements have been made of the capture gamma ray spectra from three groups of resonances in chlorine between 10 and 60 keV. A target of 1.4 kg NaCl was used with the large Ge(Li) detector fitted with improved shielding to reduce the effects of scattered neutrons. A notable feature of the results is the observation of a transition to the first excited state (3^+) in ^{36}Cl for a number of resonances between 10 and 60 keV. Known resonances in this region have been allocated spins of 0 or 1 from cross section measurements, but it seems likely that additional higher spin resonances are present.

3.2.4 Compilation (J. R. Bird, B. J. Allen)

A compilation of capture spectra results for 5 to 300 keV neutrons has been completed and submitted for publication in Nuclear Data.

3.3 Facilities and Techniques

3.3.1 3 MeV Accelerator (H. Broe, J. Copland, A. van Heugten, S. Kannard, P. Lloyd)

The accelerator was used in experiments for 2904 hours distributed as shown in Table 2. Maintenance required 851 hours including the repair of a number of failures in beam pulsing systems. The accelerator tube now has only one section shorted out and it is expected that this can be put back into service.

Some time ago the double electrodes of the deflection chambers were modified to an AAEC design. For want of a better material, the insulating sleeves were made of Araldite, which deteriorates from the heat of the deflection plates and probably has caused some outgassing in the past. A set of alumina sleeves, ground by Ceramics Section, will be installed and tested at the first opportunity.

The high cost and short life of the 5.08 cm Aximax blowers in the terminal prompted us to investigate their characteristics. Since they were originally designed to operate under atmospheric pressure and tank pressure is 2070 kPa, it was suspected that they operated far below the design speed of 10000 rev min^{-1} and that the excessive heat from the resulting high current caused the failures. Under 2070 kPa in the test tank it was found that the actual operating speed was only 2400 rev min^{-1} and the power consumed 8 watts (70 per cent above rated). After inserting 560 ohms in series with the blower, the speed fell to 1600 rev min^{-1} and the power consumed dropped to 4 watts. No trouble has occurred in the three months since modification.

A small, undetected cooling water leak in one of the two coils of the switching magnet caused a complete failure. On removal, it was found that corrosion had caused the electrical terminals to separate from the windings leading to a short circuit between the two halves of the coil (across the cooling plane). Careful dismantling showed the cooling plane to be beyond repair, but the coil-halves have been salvaged. A modified cooling plane will be manufactured as soon as time permits.

Both 300 ℓ/sec^{-1} turbo-molecular vacuum pumps in use exhibit a very small flow-back of lubricating oil from the rotor bearing compartment to the oil pot of the primary drive. According to the agents for the pump this seems to be a characteristic which is commonly experienced and cannot be rectified. To overcome the inconvenience of periodically having to stop the pump and add oil to the rotor compartment, a device has been made and installed which makes it possible to transfer oil back from the primary drive to the rotor drive without the vacuum pressure being affected.

The external source-gas system is nearing completion and installation is planned for the near future. A prototype fixed leak was tested on the bench and in the terminal and performed well. Tests were carried out to make sure that the calculated minimum gas pressure of about 104 kPa between case and terminal was correct. No discharge could be detected in the gas line at 83 kPa up to 2.5 MV. After lowering the pressure to 35 kPa a discharge was noticed at 1.25 MV and the line was punctured at 1.5 MV. This confirms the feasibility of operating at the proposed minimum pressure of 172 kPa.

An elevated target facility is being installed for use in experiments requiring minimum back scattering of neutrons. The support structures are fixed in position and two 70 ℓ sec^{-1} turbo-molecular pumps are ready for use. A third such pump will be installed on an existing target station to allow minimum access requirements during long experiments.

3.3.2 Data acquisition facilities (M. D. Scott, R. J. Cawley)

Various modifications have been made to the PDP7-PDP15 link interface to remedy intermittent faults associated with electrical interference and to facilitate servicing of each computer independently of the other.

A multi-way coaxial plug and socket system has been successfully tried within the accelerator control room. This system allows each current user to disconnect other experimenters' equipment without disruption of the latter's cabling arrangement.

3.3.3 Large Ge(Li) detector (M. J. Kenny)

A true coaxial detector with 17 per cent efficiency relative to 7.5 x 7.5 cm NaI at 1.33 MeV has been calibrated for relative peak efficiencies from 0.5 to 11 MeV. A timing resolution of 3 nsec has been obtained with this detector.

3.3.4 (p,γ) analysis (L. H. Russell)

Simultaneous determination of the three stable isotopes of oxygen has been demonstrated using a Ge(Li) detector to observe gamma rays resulting from proton bombardment of thick targets with various isotopic ratios. A thin window target chamber is used to minimise absorption of low energy gamma rays and a survey of spectra for various proton energies up to 2.3 MeV has established suitable operating conditions.

3.3.5 Neutron capture analysis (L. H. Russell, M. D. Scott, R. J. Cawley, in collaboration with James Cook University)

The potential for using thermal neutron capture gamma ray spectra for materials analysis is being investigated using a MOATA beam, Ge(Li) detector and PDP15 on-line computer. Tests aimed at optimising the experimental configuration have been carried out and the results used to test software for data reduction. Published catalogues of gamma ray energies and intensities for all elements have been incorporated in a peak attributor program developed for automatic determination of elements present in a sample.

3.3.6 Prompt nuclear analysis (J. R. Bird, B. L. Campbell*, P. B. Price**)

A review and bibliography of methods for using prompt radiation from nuclear reactions as a tool for materials analysis has been prepared for publication.

4. THEORETICAL PHYSICS SECTION

4.1 Nuclear Data Group

4.1.1 Nuclear parameter library (W. K. Bertram, J. Cook, E. Rose)

Following the successful completion of our fission product cross section library project a need was recognised for a more basic nuclear parameter library. Planning of the library content is under way; it is expected to include beta and gamma decay schemes, spins and energies of nuclear levels, level density parameters, statistical information on neutron reactions and prompt and delayed yields from the fission process. It is envisaged that the final library will contain such information on some 2,000 nuclides.

Ancillary programs are to be adapted to process this information to prepare libraries for use in reactor calculations.

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

A numerical method for computing reaction matrix parameters and Kapur-Peierls parameters from Adler-Adler cross section parameters has been evolved. Unfortunately, only relatively few levels can be treated with this method. Work on calculating Adler-Adler parameters has been completed.

4.1.3 Resonance parameter statistics (W. K. Bertram, J. Cook, E. Rose)

The analysis of the statistics of Adler-Adler resonance parameters has been completed. It was found that such parameters are well represented by

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*Isotopes Division   **University of New South Wales various convolutions of Gaussian distributions. In the next stage of this project, a program similar to GENEX is to be written which should prove to be much faster than GENEX on the IBM360/50 and give a better representation of the effects of level interference.

4.1.4 Photon cross section data (E. Clayton)

A program to generate multigroup data from the point cross section library described in the previous report has been written and tested during the period. Effective absorption cross sections and P_0 to P_3 scattering matrices are generated.

4.1.5 Retrieval of ENDF/B data (H. Ferguson)

Requests for the retrieval and display of data from ENDF/B-III were serviced during the period. The ENDF/B data processor SUPERTOG-II has been used for data preparation on a limited scale, but has proved inadequate for certain materials. Consequently, a request has been made for SUPERTOG-III which, it is anticipated, will overcome most of the objections encountered in SUPERTOG-II.

4.2 Reactor Physics Group

4.2.1 Fast reactor calculations (G. Robinson)

Though no recent microscopic neutron data suitable for fast reactor calculations is currently available, the properties of a range of experimental fast critical assemblies have been calculated in order to

(a) obtain some experience in fast reactor calculations,
(b) establish the AUS modular scheme as a working system,
(c) establish the limitations of the present data and methods, and
(d) build up a set of specifications of critical experiments against which future methods and data can be checked.

The experiments chosen for analysis were a selection of relatively simple systems studied on the ZPR-3 critical facility. Both ^{235}U and ^{239}Pu fuelled assemblies were covered as well as a wide range of dilutents and spectra. All the assemblies were surrounded by a blanket of depleted uranium except for numbers 54 and 59 which had steel and lead reflectors respectively. A summary of the assembly characteristics is given in Table 3 along with the k_{eff} obtained using GYMEA, Hansen and Roach and the 1964 ABBN data sets. The results are also presented graphically in Figure 5 as a function of a spectrum index.

The method used in these calculations consisted of the steps indicated below.

1. A 2 region resonance calculation in GYMEA or POW.
2. A multi-region cell calculation in ICPP.
3. A fundamental model calculation with edit and condensation in EDIT1D.
4. An RZ diffusion calculation in POW.
5. A calculation of the spherical system giving the same k_{eff} as in Step 4 using POW.
6. An S_8 spherical transport calculation in WDSN.
7. An edit of WDSN results using EDIT1D.

Steps 4 and 5 were carried out for one data set only.

The GYMEA data are the most recent; however they give no particular consideration to resonance scatterers such as Fe and Na. Infinite dilution cross sections are used in far too few groups for such a treatment, and this causes the high k_{eff} obtained for the U5/steel core. The Hansen-Roach data give reasonable results for the criticality of these systems, though there is an obvious trend with the degree of moderation of the assembly (Figure 5). These data are very old, adjusted and of limited value for detailed calculations. The ABBN data give consistently high reactivity which is believed to be due mainly to the ^{235}U and ^{239}Pu fission cross section. There also appears to be a large underestimate of captures in stainless steel.

Other parameters for these assemblies being calculated include central fission ratios and central material worths. Detailed consideration is being given to the important assembly number 48 where a vast amount of experimental information is available.

4.2.2 <u>Heterogeneous method</u> (I. Donnelly)

The conventional method of evaluating boundary conditions for the heterogeneous reactor code SOS-1 is to perform a cell calculation and derive the required parameters from this using neutron conservation relations. This is adequate as long as the derived boundary conditions are not sensitive to the flux environment of the cell.

A method of evaluating boundary conditions which are independent of flux environment is now sketched for the simple case of a homogeneous channel satisfying diffusion theory in G groups. Using matrix notation the multigroup diffusion equation in the channel is

$$- \underline{\underline{D}}\nabla^2\underline{\phi} + \underline{\underline{\Sigma}}\,\underline{\phi} = \underline{0} \quad . \qquad \ldots(1)$$

A pseudo flux $\underline{Q}$ can be defined such that

$$\underline{Q} = \underline{\underline{C}}\,\underline{\phi} \quad , \qquad \ldots(2)$$

$$\nabla^2\underline{Q} = \underline{\underline{K}}^2\underline{Q} \qquad \ldots(3)$$

and $\underline{\underline{K}}^2$ is a diagonal matrix.

Using the solutions of (3) a relationship of the form

$$\nabla Q_g(r) = \alpha_g(r)\, Q_g(r) \quad , \qquad \ldots(4)$$

where $\alpha_g(r)$ is a known function of r, can be established for each component of $\underline{Q}$. Using (2) to replace $\underline{Q}$ by $\underline{\phi}$ and taking $r = \rho$, the channel radius, leads to the relationship

$$\nabla\underline{\phi}(\rho) = \underline{\underline{\Upsilon}}\,\underline{\phi}\,(\rho) \quad . \qquad \ldots(5)$$

The components of the matrix $\underline{\underline{\Upsilon}}$ are the desired boundary conditions.

An evaluation of the components of the $\underline{\underline{\Upsilon}}$ matrix which follows the analytical derivation given above, runs into difficulties because

(i) complex values of the eigenvalue elements of the matrix $\underline{\underline{K}}^2$ arise in multigroup problems, and

(ii) numerical errors can occur due to the inversion of ill-conditioned matrices.

As an alternative, the Lie series method is being used to obtain analytic solutions to the diffusion equation and hence evaluate the $\underline{\Upsilon}$ matrix.

4.2.3 Accident studies (B. Clancy)

A pilot program has been written to study design brief accidents for the Critical Facility. Power variations are studied by a one energy group point reactor kinetics model with Doppler and expansion feedback determined from temperature distributions calculated from a one dimensional plane geometry heat transfer subroutine. The feedback is then coupled into the kinetics calculation as the assumed excursion proceeds. The code, written for the IBM360/50 has been structured to make modifications to the assumed models a relatively simple task.

4.3 Reactor Code Group

4.3.1 The AUS modular scheme (G. Doherty, B. Harrington, J. Pollard, G. Robinson)

The AUS modular scheme consists of a suite of 'modules' (codes) communicating with each other via disk 'data pools' (cross section, geometry and flux libraries). At present the scheme is orientated to 0, 1 and 2-dimensional neutronics calculations and over the period has been extensively tested with calculations on fast critical experiments (section 4.2.1).

The currently available modules are:

- AUSYS for system control
- GYMEA for OD diffusion, resonance theory, burnup calculations
- WDSN for ID S_n transport theory calculations
- ICPP for ID collision probability transport theory calculations
- EDITID for edit of ID modules
- POW the 'workhorse' module - for data preparation (including 2 region resonance theory), editing (including perturbation theory) and 0, 1 and 2D diffusion steady state and kinetics calculations
- Utilities for data management of the scheme

The currently available libraries are:

- 127 group GYMEA library (including resonance parameters)
- 16 group Hansen-Roach library (including resonance shielding tabulation at 300K)

At present the scheme does not include a 2000 group fast spectrum module although the need for the module is apparent from some of the results of fast reactor calculations (section 4.2.1).

4.3.2 AUS module POW (B. Harrington and J. Pollard)

POW is a 0, 1 and 2D diffusion module of the AUS scheme (as well as an independent code). Features of the module include:

(a) Data preparation

- 2 region resonance theory for σ_p and temperature interpolation in tables of AUS libraries
- General mixing of materials

(b) Neutronics calculation (both steady state and kinetics)

- SLOR inner iteration, group and region rebalance and Chebyshev source extrapolation for edge based fluxes.
- Criticality searches on mixtures, mesh spacing or control rod positioning
- Source calculations

(c) Edit facilities

- Editing of all reactions by regions
- Point editing of selected reactions including 1 and 2D plots
- Perturbation options

Except for the kinetics option the module has been extensively tested against other available codes (CRAM and GOG). Accuracy and speed of the module compared with other 2D codes is more than favourable. Some difficult problems in the literature (regions of massive voids, reactor representations with dominance ratio of fission source eigenvalues close to unity, as well as others) have been successfully tackled.

Presently the kinetic option is for a specified reactivity and/or source pulse as a function of time and feedback effects are ignored.

4.3.3 AUS modules ICPP and EDIT1D (G. Doherty)

The ICPP module of AUS provides a collision probability alternative to the S_n module WDSN for transport calculations. It is intended that ICPP will be used for calculations in slab geometry and for few region, many group calculations of the condensing type while WDSN will be used for few group, many region calculations in cylindrical and spherical geometry.

The module EDIT1D reads the flux data set produced by either ICPP or WDSN and performs reaction rate editing and group collapsing functions. Benoist diffusion coefficients and homogeneous buckling searches are included.

4.4 Nuclear Physics Group

4.4.1 Unfolding of resolution functions from experimental data (D. Lang)

As part of a study of resolution functions, a gedanken experiment was set up on the IBM 360. A data set typical of a nuclear (or optical) experiment with a known resolution function was first created and then analysed. The data set was created in three stages. First a spectrum was produced consisting of three resonances of varying strengths and widths superimposed on and interfering with a background increasing with energy. The signal was processed as if it were analysed by an energy spectroscope with resolution governed by a single broad slit and the signal fed to a multichannel analyser. The noise signal corresponding to a uniform scattered background plus statistics on the actual signal was added.

Analysis programs were tested using the inverse of the resolution matrix and with modifications that impose a requirement of smoothness on the spectrum. It was shown that all such treatments shared the defects caused by a failure to concentrate on making the best use of the information available. A program was written using an iterative procedure where at each iteration the modification to the spectrum is made in the direction of maximum likelihood. The results were almost immediately adequate for the given data set.

Attention was then turned to more difficult data sets. A standard test involved a twenty by twenty Hilbert matrix. An inversion based on ordinary computer techniques would require carrying twenty-two significant figures to obtain one significant figure in the answer. By use of a least squares technique and a demand that the solution be positive throughout, three significant figures were obtained with single precision arithmetic on the IBM360.

The same technique was used to recover results from a situation corresponding to a resolution function that is a generalisation of the Hilbert operator. In this case, the result was equivalent to using the requirement of a positive spectrum to obtain an effective inverse of a rectangular matrix. Obviously, the procedure is extremely powerful provided that it is handled with caution.

4.4.2 Applications of unfolding techniques (E. Clayton, H. Ferguson, D. Lang, A. Musgrove)

(a) Fast neutron spectra by proton recoil.

A study is in progress of the computer techniques that have been used in other laboratories. Alternative programs making use of the technique developed here are being prepared.

(b) Fast neutron spectra by time of flight.

Computer programs for unfolding time of flight neutron spectra are being prepared.

(c) Fast neutron spectra by activation:

An unfolding program is in the process of testing.

(d) (n,γ) spectra on barium:

A program has been written to unfold resolution functions from (n,γ) spectra on the barium isotopes. Some snags have appeared and the program is being modified.

4.4.3 Errors in unfolded spectra (D. Lang)

A study of the variance of spectra obtained by the local computer method is in progress. Progress to date has included clarification of the questions raised and tentative answers are emerging.

5. PUBLICATIONS

5.1 Papers

Bertram, W. K. and Cook, J. L. (1972) - On the non-invariance of distributions of reaction matrix parameters under changes in boundary conditions. Aust. J. Phys. 25, 349.

Cook, J. L. (1972) - Solutions of the relativistic two-body problem. I Classical mechanics. Aust. J. Phys. 25, 117.

Cook, J. L. (1972) - Solutions of the relativistic two-body problem. II Quantum mechanics. Aust. J. Phys. 25, 141.

Cook, J. L. (1972) - A note on the Adler-Adler resonance formalism. Aust. J. Phys. 25, 247.

Cook, J. L. (1972) - Reaction matrix approach to the inverse problem. Aust. J. Phys. 25, 167.

5.2 Reports

Moo, S. P., Rainbow, M. T. and Ritchie, A. I. M. (1972) - Application of the pulsed neutron technique to fast metal systems. AAEC/TM613.

5.3 Conference Papers

Conference on Nuclear Structure Study with Neutrons, Hungary, August 1972:

Kenny, M. J., Martin, P. W. and Bird, J. R. - Gamma ray transitions from keV capture in nickel.

Bird, J. R., Pattenden, N. J. and Kenny, M. J. - keV neutron capture near A=100.

5.3 Conference Papers (cont'd)

1972 Decus-Australia Symposium (held at Sydney):

Scott, M. P. - AAEC neutron physics data collection hardware - the PDP22.

Cawley, R. J. - Neutron physics data collection software.

6. RESEARCH CONTRACTS

6.1 Title: Study of Single Particle Wave Functions
Reference No: 70/E/1
Period: 1/4/72-21/4/72
Supervisor: Professor I. E. McCarthy
University: School of Physical Sciences, Flinders University
Liaison Officer: D. W. Lang

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: Work on the potential used to describe single particle wave functions has reached a satisfactory stage. The emphasis is now changed to the use of optical model computer codes. A new contract is under consideration reflecting the change.

6.2 Title: Development of Nuclear Analysis Methods for Light Elements
Reference No: 70/D/32
Period: 1/10/71-31/9/72
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: Work on deuterium analysis has continued using a 6 MeV medical electron linac having much better dosimetry systems than were previously used. This has made the previous intercomparison technique unnecessary and results with good repeatability have been obtained. However, the results are about 10 per cent higher than they should be and investigations of effects which might explain this discrepancy are continuing.

6.3 Title: Possible Technique for Identifying Energy Levels of Short Lived Fission Fragments

Reference No: 71/D/32

Period: 1/9/71-31/8/72

Supervisor: Dr. G. J. F. Legge

University: School of Physics, University of Melbourne

Liaison Officer: M. J. Kenny

Objective: To measure accurately the total neutron cross section of zirconium as a function of neutron energy below 5.1 and 6.6 MeV. The measurements are to be made using the absorption technique and to a relative accuracy such that fluctuations of one per cent or greater can be seen in the cross section as a function of energy. The data is to be used to show whether analogues of low lying states in ^{91}Y are seen as fluctuations in the total cross section.

Status: The measurements have been completed and there is evidence that five or six analogue states of ^{91}Y have been observed in the expected places. Whilst the technique appears to have been successful more detailed analysis and assessment is required to decide whether subsequent measurements should be performed with a mono-energetic or a white neutron source.

TABLE 1

COMPARISON OF DELAYED NEUTRON AND CHEMICAL ANALYSES OF SOME URANIUM ORE SAMPLES

Ore	Delayed neutron measurement (wt % U)	Chemistry measurement (wt % U)
A	0.262 ± 0.006	0.254
B	0.348 ± 0.007	0.355
C	0.0101 ± 0.0009	0.0102
D	0.118 ± 0.003	0.114
E	0.620 ± 0.009	0.621
F	0.249 ± 0.005	0.268

TABLE 2
ACCELERATOR TIME ALLOCATION

Topic	Expt. NO.	Title	Personnel	Origin	Running time (hours)
Fission	11	Nubar ^{235}U	Boldeman, Walsh	Physics	11
	61	Nubar ^{252}Cf	Boldeman, Walsh	Physics	323
	51	Angular distribution	Caruana	Wollongong	210
Capture	57	keV spectra	Kenny	Physics	694
Transport	55	Thorium assemblies	Rainbow, Ritchie, Moo	Physics Tasmania	535
	65	Source spectra	Whittlestone	Physics	165
	75		Whittlestone	Physics	12
Radiation Damage	16	Crystals	Anderson	UNSW	25
Nuclear Analysis	48	Oxygen isotopes	Russell Murch	Physics Flinders	22
	68	^{19}F	Russell	Physics	13
Dosimetry	23	Proton recoil	Cripps	Health Physics	28
Atomic Physics	44	Channelling	Price	UNSW	241
Charged Particle	59	(p,γ) reactions	Lasich	Queensland	13
	69	(p,γ) reactions	Boydell	Melbourne	134
	70	(d,n) reactions	Armitage	Melbourne	225
	79	(p,γ) reactions	Sargood	Melbourne	98

Tests: 84 hours
Total Operating Time: 2904 hours
Maintenance: 851 hours

TABLE 3

CRITICALITY RESULTS FOR ZPR-3 ASSEMBLIES

Experiment No.	Composition by Atom Ratio	Critical mass kg of U5 or Pu9	k_{eff}		
			GYMEA	H-R	ABBN
11	U5/U8/SS = 1/7.5/1.7	237.4	0.9825	0.9814	1.0112
12	U5/U8/C/SS = 1/3.8/5.9/1.7	174.9	0.9962	0.9995	1.0230
14	U5/C/SS = 1/11.9/1.7	134.8	1.0173	1.0116	1.0145
23	U5/Al/SS = 1/5.8/1.8	255.9	1.0155	0.9938	1.0238
29	U5/U8/Al/O/SS = 1/2/6.2/5.8/8.8	417.5	1.0060	1.0032	1.0409
32	U5/SS = 1/15.6	224.3	1.0477	0.9907	1.0329
33	U5/Na/SS = 1/0.9/12	234.8		0.9947	1.0345
34	U5/U8/C/Al/SS = 1/2.2/3.4/6.8/9.4	496.6		0.9968	1.0346
36	U5/U8/Na/SS = 1/5.3/0.9/2.4	239.5		0.9858	1.0190
48	Pu/U8/C/Na/SS = 1/4.2/11.8/3.5/7.8	270.9		1.0014	1.044
49	Pu/U8/C/SS = 1/4.2/11.8/7.8	293.5		1.0018	
50	Pu/U8/C/SS = 1/4.2/26.1/5.6	223.7		1.0158	
53	Pu/U8/C/SS = 1/1.5/31.3/5.7	148.3		1.0196	
54	Pu/U8/C/SS = 1/1.5/31.3/5.7	129.5		1.0445	
58	Pu/C/SS = 1/26.8/4.8	101.6		1.0221	
59	Pu/C/SS = 1/26.8/4.8	75.9		1.0481	

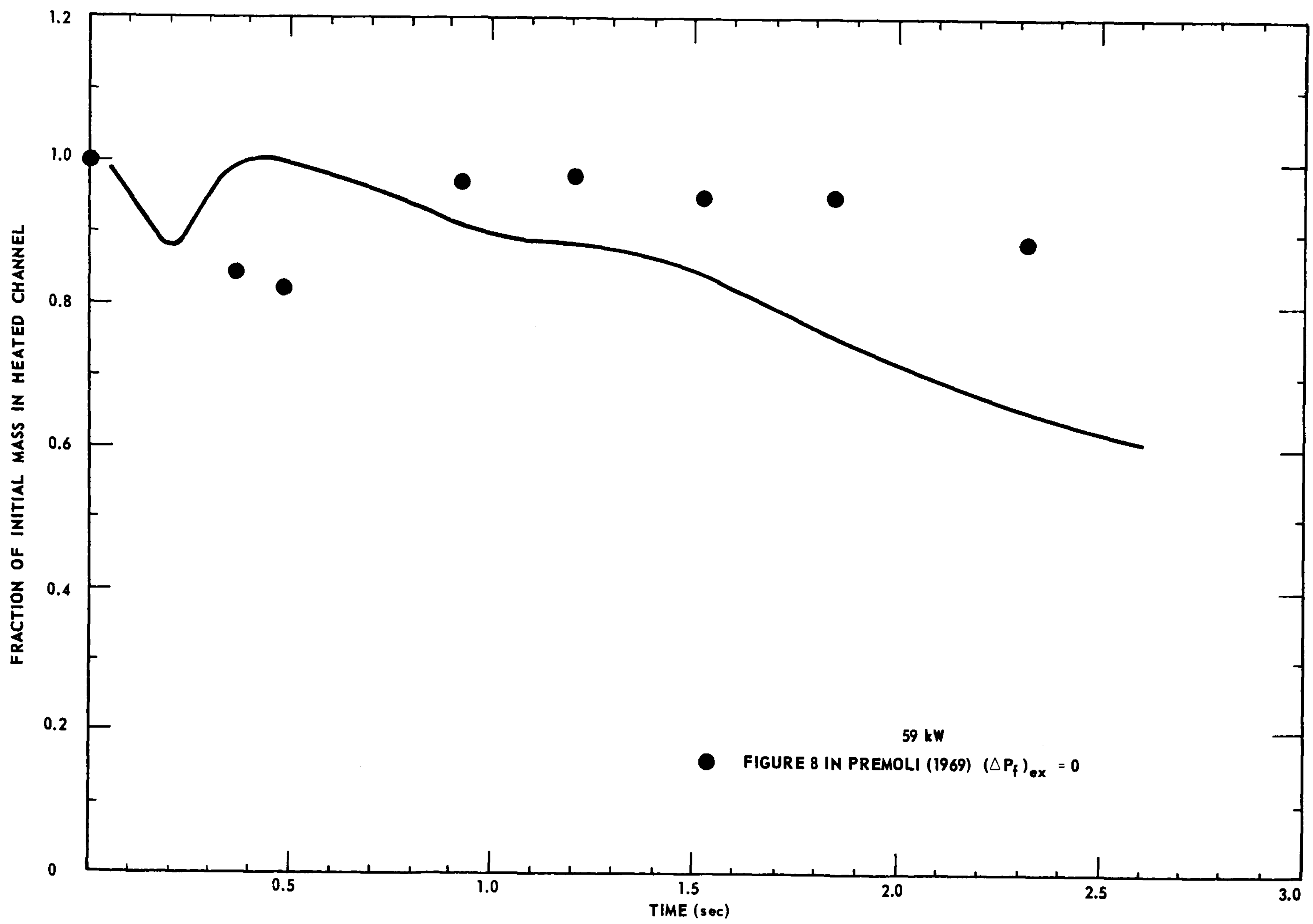

FIGURE 1. BLOWDOWN AT RISER OUTLET WITH CONSTANT FLOW AT FEEDER INLET

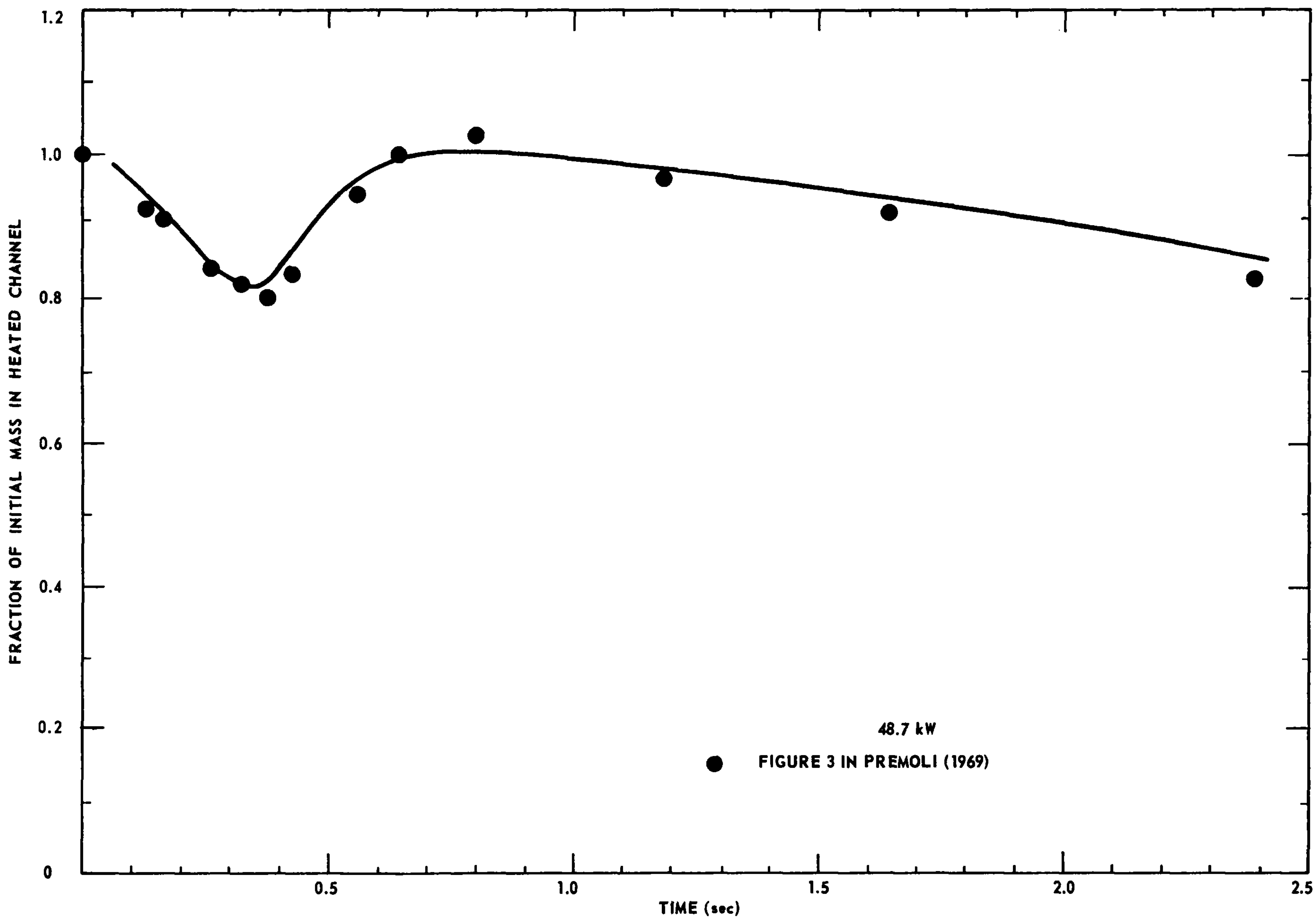

FIGURE 2. BLOWDOWN AT RISER OUTLET WITH CONSTANT FLOW AT PUMP

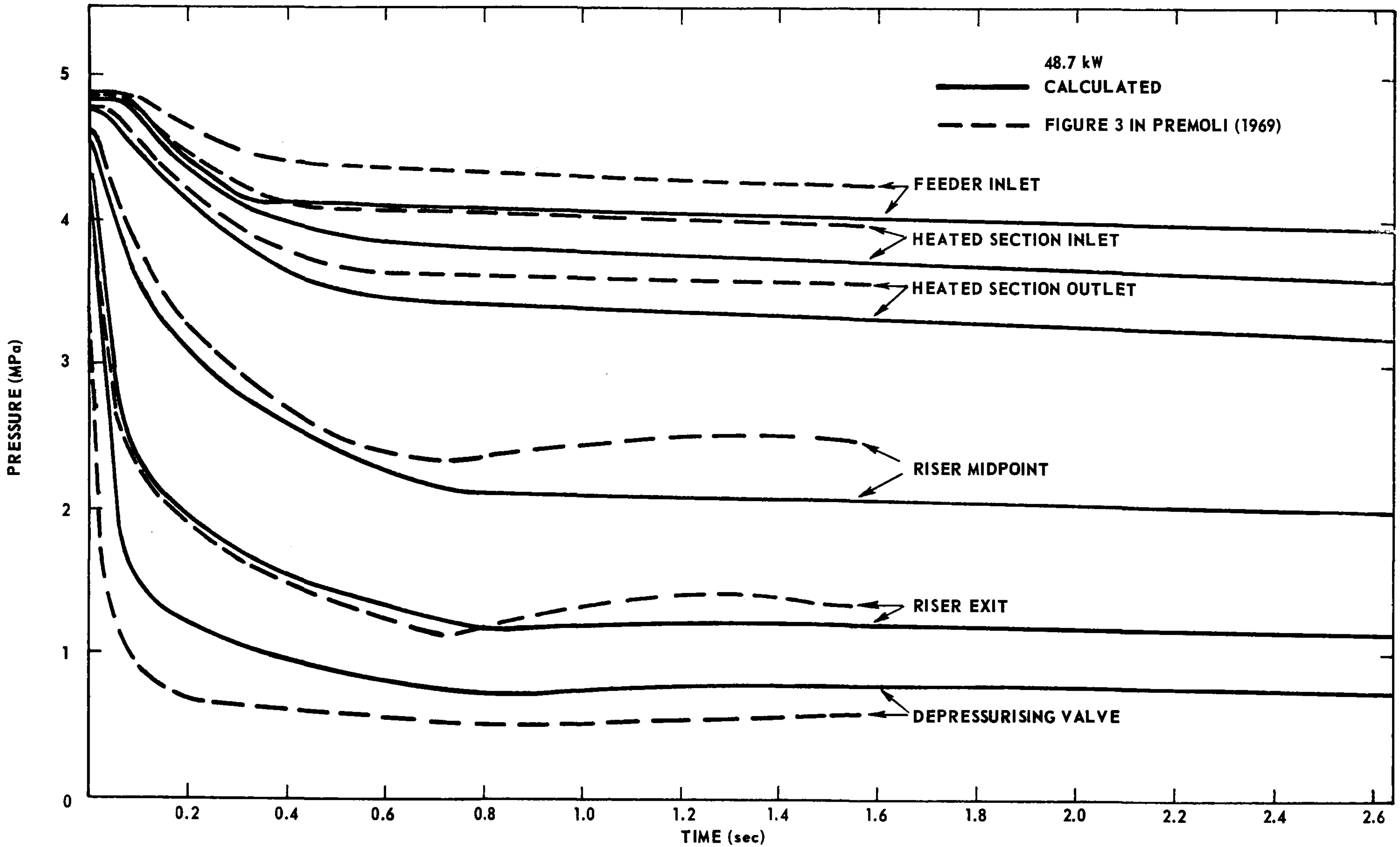

FIGURE 3. PRESSURES DURING BLOWDOWN AT RISER OUTLET WITH CONSTANT FLOW AT PUMP

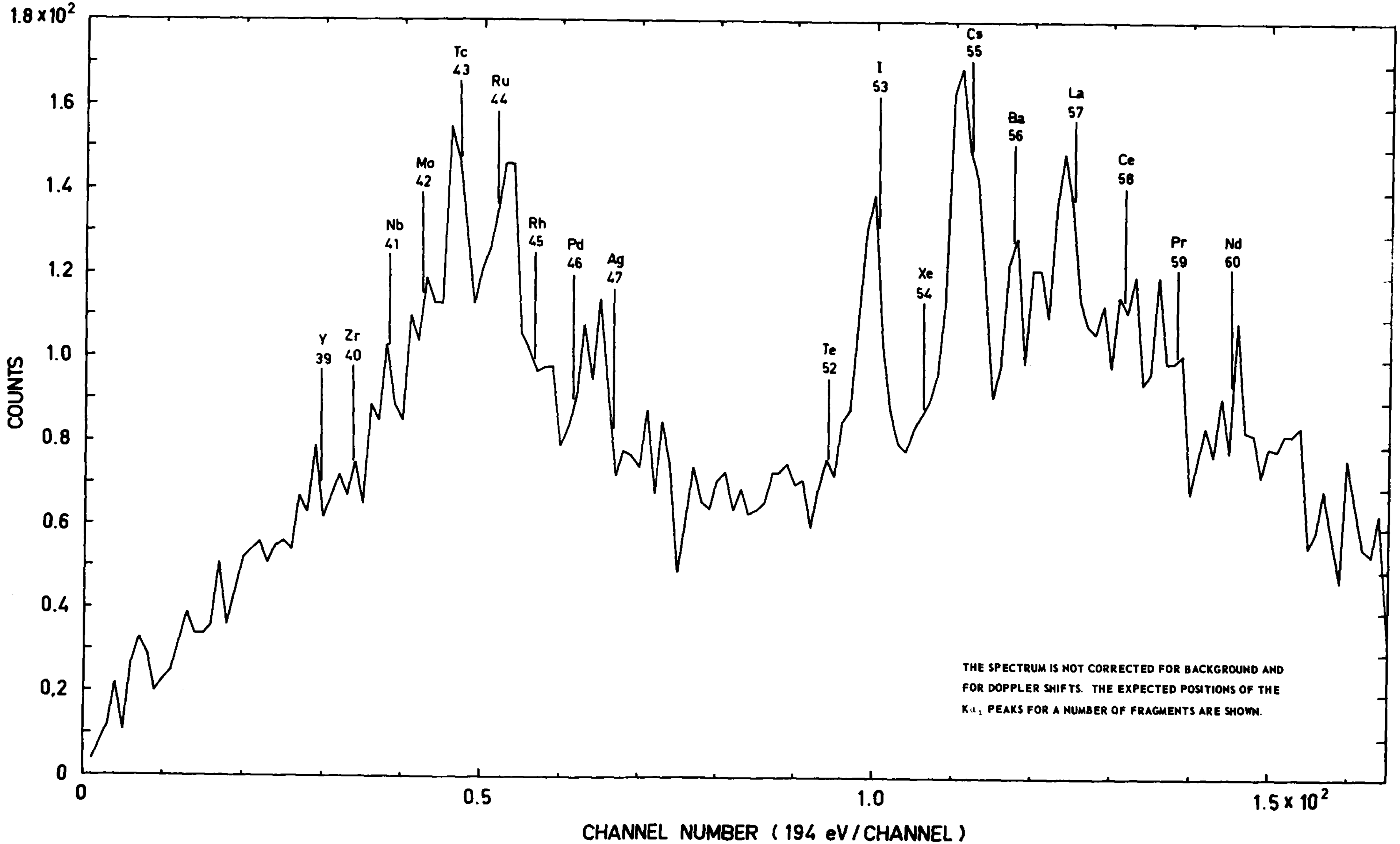

FIGURE 4. OBSERVED ENERGY SPECTRUM OF K X-RAYS FROM ^{252}Cf FISSION FRAGMENTS

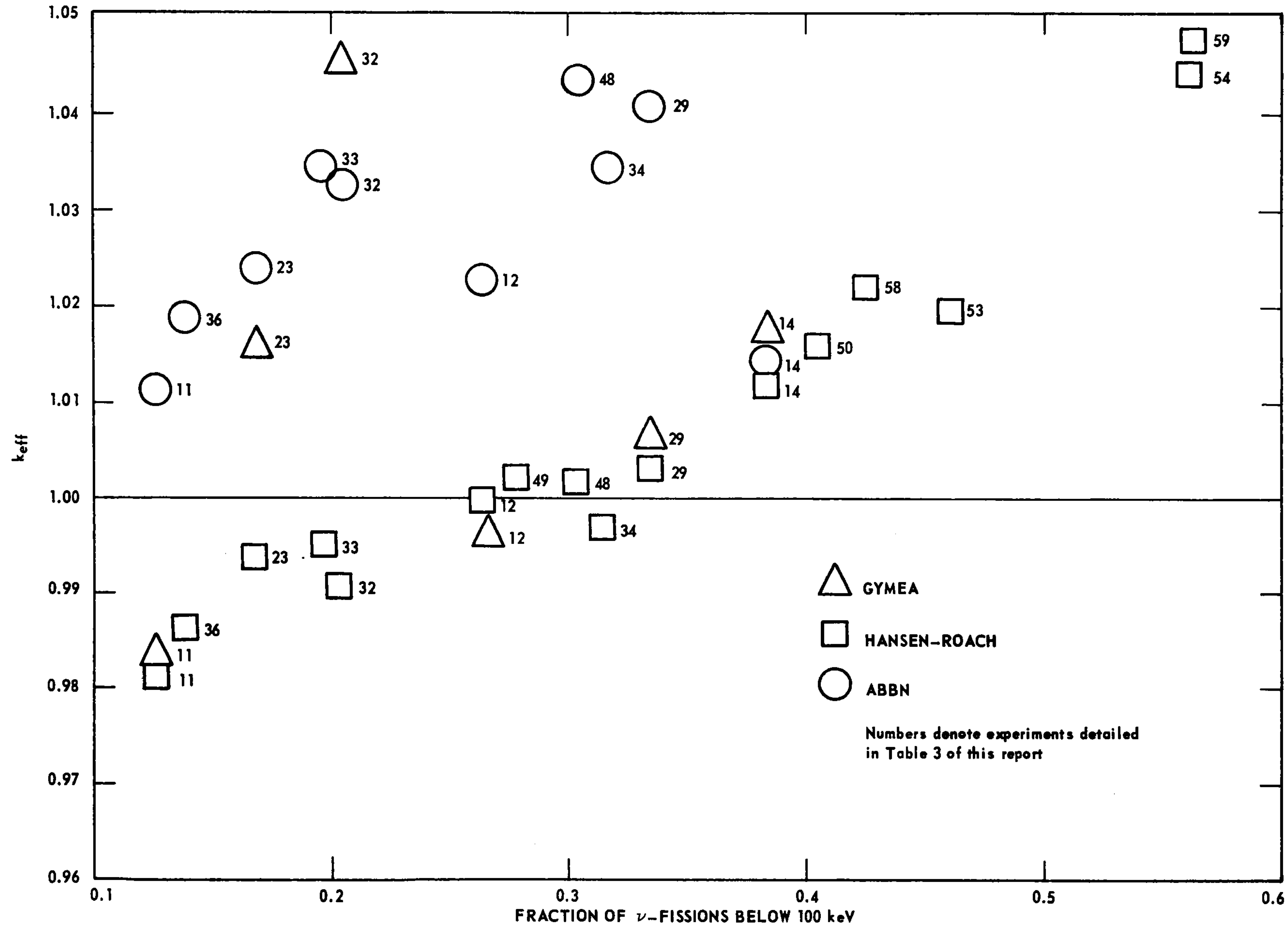

FIGURE 5. k_{eff} FOR ZPR-3 ASSEMBLIES

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