INITIAL DEVELOPMENT OF A BENJAMIN-TYPE NEUTRON SPECTROMETER SYSTEM

by

C. MICHAEL ESTES

B. S., Kansas State University, 1970

5274

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Nuclear Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

Approved by

Walter Meyer
Major Professor

THIS BOOK CONTAINS NUMEROUS PAGES WITH THE ORIGINAL PRINTING BEING SKEWED DIFFERENTLY FROM THE TOP OF THE PAGE TO THE BOTTOM.

THIS IS AS RECEIVED FROM THE CUSTOMER.

LD
2668
T4
1971
E8
C.2

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 THE BENJAMIN-TYPE NEUTRON PROPORTIONAL COUNTER AND LINEAR PULSE-SHAPING SYSTEM 3

2.1 The Benjamin Proportional Counter 3

2.2 Biasing of the Detector 3

2.3 The Charge-Sensitive Preamplifier 7

2.4 Linear Pulse-Shaping Considerations 10

3.0 DEVELOPMENT OF A GAMMA-RAY PULSE SHAPE DISCRIMINATION SYSTEM 19

3.1 Pulse Shape Differences 19

3.2 Pulse Shape Discrimination Methods 20

4.0 UNFOLDING OF COMPLEX NEUTRON-PROTON RECOIL SPECTRUMS 28

4.1 Development of the Unfolding Procedure 28

4.2 Verification of SPEC 4 32

5.0 MEASUREMENT OF COMPLEX NEUTRON SPECTRUMS FOR CALIBRATION 44

5.1 Calibration of the Benjamin-Type Neutron Spectrometer System by Neutron Penetration Studies 44

5.2 Measurement of a Californium-252 Neutron Spectrum 54

6.0 DISCUSSION OF RESULTS AND CONCLUSIONS 57

7.0 SUGGESTIONS FOR FUTURE STUDY 63

8.0 ACKNOWLEDGEMENTS 65

9.0 REFERENCES 66

10.0 APPENDICES 68

APPENDIX A: Unfolding Code, SPEC 4 69

A-1.0: Operation of SPEC 4 69

A-1.1: Input Data Format for SPEC 4 73

A-1.2: Listing of SPEC 4 75

APPENDIX A (cont'd)

A-2.0: Calling Sequence SNIDOW 83

A-2.1: Listing of SNIDOW 84

A-3.0: Calling Sequence SPEC 2S 88

A-3.1: Listing SPEC 2S 89

A-4.0: Calling Sequence VSMTH 92

A-4.1: Listing VSMTH 93

A-5.0: Calling Sequence CONTIN 95

A-5.1: Listing CONTIN 96

APPENDIX B: Typical Output of SPEC 4 98

APPENDIX C: Measured Raw Pulse Height Spectra 113

LIST OF FIGURES

1. Cross Section of a Benjamin-Type Detector 4
2. Biasing Configuration for the KSU Benjamin-Type Detectors 6
3. A Basic Charge-Sensitive Preamplifier 8
4. Schematic of the KSU Larson Preamplifier 12
5. Linear Pulse Shaping System 13
6. Photographs of Linear Pulse Shapes 14
7. 10 Atmosphere Calibration Source Spectrum 15
8. 4 Atmosphere Calibration Source Spectrum 16
9. 1 Atmosphere Calibration Source Spectrum 17
10. Comparison of Neutron Induced and Gamma-Ray Induced Pulses 22
11. Pulse Shape Discrimination System (PSD) 23
12. Sketches of PSD Pulses 24
13. Photographs of PSD Pulses 25
14. Photographs of PSD Pulses 26
15. Result of Gamma-Ray Discrimination on a Californium-252 Recoil Proton Spectrum 27
16. Artificially Generated Monoenergetic Neutron-Proton Recoil Distributions 35
17. Unfolded Monoenergetic Response Functions for the 10 Atmosphere Detector at 2% Resolution 36
18. Unfolded Monoenergetic Response Functions for the 10 Atmosphere Detector at 6% Resolution 37
19. Unfolded Monoenergetic Response Functions for the 10 Atmosphere Detector at 10% Resolution 38
20. Unfolded Monoenergetic Response Functions for the 1 Atmosphere Detector at 2% Resolution 39
21. Unfolded Monoenergetic Response Functions for the 1 Atmosphere Detector at 6% Resolution 40

22. Unfolded Monoenergetic Response Functions foor the 1 Atmosphere Detector at 10% Resolution 41-42

23. Consecutive Unfolding for the Three Detectors 43

24. Unfolded Recoil Proton Distributions from SNIDOW 46

25. Experimental Arrangement for Measuring Transmitted Neutron Spectrums 47

26. Unshifted Iron Penetration Spectrum 48

27. Unshifted Aluminum Penetration Spectrum 49

28. Comparison of the Shifted Iron Penetration Spectrum with Results by Cerbone 50

29. Shifted Aluminum Penetration Spectrum 51

30. Comparison of Calculated and Measured Penetration Spectrum Through Aluminum 52

31. Unfolding with Different Resolutions for the 10 Atmosphere Detector 55

32. Calculated and Measured Californium-252 Neutron Spectrum 56

33. Comparison of Calculated and Measured Penetration Spectrums with Different Resolutions 60

34. Estimated Resolution Function of the 10 Atmosphere Benjamin Detector 61

NOMENCLATURE

a	Radius of detector
A	Atomic mass
C_T	Total number of recoil protons
$C(E)dE$	Number of protons which will deposit an energy between E and E + dE in the detector
d	Deuteron
$DM^i = \frac{\partial M^i}{\partial E_p}$	Differential of the number of recoil protons in the ith group
$DM_o^{i,j} = \frac{\partial M_o^{i,j}}{\partial E_p}$	Differential of the number of recoil protons in the ith group resulting from monoenergetic neutrons in the jth group
E	Energy in MeV
E_{max}	Maximum energy to be analyzed
E_n	Neutron energy
E_p	Proton energy
$F(E)dE$	Fraction of neutrons with energy between E and E + dE that will stop in the detector
$M_o(E_p,E_n)$	Monoenergetic recoil proton distribution
$M^*(E_p)$	Complex recoil proton spectrum
M^i	Number of recoil protons in the ith group
$M^{i,j}$	Number of recoil protons in the ith group resulting from neutrons in the jth group
$M_o^{i,j}$	Monoenergetic response functions of protons in the ith group resulting from neutrons in the jth group
$n = {}_o^1n$	Neutron
N_p	Number of protons per unit volume
$N(L)dL$	Probability that a proton will see a path length to the counter wall between L and L + dL

$p = {}^{1}_{1}H$	Proton
PSD	Pulse shape discrimination
$P(E_p)dE_p$	Probability of neutron scattering in a energy range between E_p and $E_p + dE_p$
R	Range in mg/cm^2
R(E)	Range of a proton with energy E
R(E,E')	Probability of a neutron of energy E' being detected at energy E
t	Triton
$U(E_n-E_p)$	Unit step function
V	Volume of detector
α	Alpha particles
$\alpha(E_n)$	Slope of a monoenergetic response function
γ	Gamma rays
Φ	Monoenergetic neutron flux
ϕ^j	Unfolded neutron spectrum for the jth group
$\phi_{trans}(E)$	Transmitted spectrum through a material
$\phi_I(E')$	Incident flux at E'
$\phi(E_n)$	Complex neutron flux
$\Sigma_t(E')$	Total neutron cross-section at E'
$\sigma_s(E_n)$	Total scattering cross section

1.0 INTRODUCTION

The measurement of fast neutron spectrums is very important in the study of nuclear reactions, neutron yields, cross sections and transport and scattering phenomena. The detection of neutrons may be realized through the following processes:

1. Neutron-induced transmutations in which the product particles are detected. This includes simple capture (n,γ), ejection of charged particles (n,d), (n,α), and (n,p) reactions, and high energy processes (neutrons around 100 MeV).
2. Neutron-induced transmutations which result in radioactive nuclei. The decay products are then detected by conventional techniques.
3. Elastic scattering of neutrons in which the charged recoil particles are detected. The most important elastic scattering process is the proton-recoil resulting from collision of a neutron and a hydrogen atom.

Of these three, the last is important for energy dependent measurements since from 0% to 100% of the neutron energy may be imparted to the recoil proton. Also, the $^{1}_{1}H(n,n)$ cross section is a smoothly varying function of energy and approaches a constant value of about 20 barns at low energies (less than 100 keV).

At KSU a neutron scintillation spectrometer system employing the proton-recoil principle was designed and put in operation by Simons[1]. This system (the KSU NE-213 Neutron Spectrometer System) has performed well[2] for relatively high (1.0 to 15 Mev) neutron energies but is incapable of analyzing neutron spectrums below 1.0 MeV. To extend the range of neutron measurements at KSU,

an effort[3] was initiated to identify a neutron detector responding to neutrons of energies from 1.0 MeV down to about 1.0 keV.

This study showed that two different detectors may satisfy the energy range requirements. The first was a cylindrical hydrogen gas-filled proportional detector designed by E. F. Bennett[9], and the second was a spherical hydrogen gas-filled proportional counter designed by P. W. Benjamin[4]. The latter was chosen for this study because spherical detectors are known to be omnidirectional and the electrostatic field distortions at the ends of this type detector are inconsequential in contrast to those of the cylindrical type[4].

The study presented here primarily involved bringing a Benjamin detector system to an operational status. As such, it was concerned with the assembly of electronics for shaping of pulses from a Benjamin-type detector, the design and implementation of a gamma-ray discrimination circuit, and the energy calibration of the system.

2.0 THE BENJAMIN-TYPE NEUTRON PROPORTIONAL COUNTER AND LINEAR PULSE SHAPING SYSTEM

2.1 The Benjamin Proportional Counter

Three Benjamin-type proportional counters, developed at Aldermaston, Berkshire, England, by Benjamin, Kemshall, and Redfearn[4] were purchased from Twentieth Century Electronics, Limited. These detectors consist of a spherical active volume of radius 20 mm with a 22 micron tungsten anode through the center of the sphere. This wire is coated with approximately 45.5 pico curies of ^{239}Pu. This internal source produces approximately 2 counts/sec of 5.15 MeV alpha particles which are used for energy calibration. Only a portion of the energy of the alpha particle is absorbed in the filling gas, depending on the gas pressure. The filling gas is pure hydrogen at pressures of 10, 4 and 1 atmospheres for the three detectors. The walls of the spheres are stainless steel, 0.020 in. thick. The glass-to-metal insulators and supports for the anode wire were carefully designed to obtain a constant electrostatic field along the length of the anode wire. End effects or distortions in the electrostatic field at the extremities of the anode are therefore minimized. Figure 1 shows a typical cross section drawing of the Benjamin detector used in this study.

2.2 Biasing of the Detector

Much time was spent in selecting a method of biasing the detector to minimize noise and high voltage breakdown. It was decided at the beginning of this study to apply a negative high voltage to the case of the detector (cathode) instead of a positive high voltage to the center anode wire. This procedure was expected to increase the life of the transistors in the charge-sensitive preamplifier, in particular the input field-effect transistor.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

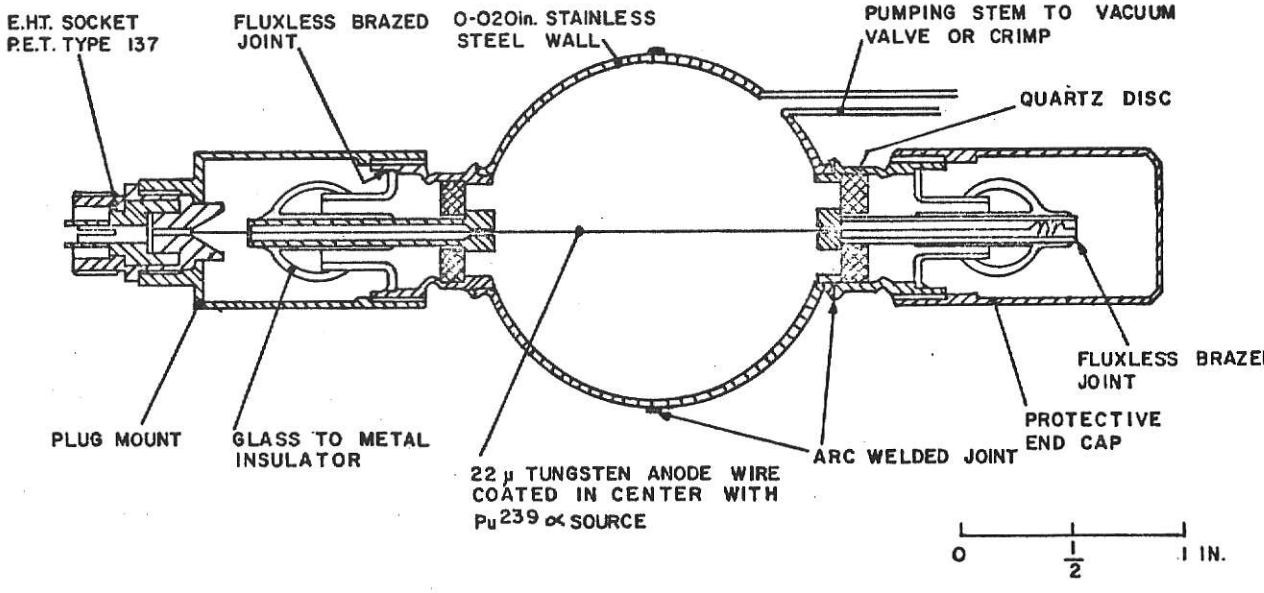
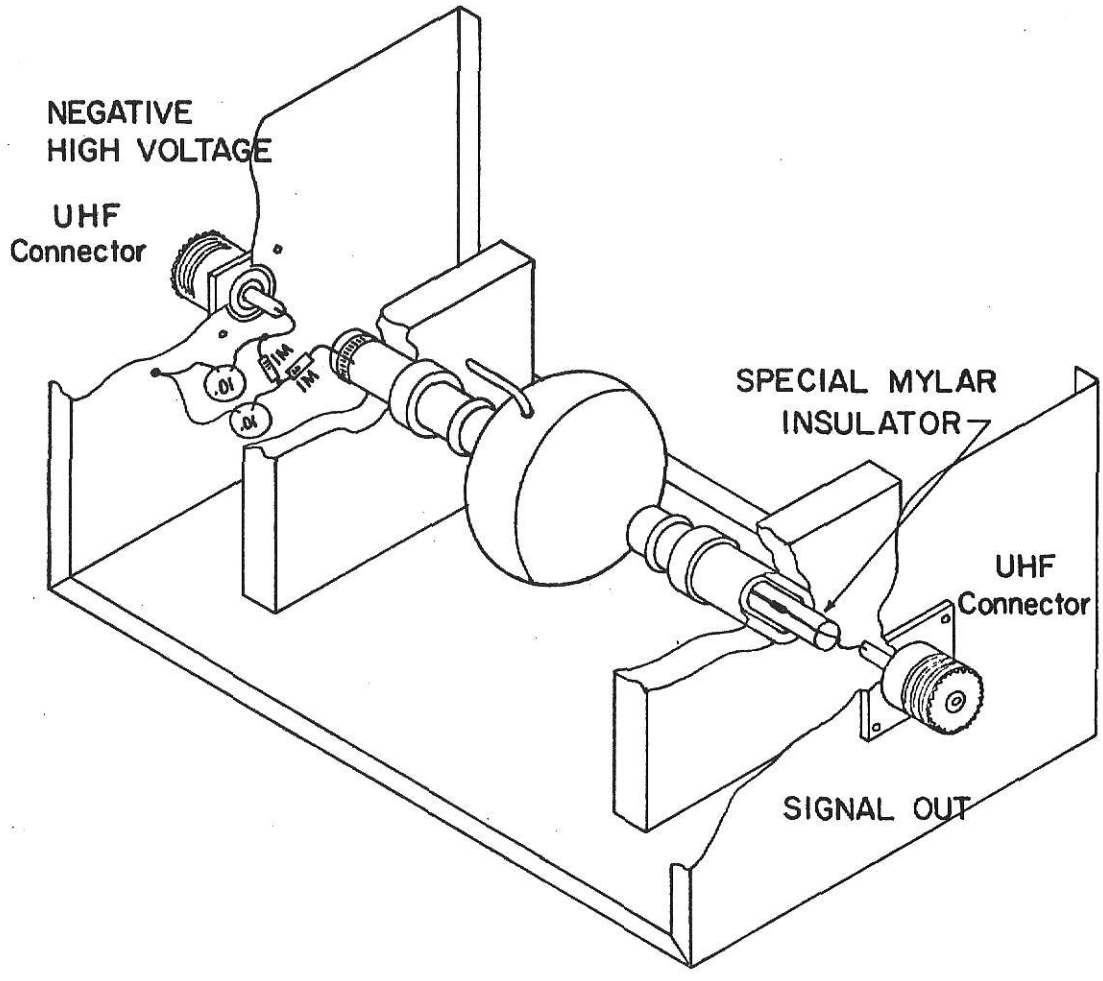


FIGURE 1. CROSS SECTION OF A BENJAMIN-TYPE DETECTOR

Figure 2 is a schematic diagram of a biasing design that provided the lowest noise levels and the least number of breakdown pulses of the several designs tested. High voltage was supplied from a John Fluke Power Supply Model 400BDA through two RC filters to the end of the detector opposite where the anode detector signal was taken. A special mylar insulator was fabricated in our shops to isolate the center of the E.H.T. socket from the detector body. Prior to fabricating this insulator this socket appeared to be a major source of high voltage breakdown for the 10 atmosphere detector operating at up to -4600 V. The detector and RC filter assembly was inserted in a metal box to eliminate noise pickup. After the detector and high voltage circuit were placed in this shielding box, the noise level (mostly 60 Hz) was lowered from approximately 2.5 V to approximately 1 mV.



NOT TO SCALE

FIGURE 2. BIASING CONFIGURATION FOR THE KSU BENJAMIN-TYPE DETECTORS

2.3 The Charge-Sensitive Preamplifier

An important factor affecting the signal quality of a gas counter is the degree of charge collection, the use of a charge-sensitive preamplifier will insure the consistency of output pulses with variations in circuit capacitances. Figure 3 shows a basic charge-sensitive preamplifier where

$$V_o = -\frac{1}{C_f}\int i\,dt = -\frac{q}{C_f} \qquad (1)$$

It should be noted that this circuit needs an extremely high input impedance, (i.e. if $C_f R_f = 10^{-4}$, with $C_f = 10^{-12}$ F, then $R_f = 10^8 \Omega$) and therefore field-effect transistors are used at the input.

A solid-state charge-sensitive preamplifier for use with proportional counters has been designed by J. M. Larson of Argonne National Laboratory[5]. It has a charge gain of 2×10^{12} V/C, a 10 pF external input capacity and a 20 V peak output swing to allow high count rate capability with no preamplifier saturation.

This preamplifier is especially suited to a mode of operation where the detector bias voltage is applied to the cathode from a negative supply as opposed to the usual mode of operation where the cathode is grounded. With the bias voltage applied to the cathode, the preamplifier may be direct-coupled to the proportional counter anode.

Direct coupling results in the following advantages:

1. Removal of an isolation resistor at the anode and thus an elimination of a noise source.
2. Removal of a coupling capacitor between the anode and the preamplifier with improvement of the signal-to-noise ratio.
3. Protection of the preamplifier's input FET against transients from the high voltage supply and breakdown pulses occurring in the detector.

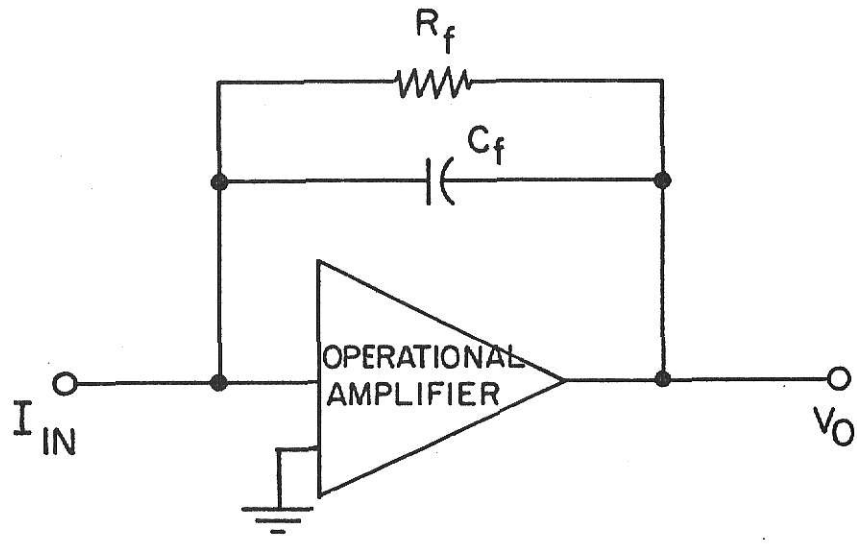


FIGURE 3. A BASIC CHARGE – SENSITIVE PREAMPLIFIER

4. The bias voltage may be applied through a low impedance at the counter's cathode. This stabilizes the high voltage bias level across the detector when high multiplication and high counting rates are present.

From the physical processes occurring inside the detector, it may be shown that:

$$E_o = \frac{eQA}{C}$$

where E_o = Peak voltage pulse from detector (V)

e = Charge on an electron (Coulombs)

Q = Initial ionization = $\frac{E_i}{W}$ (number of ion pairs)

A = Gas multiplication constant.

C = Detector capacitance (approximately 20 pF) + cable capacitance (approximately 30 pF)[6]

W = Specific ionization (30 eV/ion pair).

E_i = Energy deposited in the detector (eV)

If A is assumed to be 1.0 and C is approximately 100 pF, then

$$E_o = \frac{1.6 \times 10^{-19}\ (C) \times E_i\ (eV)}{10^2 \times 10^{-12}\ (pF) \times 30.0\ (eV/ion\ pair)} .$$

Assuming 0.36 MeV of energy[7] is deposited in 1.0 atmosphere of hydrogen gas from the ^{239}Pu 5.15 MeV alpha particle, then

$$E_o = \frac{1.6 \times 10^{-19} \times 0.36 \times 10^6}{10^2 \times 10^{-12} \times 30.0} = 0.192 \times 10^{-4} = 0.0192\ mV$$

The gas multiplication constant is typically 20 to 150, maximum[7]. Therefore, even at best, the output voltage will be only approximately 3 mV. Consequently it is necessary to amplify a very small signal with a high signal-to-noise ratio and good linearity with no saturation occurring in the

preamplifier due to extraneous voltage breakdowns. The Larson preamplifier was particularly designed for this type of service.

A commercial preamplifier with the same basic design features as Larson's preamplifier generated noise to a level that was intolerable if low energy neutron measurements were to be made. The Larson preamplifier performed well in this regard. Its noise level as indicated by Larson[5] was measured to be approximately 0.120 mV.

Two modifications made to increase the signal-to-noise ratio in the Larson preamplifier were (1) to replace the 1000 MΩ feedback resistor by a 2000 MΩ resistor and (2) to lower the adjustable feedback capacitance. Lowering the feedback capacitance increased the gain from approximately 2 to approximately 60. A schematic diagram of the Larson preamplifier is shown in Figure 4.

2.4 Linear Pulse Shaping Considerations

A block diagram of the linear pulse shaping system is shown in Figure 5 while Figure 6 shows photographs of the signal pulses at various points in the system. The signal produced by the detector was a negative pulse with rise time varying according to the type of particle initiating the pulse. All pulses have a long tail of about 4 msec and are from 1 mV to 10 mV in amplitude, depending on the gas multiplication. This low voltage signal was passed from the detector to the Larson preamplifier for amplification and impedance matching. The positive signal obtained after inversion and amplification was transmitted through 300 feet of coaxial cable to the location of the pulse shaping electronics and TMC 4096 multiparameter analyzer. (The experimental facilities are discussed in Section 5.0.) The transmitted signal was then passed through the third stage of a TC-220BLR amplifier where it was

integrated and differentiated with time constants of 6.4 μsec. These integration and differentiation settings yielded the best signal-to-noise ratio (6.4 μsec was close to the maximum rise time of the pulses.)

The unipolar pulse produced in the TC-220BLR was then passed through an ORTEC 410 Shaping Amplifier where it was integrated again with a time constant of 10 μsec. This integration smoothed the pulse and resulted in the best resolution of the alpha particle energy from the internal ^{239}Pu source. All analog-to-digital converters (ADC's) in the multichannel analyzers available at KSU required pulses of 1 μsec or less rise time. It was impossible to shape the pulses to a rise time of 1 μsec or less and still obtain good energy resolution. As an alternative, the time constants in an ADC unit were altered to accept longer rise time pulses. This change improved the resolution considerably, but the result was still not satisfactory.

An adequate solution was found by employing an ORTEC 442 Linear Gate and Stretcher. This unit generates a pulse of the same height as the incoming pulse but with a standard rise time of 0.4 μsec. Using this unit, a linear energy pulse that matched the ADC input pulse characteristics was obtained and produced results with much better resolution than specified by Twentieth Century Limited.

The electronic system described above was used to measure the resolution of the internal ^{239}Pu source for each of the three Benjamin detectors. For these measurements the signal from the ORTEC 442 Linear Gate and Stretcher was fed to a Technical Measurements Corporation (TMC) Model 102 Gammascope. This 100 channel pulse height analyzer has input signal requirements similar to the TMC 4096 analyzer used for accumulating complex neutron spectrums in this study. The alpha spectrums for the 10, 4 and 1 atmosphere detectors are shown in Figures 7, 8 and 9, respectively.

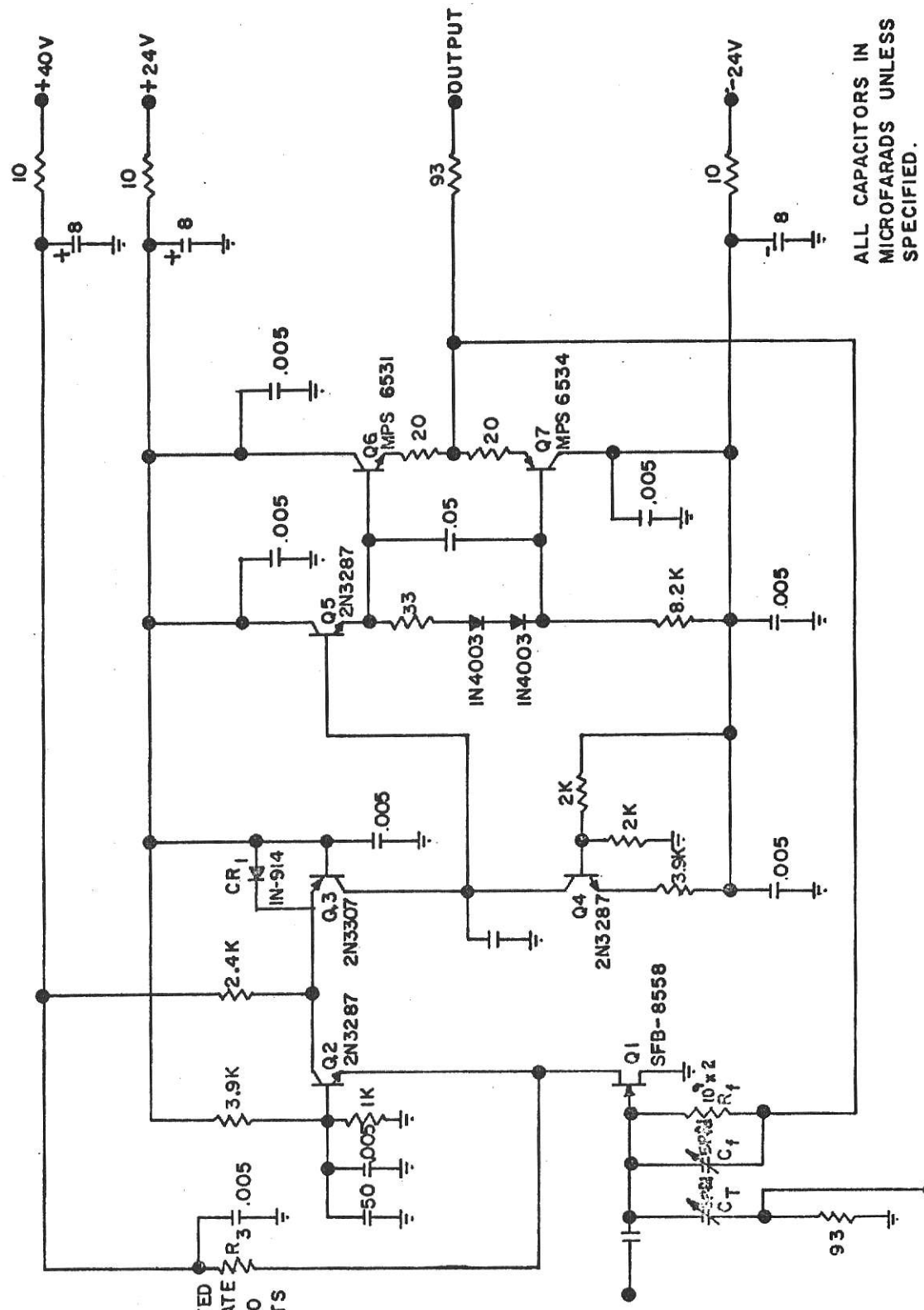


FIGURE 4. SCHEMATIC OF THE KSU LARSON PREAMPLIFIER

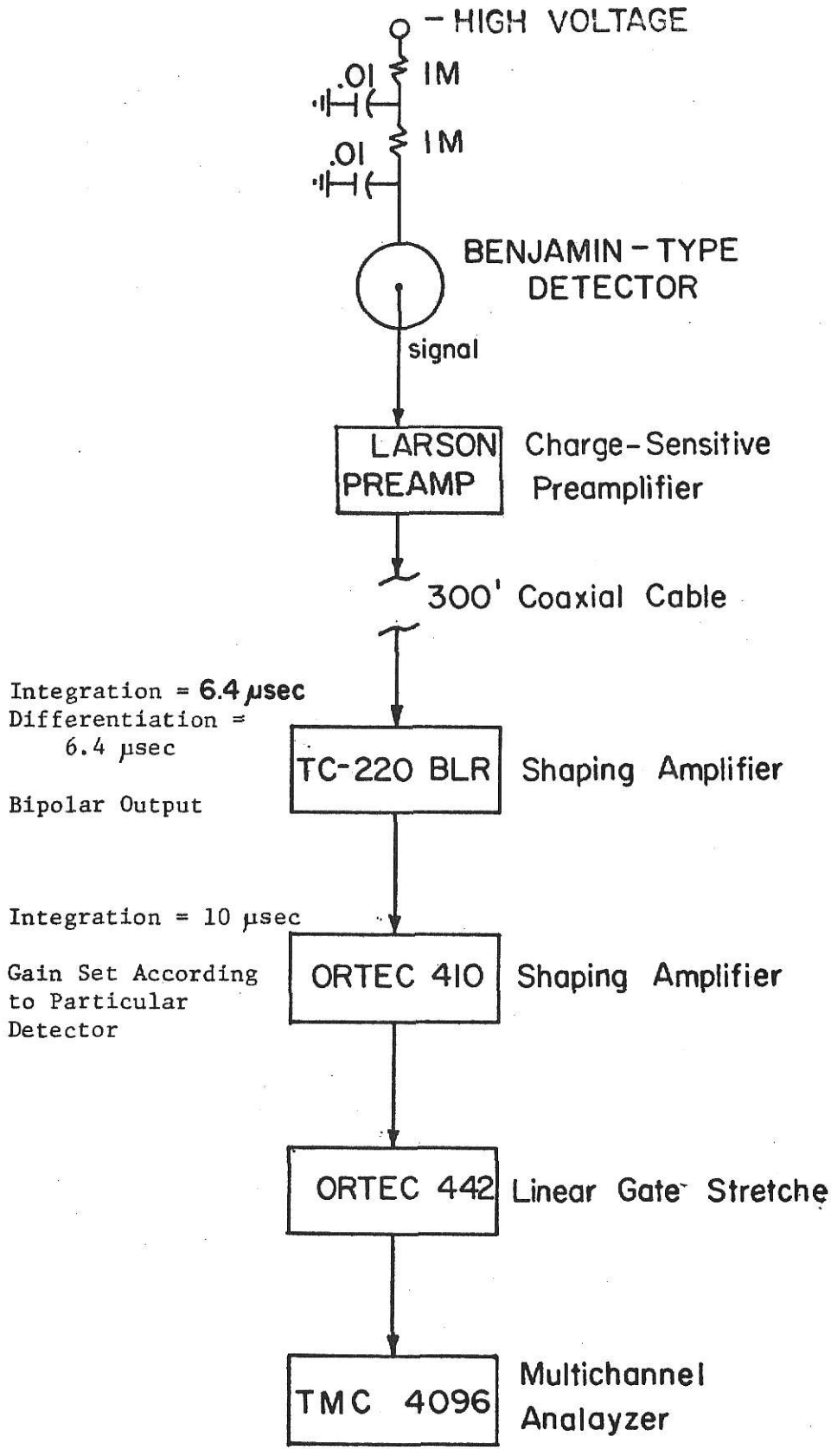
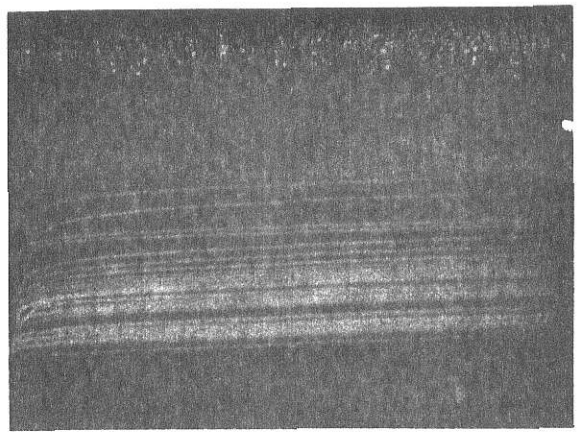


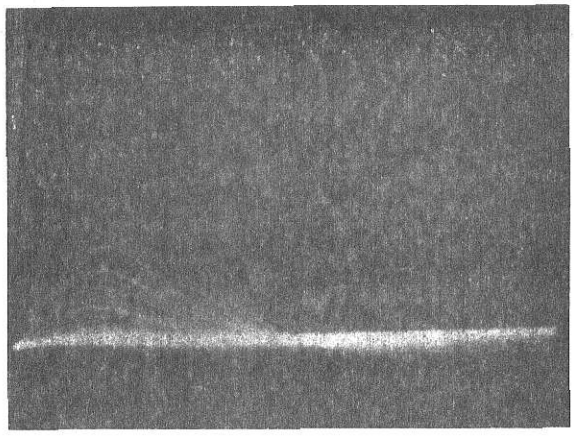
FIGURE 5. LINEAR PULSE SHAPING SYSTEM



Pulses through 300 ft
of coaxial cable from
Larson's Preamplifier

Oscilloscope settings:

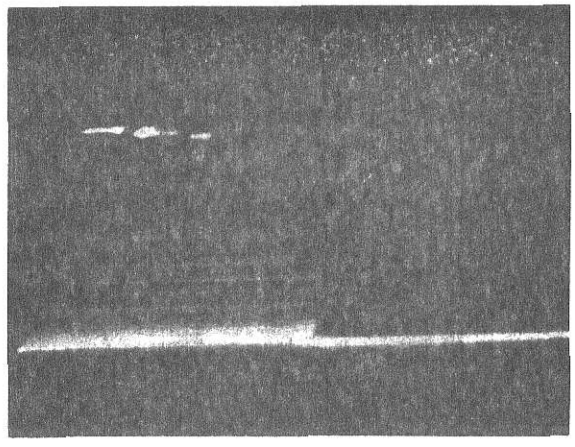
Vertical 0.2 v/cm
Horizonal 10 μs/cm



Pulses out of ORTEC 410
Shaping Amplifier

Oscilloscope settings:

Vertical 2 v/cm
Horizonal 10 μs/cm



Pulses out of ORTEC 442
Linear Gate and Stretcher

Oscilloscope settings:

Vertical 2 v/cm
Horizonal 1 μs/cm

Figure 6. Photographs of Linear Pulse Shapes

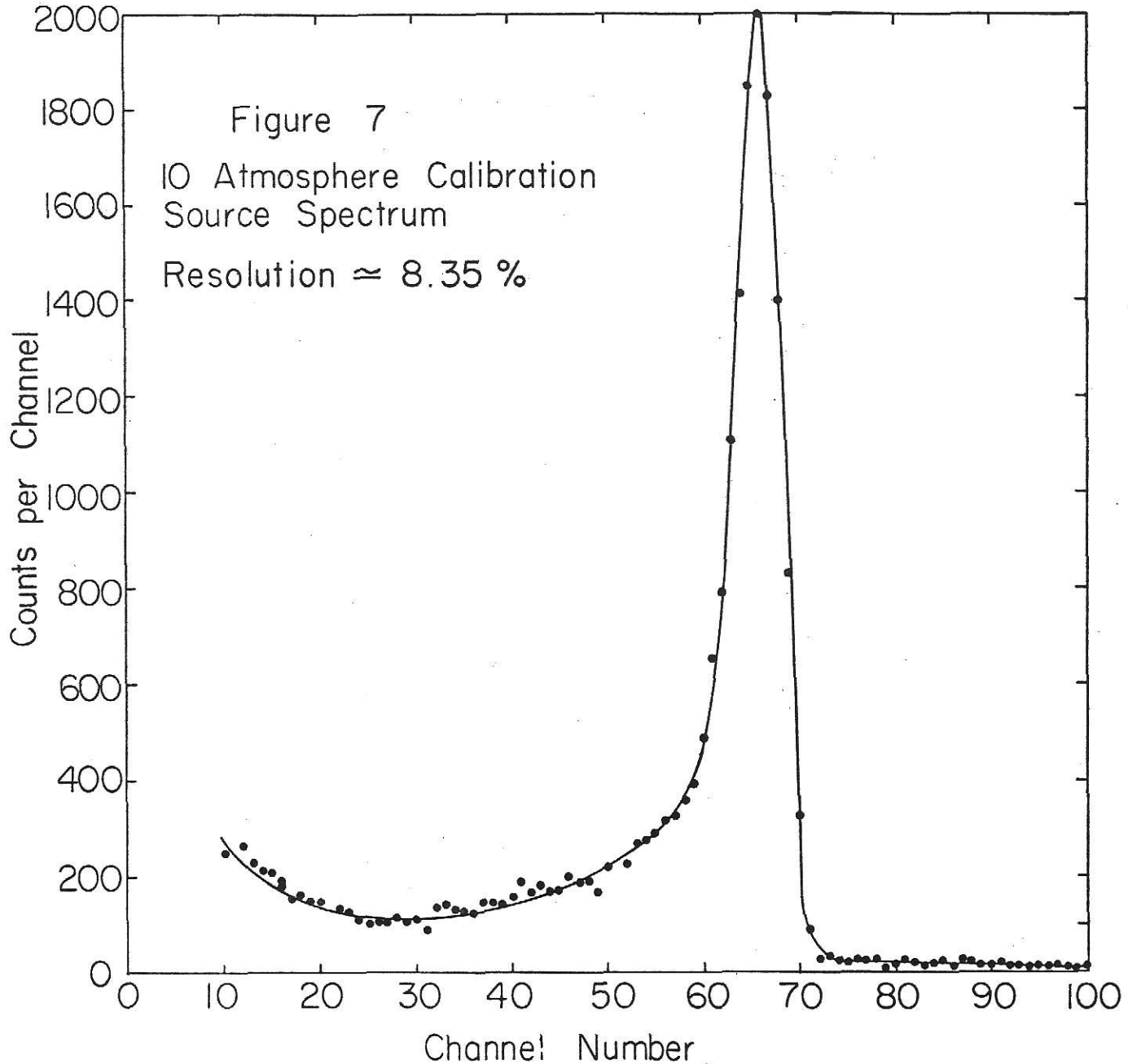
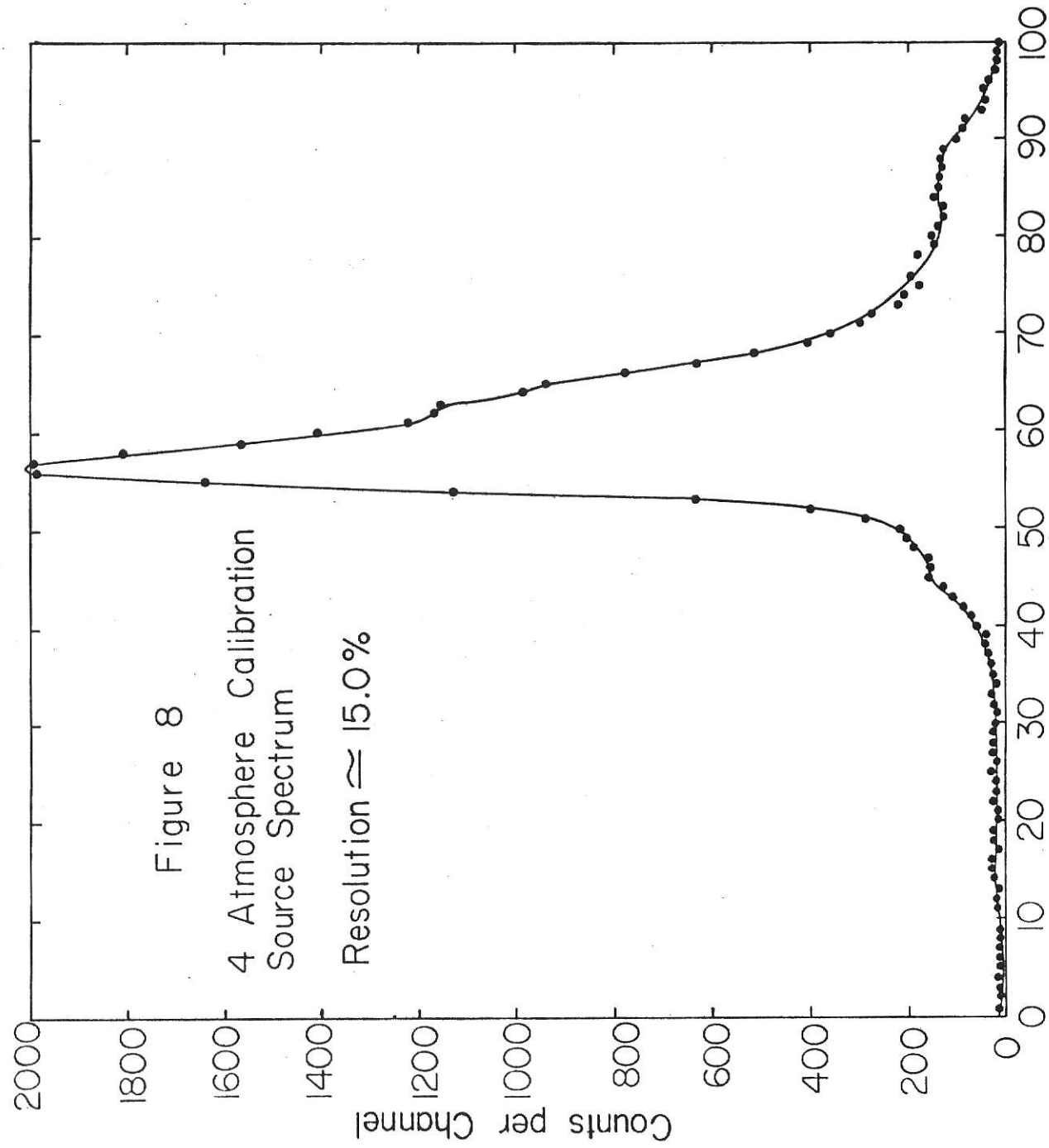


Figure 7
10 Atmosphere Calibration
Source Spectrum
Resolution ≃ 8.35 %
Counts per Channel
Channel Number
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
10
20
30
40
50
60
70
80
90
100


Counts per Channel
Channel Number
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
10
20
30
40
50
60
70
80
90
100
Figure 8
4 Atmosphere Calibration
Source Spectrum
Resolution ≃ 15.0%

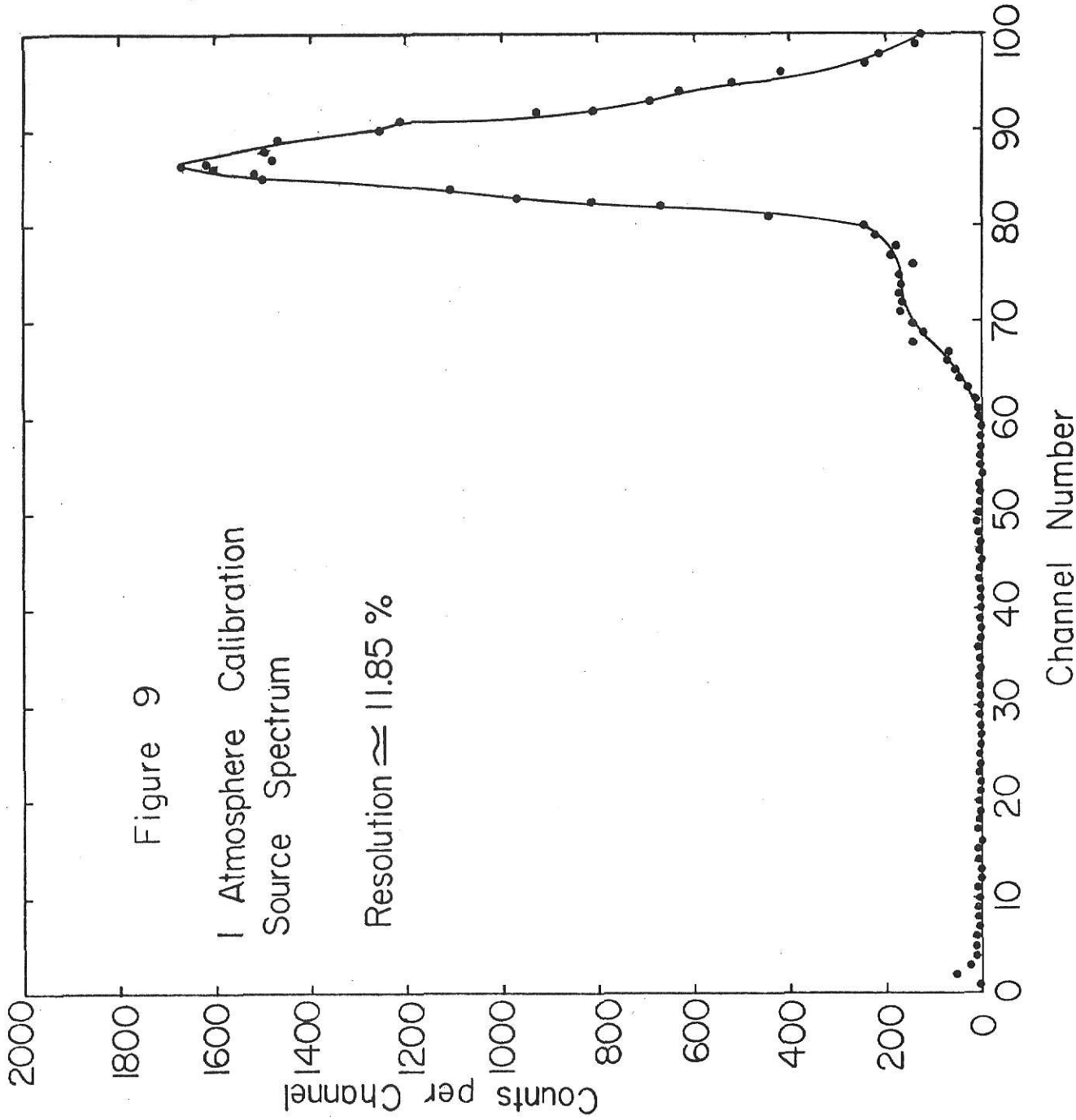


Figure 9
I Atmosphere Calibration
Source Spectrum
Resolution ≃ 11.85 %
Counts per Channel
Channel Number
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
10
20
30
40
50
60
70
80
90
100

The Twentieth Century Limited specifications for the proportional counters state that the 1 and 4 atmosphere detectors shall have a resolution of between 10% and 15% for the internal alpha calibration source and between 15% and 20% for the 10 atmosphere detector. The resolution of the detector due to the internal calibration source is very dependent upon the location of the ^{239}Pu on the center anode wire. Also the percentage resolution of the detector is increased due to alpha particles entering the anode wire and losing some of their energy there before entering the active volume of the detector. The above factors would suggest that the resolution of the detector for neutrons would be less (better) than for the internal calibration source. To check the energy resolution of the electronic system other than the detector, a DATAPULSE 100B pulse generator was used in place of the detector to provide an input to the preamplifier. The results recorded by the TMC Gammascope showed a resolution of less than or equal to 2%. Based on this result the factor limiting the resolution was probably the TMC Gammascope and not the pulse shaping circuitry. The spectrums in Figures 7, 8 and 9, therefore, accurately represent the internal alpha source resolutions of the three detectors.

3.0 DEVELOPMENT OF A GAMMA-RAY PULSE SHAPE DISCRIMINATION SYSTEM

3.1 Pulse Shape Differences

In measuring nuclear reactor complex neutron spectrums, the two types of radiation present in significant amounts are neutrons and gamma rays. Only by using neutron generators and time of flight or associated particle techniques may neutrons be detected exclusively. Since gamma rays do interact with the hydrogen gas in the proportional counters stripping off electrons and thus causing ionization, some form of discrimination must be developed to distinguish between neutron induced and gamma ray induced events.

In the past, low level biasing of pulses has been the main method of discriminating against gamma rays[8]. If it is assumed that an electron, stripped off by a gamma ray, cannot lose more energy than that corresponding to the most ionizing electron traveling the diameter of the detector, there will then be an upper limit for energy deposited in the detector by gamma radiation which is approximately 60 keV[8,9]. The usuable low-energy neutron response of the proportional counter is therefore sacrificed.

Since the energy response range of the 10 atmosphere detector is approximately 1.25 MeV to 0.4 MeV while the response range of the 4 atmosphere and 1 atmosphere detectors are respectively 0.65 MeV to 0.15 MeV and 0.30 MeV to the lower limit of the 1 atmosphere detector, only with the 1 atmosphere detector will gamma-ray discrimination be necessary. (The choice of these energy limits was based on the correction factors reported by Benjamin[15].)

To improve the low energy neutron response of the 1 atmosphere detector, electronic distinction between gamma-ray and neutron induced pulses is essential. The basis of the pulse shape discrimination (PSD) system developed during this study, is the relative collection time of the ionization charge

produced by recoil protons and gamma-ray induced electrons. The range of a 60 keV proton in 1 atmosphere of hydrogen is about 2.36 mm[10], whereas the range of a 60 keV electron is about 620 mm. (These results are based on the range-energy formula for electrons provided in "Nuclear Radiation Detection" by Price. The relation $R = 412E^n$ was used with $n = 1.265 - 0.0954\ \ell nE$, where R is in $\frac{mg}{cm^2}$, and E is in MeV. Therefore ionization produced by a recoil proton will occur over a relatively short path length. This results in a comparatively long collection time for the total charge induced by gamma rays while the total charge of recoil protons is essentially produced at a point and collected in a relatively short period of time. Figure 10 shows the rise time of neutron induced pulses to be about 1 μsec and the rise time of gamma-ray induced pulses to be about 4 μsec.

3.2 Pulse Shape Discrimination Methods

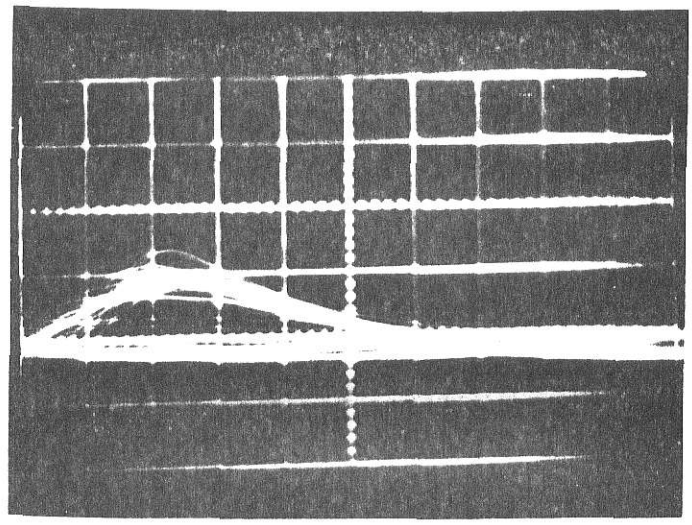
Several methods of accomplishing pulse shape discrimination are available. One method involves double differentiation of the pulse to obtain a bipolar pulse whose zero cross-over point is a function of pulse shape only. A gating signal generated from the zero cross-over point by a timing single channel analyzer (such as an ORTEC 455 or 420A) along with a linear signal may be combined in coincident timing logic. Alternatively, the signal generated from the zero cross-over point may be shaped and fed into a two parameter multichannel analyzer along with the linear signal. This method was successfully applied by Seck[11] for the two inch KSU NE-213 neutron spectrometer system, but this method was not satisfactory for these Benjamin-type proportional counters because of widely varying pulse rise times.

A second method involves an application of the ORTEC 458 Pulse Shape Analyzer[12]. This device can produce a linear transformation from rise time

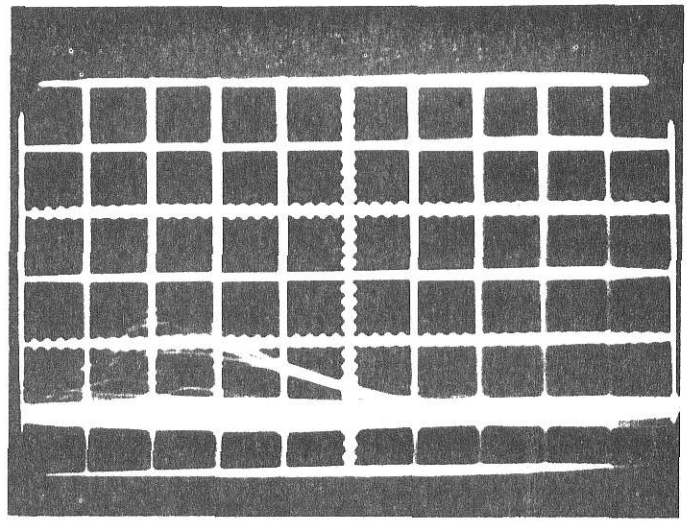
to pulse height; the process is described in ORTEC Application Notes AN37, Pulse Shape Analysis Using the ORTEC 458.

The method of pulse shape discrimination used in this study is similar to that used by E. F. Bennett[9]. The basic procedure uses a fast and a slow component of the pulse. The amplitude of the fast component is adjusted and added to the slow component so that there is no negative portion for a pure gamma-ray source. Neutron induced pulses will, however, produce negative portions after the two components are added.

Figure 11 shows the block diagram for the pulse shape discrimination system developed during this study. Photographs and sketches of pulses at different stages in the PSD system are shown in Figures 12, 13, and 14. The fast component of the signal was obtained by transmitting the preamplifier output signal (no pulse shaping present) to a double differentiation and integration circuit, with a 1.0 μsec time constant which integrated the signal over 1.0 μsec and clipped it. The signal was fed to an ORTEC 442 Linear Gate and Stretcher and then delayed. The signal was next inverted and fed to a summing circuit (see Figure 11) along with the linear signal (slow component). The gain of the fast component was adjusted so that a gamma-ray induced pulse cancelled itself in the slow component portion. This results in zero output from the adder for gamma-ray induced pulses and negative output pulses for neutron induced pulses. The negative pulses are then fed into a TD101 Differential Discriminator operated in the integral mode and then into an EG&G Gate Generator which provides the gating input to the ADC of the 4096 Multichannel Analyzer. Figure 15 shows the effect of this gamma-ray discrimination system on a Californium-252 recoil-proton distribution.



Pulses from ^{252}Cf



Pulses from ^{252}Cf

Oscilloscope Settings:

Vertical 2 v/cm
Horizontal 1 μsec/cm

NOTE: External triggering of the oscilloscope was accomplished by utilizing the single channel mode of the TMC MODEL 102 GAMMASCOPE.

Figure 10. Comparison of Neutron Induced and Gamma-Ray Induced Pulses

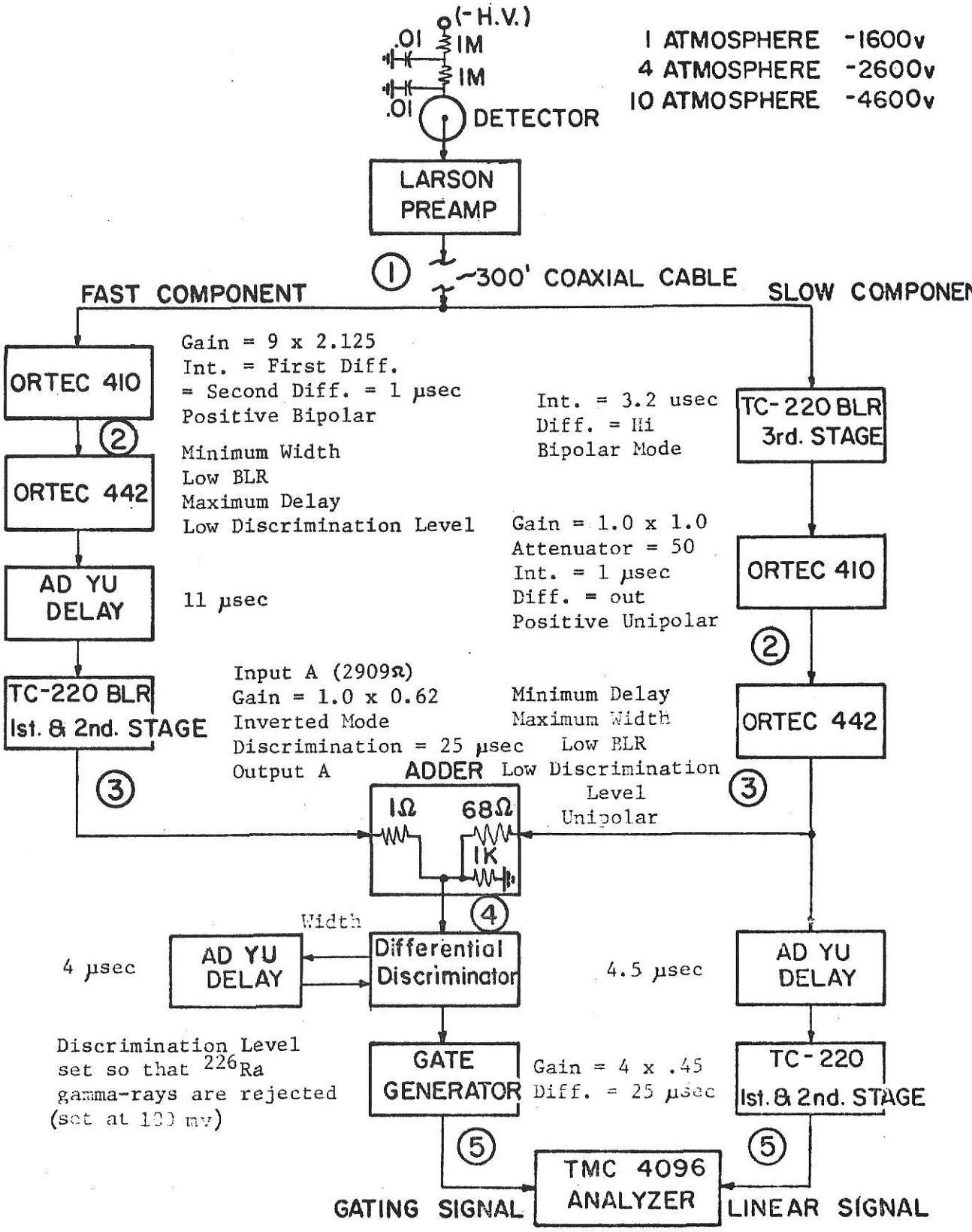


FIGURE 11. PULSE SHAPE DISCRIMINATION SYSTEM (PSD)

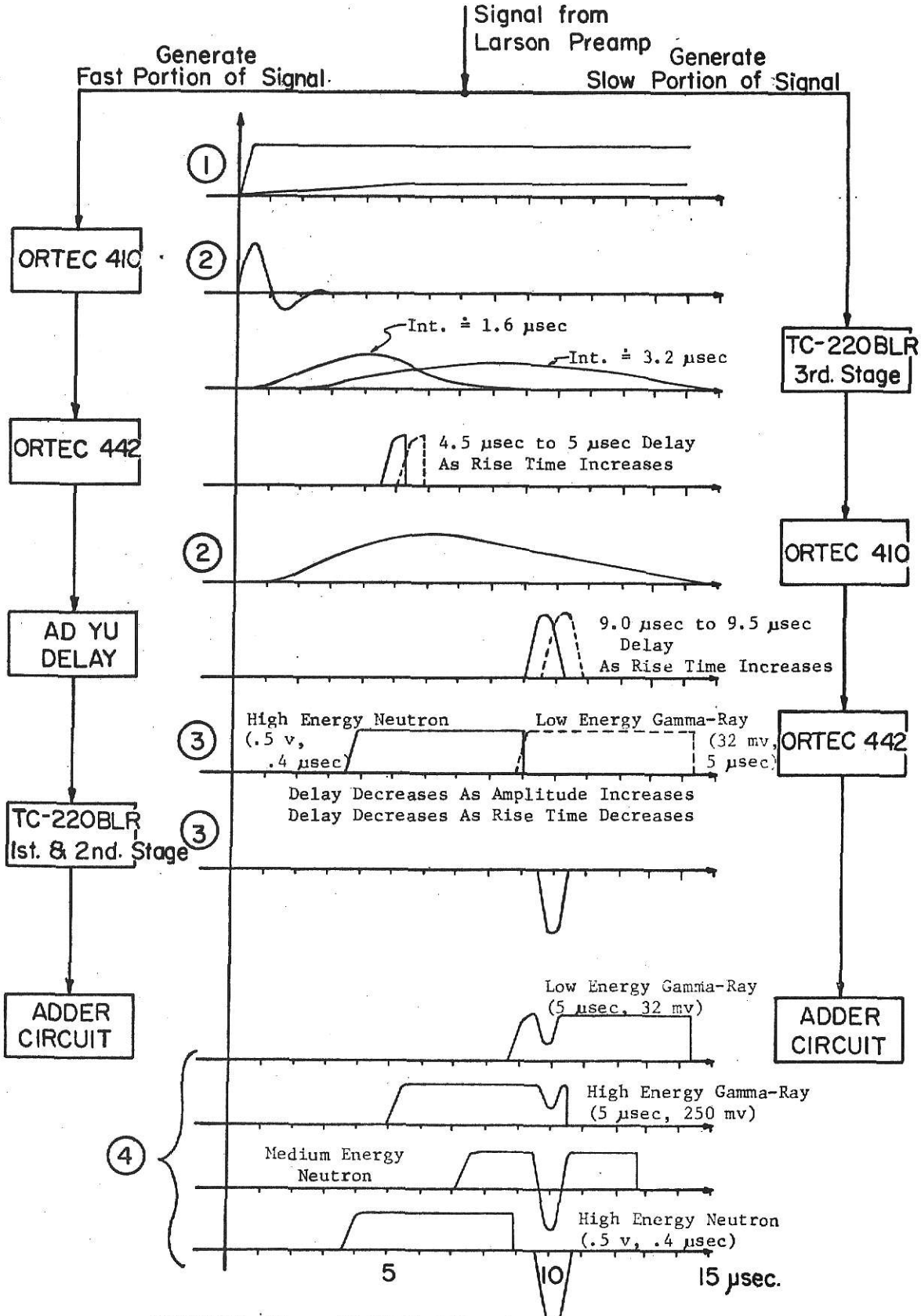
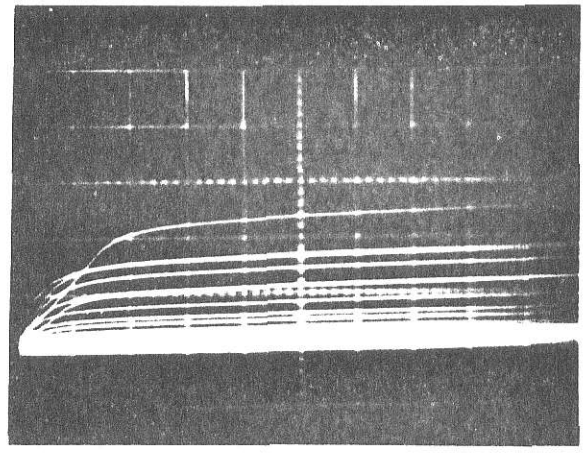


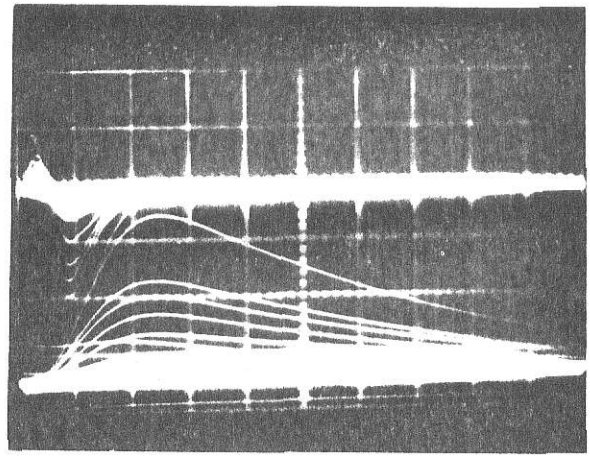
FIGURE 12. SKETCHES OF PSD PULSES



Pulses at 1 from ^{252}Cf
(See Figures 11 and 12)

Oscilloscope Settings:

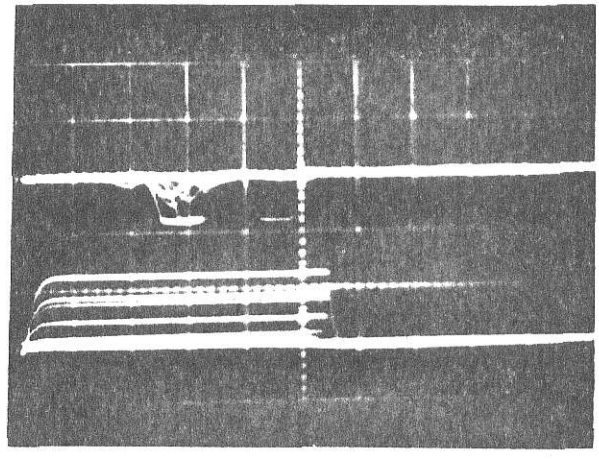
Vertical 0.5 v/cm
Horizontal 2 μs/cm



Pulses at 2 from ^{252}Cf
(See Figures 11 and 12)

Oscilloscope Settings:

Vertical 2 v/cm
Horizontal 2 μs/cm

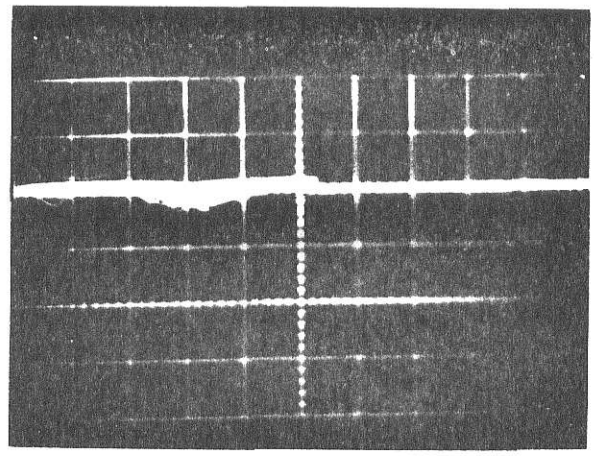


Pulses at 3 from ^{252}Cf
(See Figures 11 and 12)

Oscilloscope Settings:

Vertical 5 v/cm
Horizontal 1 μs/cm

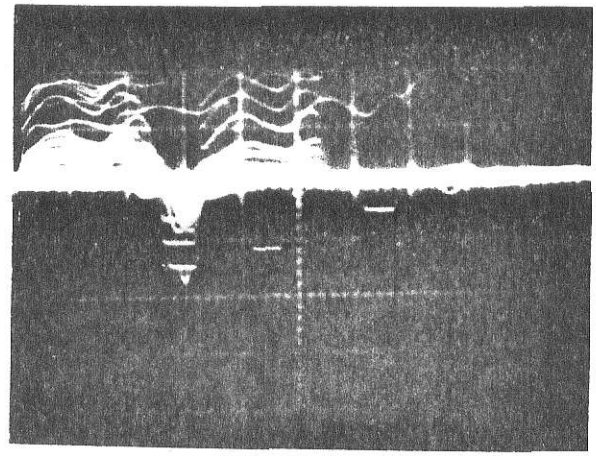
Figure 13. Photographs of PSD Pulses



Pulses at 4 from ^{226}Ra
(See Figures 11 and 12)

Oscilloscope Settings:

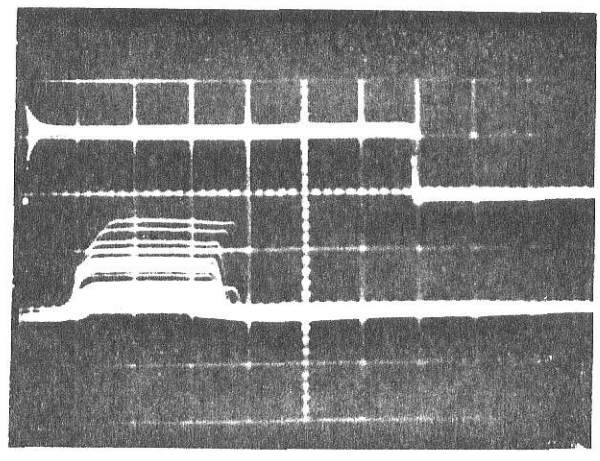
Vertical 1 v/cm
Horizontal 1 μs/cm



Pulses at 4 from ^{252}Cf
(See Figures 11 and 12)

Oscilloscope Settings:

Vertical 1 v/cm
Horizontal 1 μs/cm



Pulses at 5 from ^{252}Cf
(See Figure 11)

Oscilloscope Settings:

Vertical Upper 10 v/cm
Lower 5 v/cm
Horizontal 2 μs/cm

Figure 14. Photographs of PSD Pulses

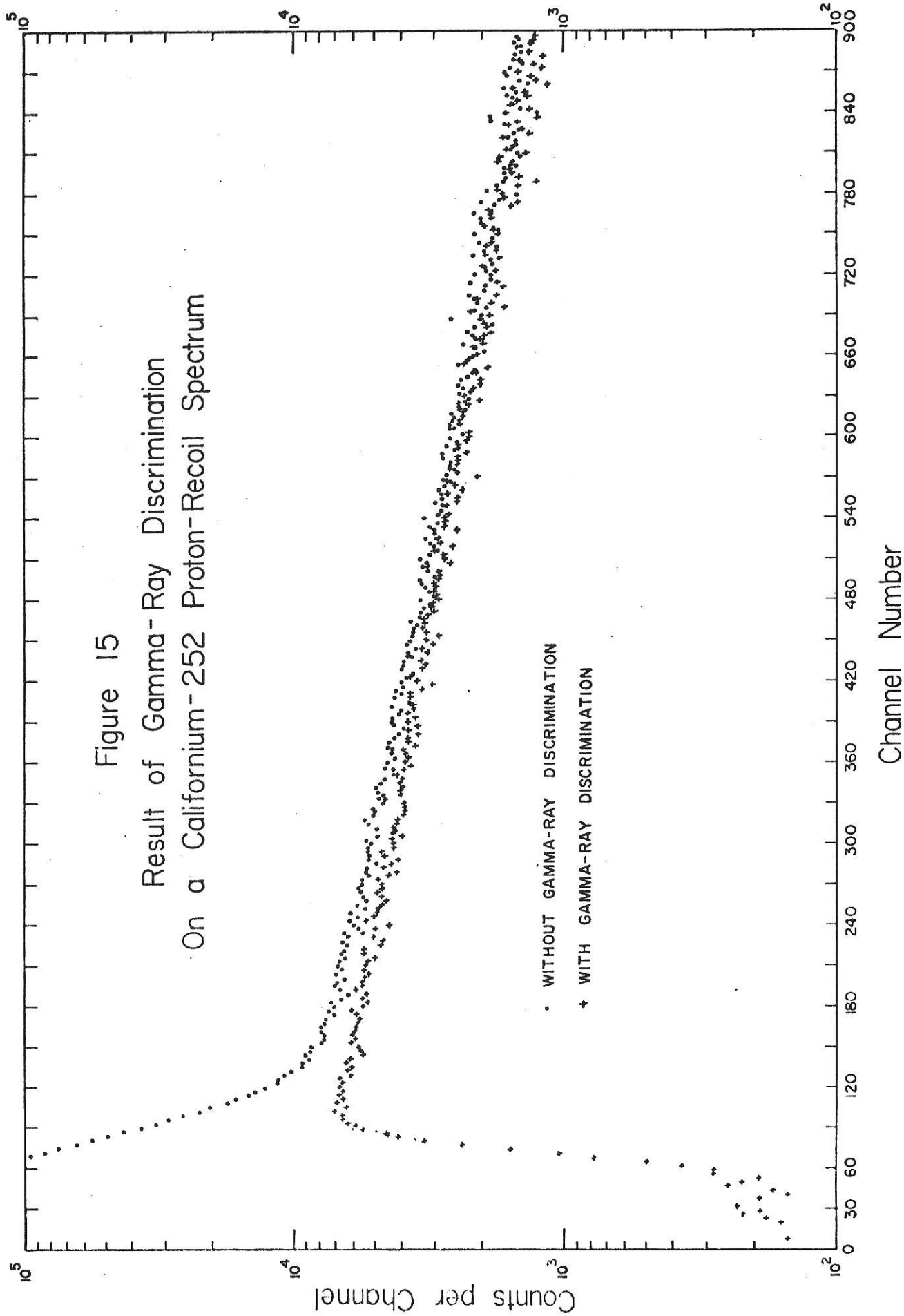


Figure 15

Result of Gamma-Ray Discrimination
On a Californium-252 Proton-Recoil Spectrum

4.0 UNFOLDING OF COMPLEX NEUTRON-PROTON RECOIL SPECTRUMS

4.1 Development of the Unfolding Procedure.

To obtain a neutron spectrum, the measured complex recoil-proton distribution must be unfolded. The unfolding procedure may consist of back substitution of single differential monoenergetic response functions into the single differential measured recoil proton distribution, or of back substitution with double differential quantities (used by SPEC 4). Unfolding may also be accomplished by the method of Coolbaugh[13]; however this procedure is not applicable to the Benjamin-type detector because the differential with respect to proton energy of the distortion factor cannot be assumed to be zero. This assumption is necessary to simplify the Coolbaugh unfolding equation to a workable scheme. A procedure, in which this assumption is not necessary to solve the unfolding equation, is being developed by Mutone[14].

The particular unfolding procedure used here may be defined through the following development:

Let

$M_o(E_p,E_n)dE_n$ = Number of recoil protons per unit energy for a unit flux of neutrons between E_n and $E_n + dE_n$

or

$$M_o(E_p,E_n)dE_n = \frac{\sigma_s(E_n)VN_p\,U(E_n - E_p)}{E_n}\,dE_n \qquad (3)$$

where V ≡ Volume of detector

N_p ≡ Number of protons/unit volume

$U(E_n - E_p)$ ≡ 1 for $E_p \leq E_n$

≡ 0 for $E_p > E_n$

E_n ≡ Neutron energy

$\sigma_s(E_n)$ ≡ Total scattering cross section at energy E_n

and defining

$M^*(E_p) \equiv$ Observed proton-recoil distribution per unit energy (number/MeV) produced by a neutron flux distribution per unit energy, $\phi(E_n)$.

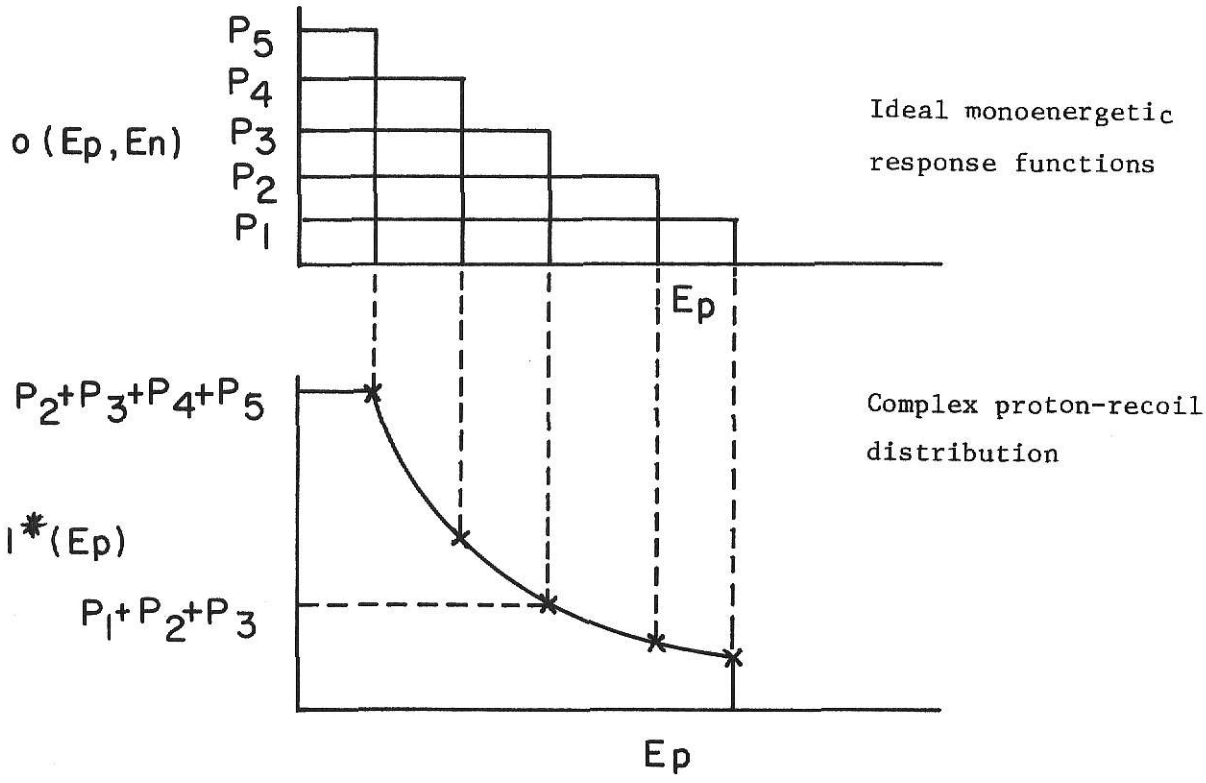
Next integrate Equation 3 over all possible neutron energies to obtain a recoil proton distribution produced from a complex neutron distribution, $\phi(E_n)$.

Then,

$$\int_{E_p}^{\infty} M_o(E_p,E_n)\phi(E_n)dE_n = M^*(E_p)$$

$$= \int_{E_p}^{\infty} \frac{\phi(E_n)\sigma_s(E_n)VN_p}{E_n} dE_n \quad . \qquad (4)$$

Now consider the following diagrams:



It may be seen from these two diagrams that the integral of $M_o(E_p,E_n)$ over all possible neutron energies yields a monotonic decreasing function $M^*(E_p)$ with a value at each E_p considered. E_p is the minimum neutron energy being considered for that particular point in the distribution, $M^*(E_p)$. This results from the fact that neutrons of lower energies cannot produce any recoil protons of energies greater than E_p. Therefore, the integral of $M_o(E_p,E_n)$ from zero to E_p over E_n is just equal to zero.

The unfolding code, SPEC 4, subtracts a proton recoil distribution due to neutrons above a maximum energy, E_{max}. The integral, then, of $M_o(E_p,E_n)$ over E_n from E_{max} to infinity is also equal to zero. From these considerations of the limits of integration, Equation 4 may be written as

$$M^*(E_p) = \int_0^{E_{max}} \phi(E_n) M_o(E_p,E_n) dE_n \tag{5}$$

Since the distribution functions only have values at discrete energy points E_i, the energy range from zero to E_{max} in Equation 5 may be divided into resolution weighted groups of given lethargy (or energy) widths. SPEC 4 operates in this manner. The number of recoil-protons in the i^{th} group may be defined as

$$M^i \equiv \int_{E_{i+1}}^{E_i} M^*(E_p) dE_p \tag{6}$$

where E_i to E_{i+1} is the i^{th} lethargy or energy group. Inserting Equation 5 in Equation 6 the following relation is obtained:

$$M^i = \int_{E_{i+1}}^{E_i} dE_p \int_0^{E_{max}} \phi(E_n) M_o(E_p,E_n) dE_n \quad . \tag{7}$$

A grouped neutron energy spectrum is now defined as,

$$\phi^j \equiv \frac{\int_{E_{j+1}}^{E_j} \phi(E_n)\,dE_n}{(E_j - E_{j+1})} \tag{8}$$

and

$$M^j(E_p) \doteq \phi^j M_o\left(E_p, \frac{E_j + E_{j+1}}{2}\right), \tag{9}$$

where $M^j(E_p)$ is the recoil proton distribution resulting from neutrons in the j^{th} group.

It therefore follows that the number of recoil protons in the i^{th} group resulting from neutrons in the j^{th} group is defined as,

$$M^{i,j} \doteq \int_{E_{i+1}}^{E_i} M^j(E_p)\,dE_p \quad . \tag{10}$$

Inserting Equation 9 into Equation 10,

$$M^{i,j} \doteq \phi^j \int_{E_{i+1}}^{E_i} M_o\left(E_p, \frac{E_j + E_{j+1}}{2}\right) dE_p \quad . \tag{11}$$

Since the number of recoil protons in the i^{th} group resulting from monoenergetic neutrons in the j^{th} group is

$$M_o^{i,j} \equiv \int_{E_{i+1}}^{E_i} M_o\left(E_p, \frac{E_j + E_{j+1}}{2}\right) dE_p \quad , \tag{12}$$

Equation 11 becomes

$$M^{i,j} \doteq \phi^j M_o^{i,j} \tag{13}$$

The proton recoil distribution in the i^{th} group resulting from all of the neutrons is simply

$$M^i \doteq \sum_{j=1}^{N} \phi^j M_o^{i,j} \tag{14}$$

In the unfolding code, SPEC 4, N is equal to i so that the monoenergetic recoil proton distribution functions that are generated by subroutine SNIDOW appear as a square matrix.

This unfolding problem may also be cast into the differential domain by differentiating Equation 14,

$$\frac{\partial M^i}{\partial E_p} \doteq \sum_{j=1}^{i} \phi^j \frac{\partial M_o^{i,j}}{\partial E_p} \quad . \tag{15}$$

In matrix notation, Equation 15 becomes

$$\frac{\partial M^i}{\partial E_p} = \frac{\partial M_o^{i,j}}{\partial E_p} \phi^j \tag{16}$$

and solving for the set ϕ^j,

$$\phi^j = \frac{\partial M_o^{i,j}}{\partial E_p}^{-1} \frac{\partial M^i}{\partial E_p} \quad . \tag{17}$$

Solving Equation 17 by this "back substitution" is commonly called "unfolding."

SPEC 4 solves Equation 17 for the set ϕ^j by differentiating the measured recoil proton distribution to obtain $\frac{\partial M^i}{\partial E_p}$, and then generating and differentiating the monoenergetic recoil proton distribution $M_o^{i,j}$ with the subroutine SNIDOW.

4.2 Verification of SPEC 4

Although SPEC 4 has been used by a number of researchers in unfolding data from Benjamin-type detectors, it was desirable to check the operation of this unfolding code before complex spectra were unfolded. A computer code was first written to generate monoenergetic neutron-proton recoil distributions for the 10 and 1 atmosphere detectors using the correction factors published by P. W. Benjamin[15]. Typical shapes of these artificially generated monoenergetic

distribution functions are shown in Figure 16. The 1.0 Mev, 0.75 MeV, and 0.50 MeV response functions were added together and unfolded for 2, 6, and 10 per cent resolution for the 10 atmosphere detector. These results are shown in Figures 17, 18, and 19, respectively. The 0.25 MeV, 0.20 MeV, 0.15 MeV, 0.10 MeV, and 0.05 MeV neutron response functions were also added together and unfolded for 2, 6, and 10 per cent resolution for the 1 atmosphere detector. These results are shown in Figures 20, 21, and 22, respectively.

Response functions were then generated for all three detectors to check subtraction of the recoil-protons due to neutrons above E_{max} which is accomplished by subroutine SPEC 2S. Neutron response functions for 1.25 MeV, 1.0 MeV, 0.75 MeV, and 0.50 MeV were added together to form a spectrum to be unfolded for the 10 atmosphere detector. E_{max} was set at 1.05 MeV. Monoenergetic response functions of 0.50, 0.38, and 0.25 MeV were added together for the 4 atmosphere detector, and 0.25, 0.20, 0.15, and 0.10 MeV response functions were added together to form a spectrum for the 1 atmosphere detector. These three artificially generated spectra were normalized to each other by conserving total counts at 0.50 and 0.25 MeV and by assuming the efficiency was directly proportional to the filling gas pressure. The unfolded results are shown in Figure 23. Figure 23 shows very good results except for the fact that the unfolded spectrum is filled in between the peaks. This filling indicates that the artificially generated monoenergetic response functions did not assume the exact shape describing a SPEC 4 monoenergetic response function. This statement can be verified using the response functions measured by Graf[8] and Benjamin[15].

As a final test, the response functions generated by SPEC 4 subroutine SNIDOW for 4 per cent resolution for the 1, 4, and 10 atmosphere detectors

were added together and fed back into SPEC 4 as input data. These unfolded spectrums are shown in Figure 24. Figure 24 shows results as expected and indicates the SPEC 4 unfolding code is operational.

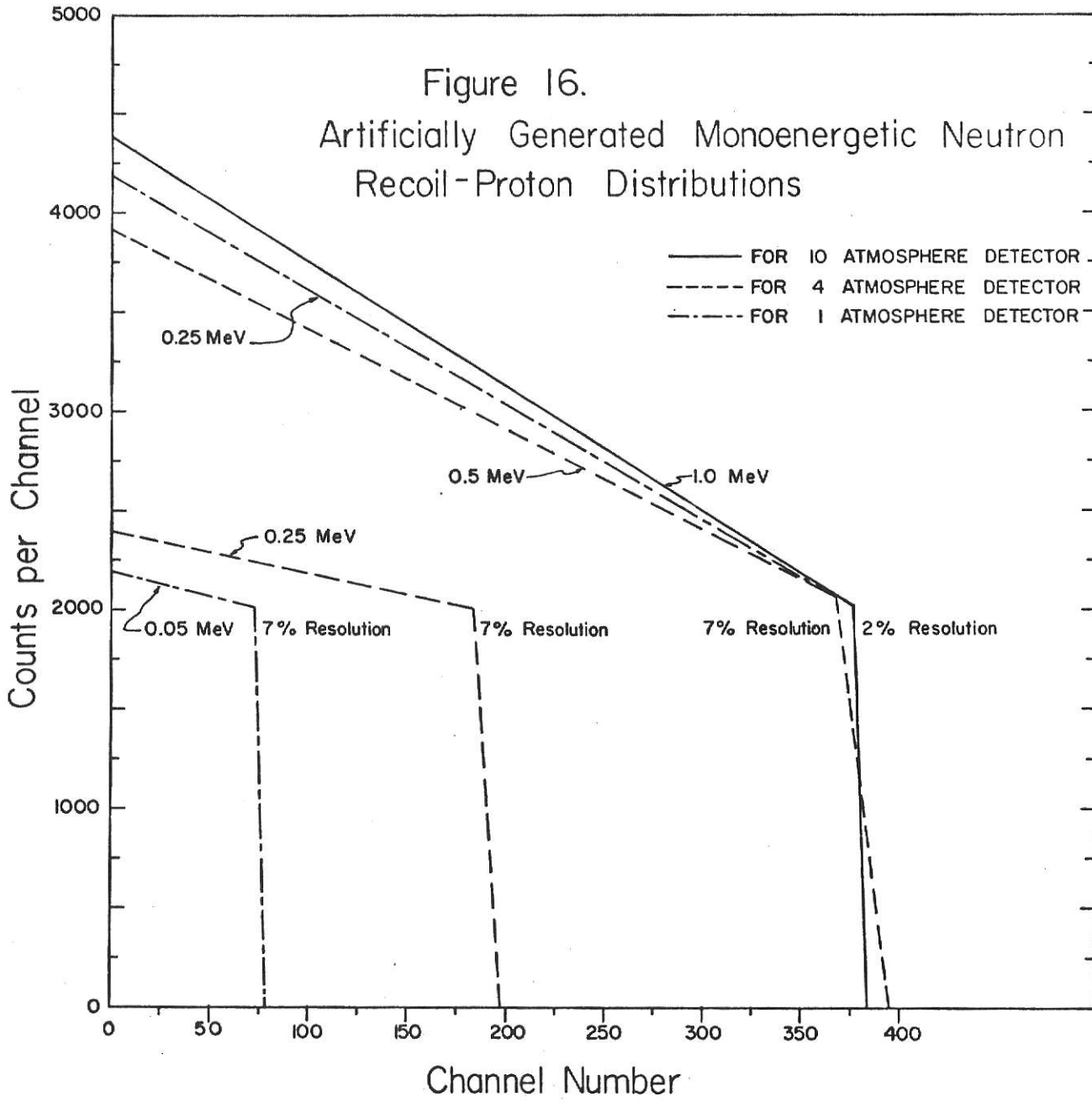


Figure 16.
Artificially Generated Monoenergetic Neutron Recoil-Proton Distributions
FOR 10 ATMOSPHERE DETECTOR
FOR 4 ATMOSPHERE DETECTOR
FOR 1 ATMOSPHERE DETECTOR
0.25 MeV
0.5 MeV
1.0 MeV
0.25 MeV
0.05 MeV
7% Resolution
7% Resolution
7% Resolution
2% Resolution
Counts per Channel
Channel Number
0
1000
2000
3000
4000
5000
0
50
100
150
200
250
300
350
400

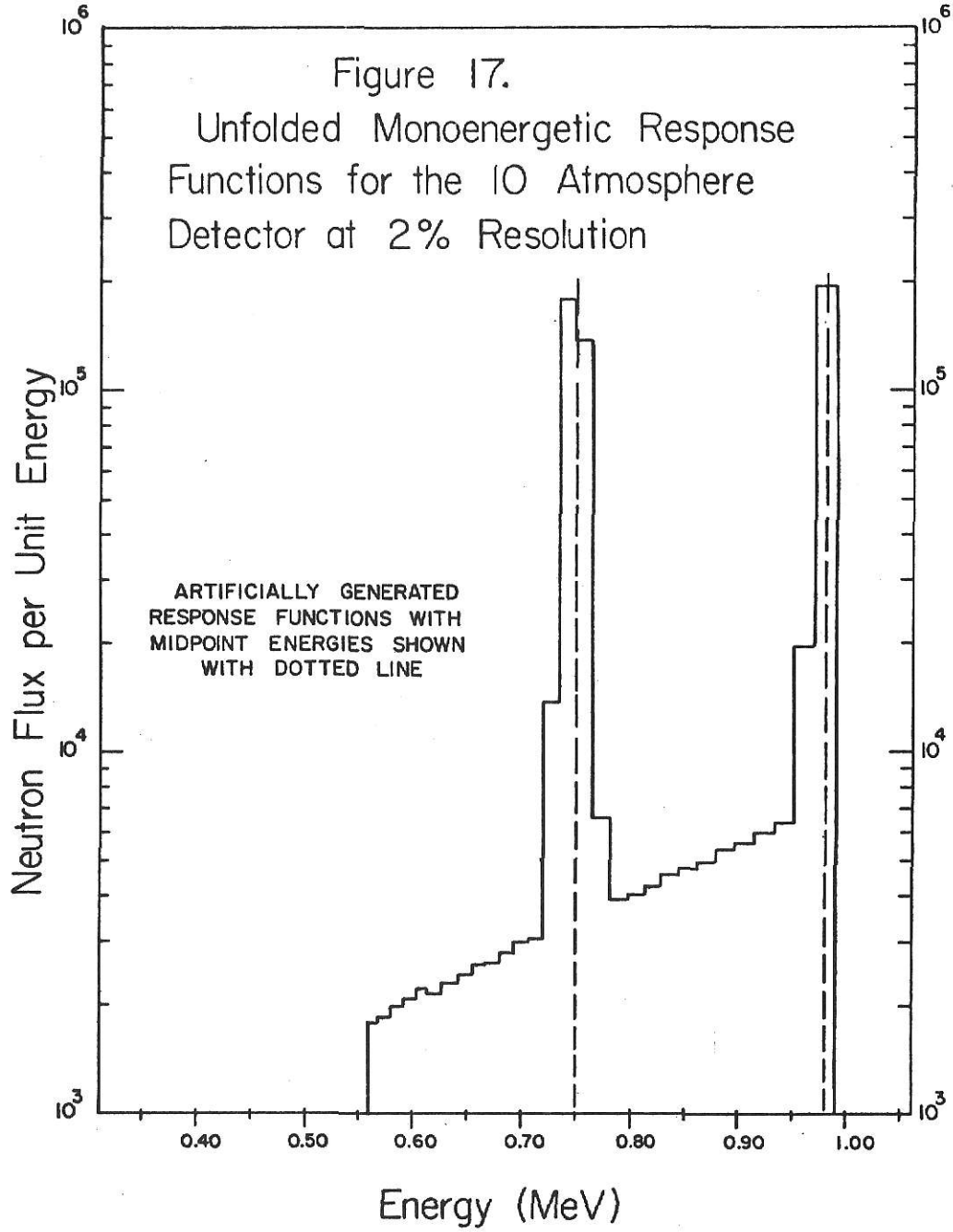


Figure 17.
Unfolded Monoenergetic Response Functions for the 10 Atmosphere Detector at 2% Resolution
ARTIFICIALLY GENERATED RESPONSE FUNCTIONS WITH MIDPOINT ENERGIES SHOWN WITH DOTTED LINE
Neutron Flux per Unit Energy
Energy (MeV)
10^6
10^5
10^4
10^3
0.40
0.50
0.60
0.70
0.80
0.90
1.00

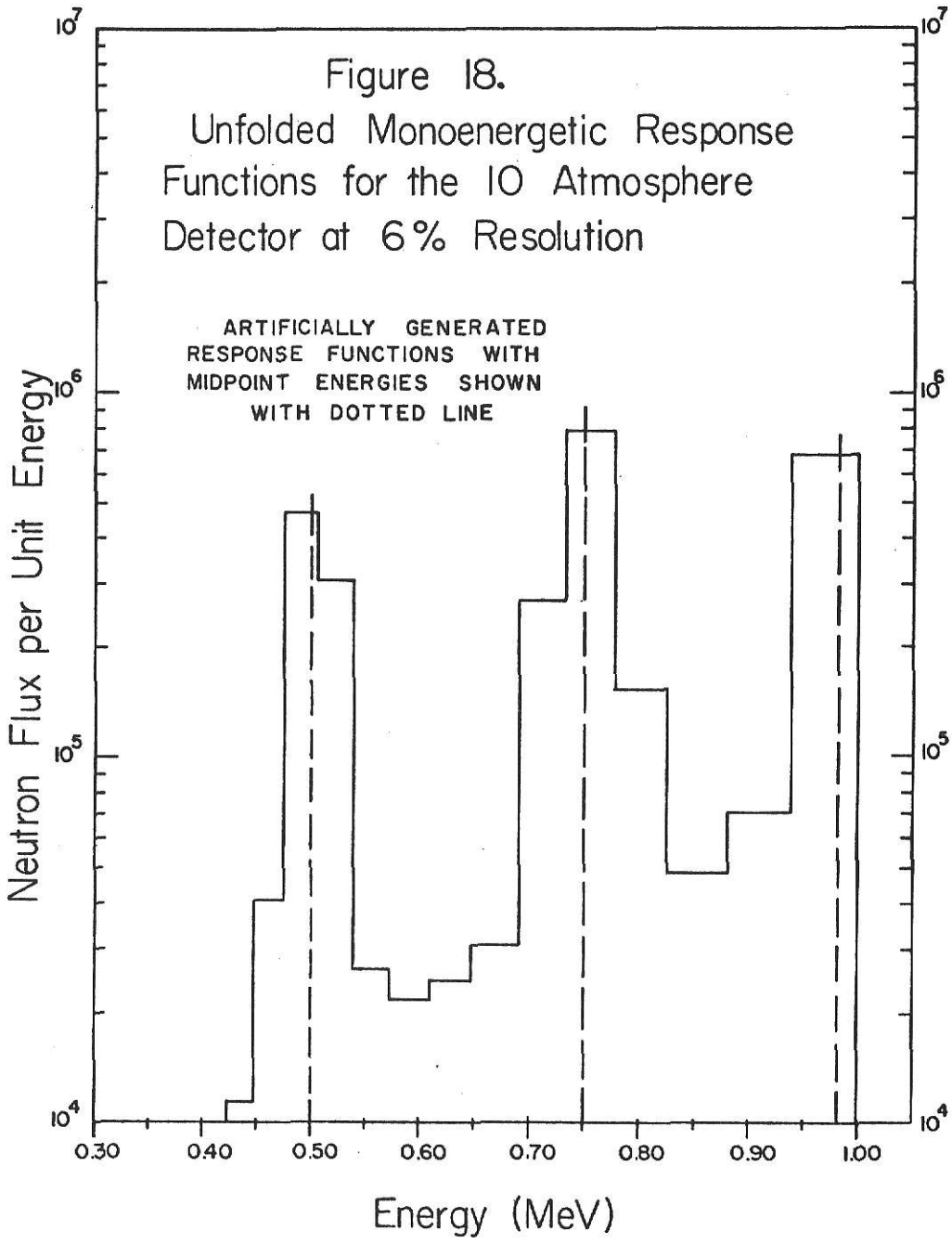


Figure 18.
Unfolded Monoenergetic Response Functions for the 10 Atmosphere Detector at 6% Resolution
ARTIFICIALLY GENERATED RESPONSE FUNCTIONS WITH MIDPOINT ENERGIES SHOWN WITH DOTTED LINE
Neutron Flux per Unit Energy
Energy (MeV)
10^7
10^6
10^5
10^4
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

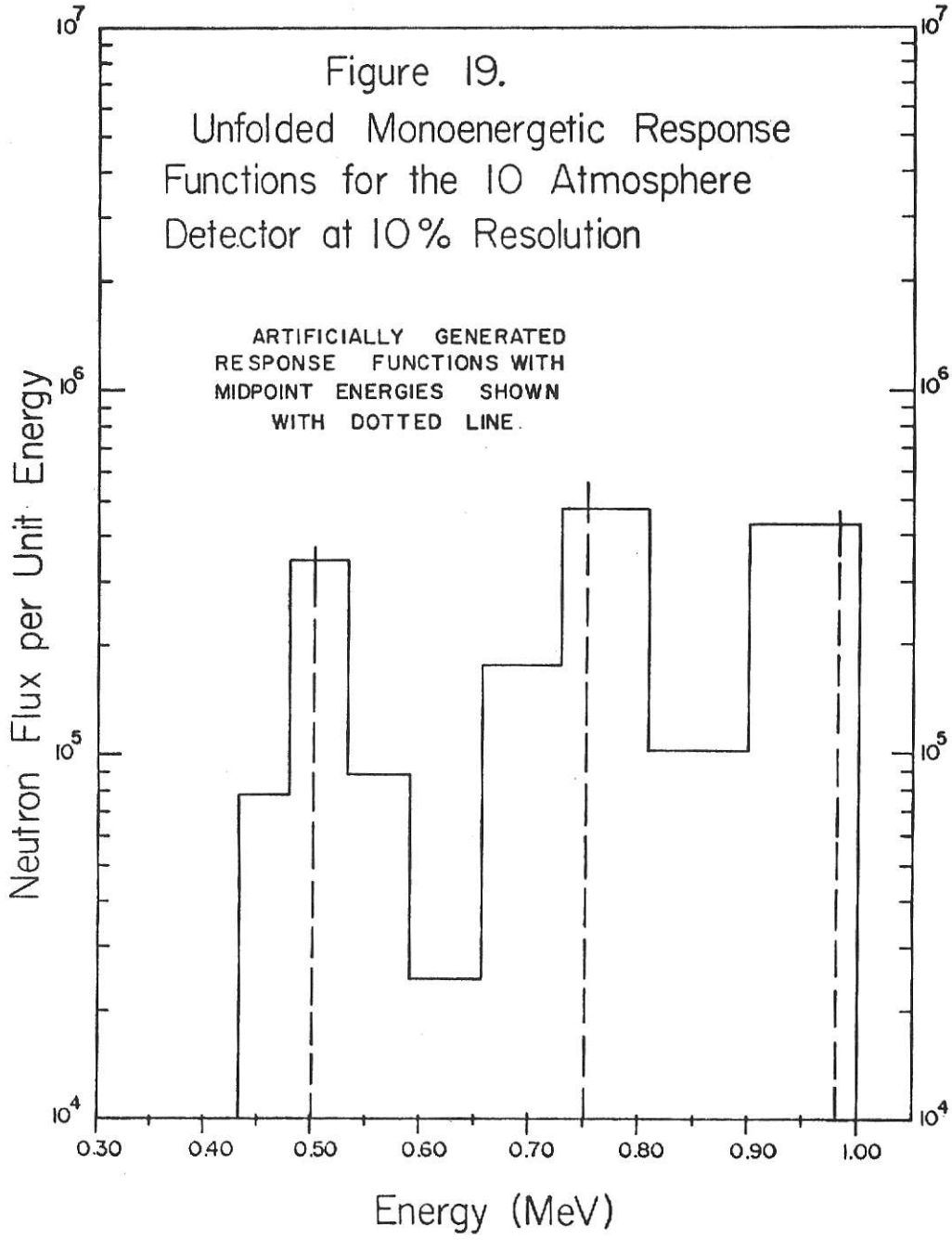


Figure 19.
Unfolded Monoenergetic Response Functions for the 10 Atmosphere Detector at 10% Resolution
ARTIFICIALLY GENERATED RESPONSE FUNCTIONS WITH MIDPOINT ENERGIES SHOWN WITH DOTTED LINE.
Neutron Flux per Unit Energy
10^7
10^6
10^5
10^4
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Energy (MeV)

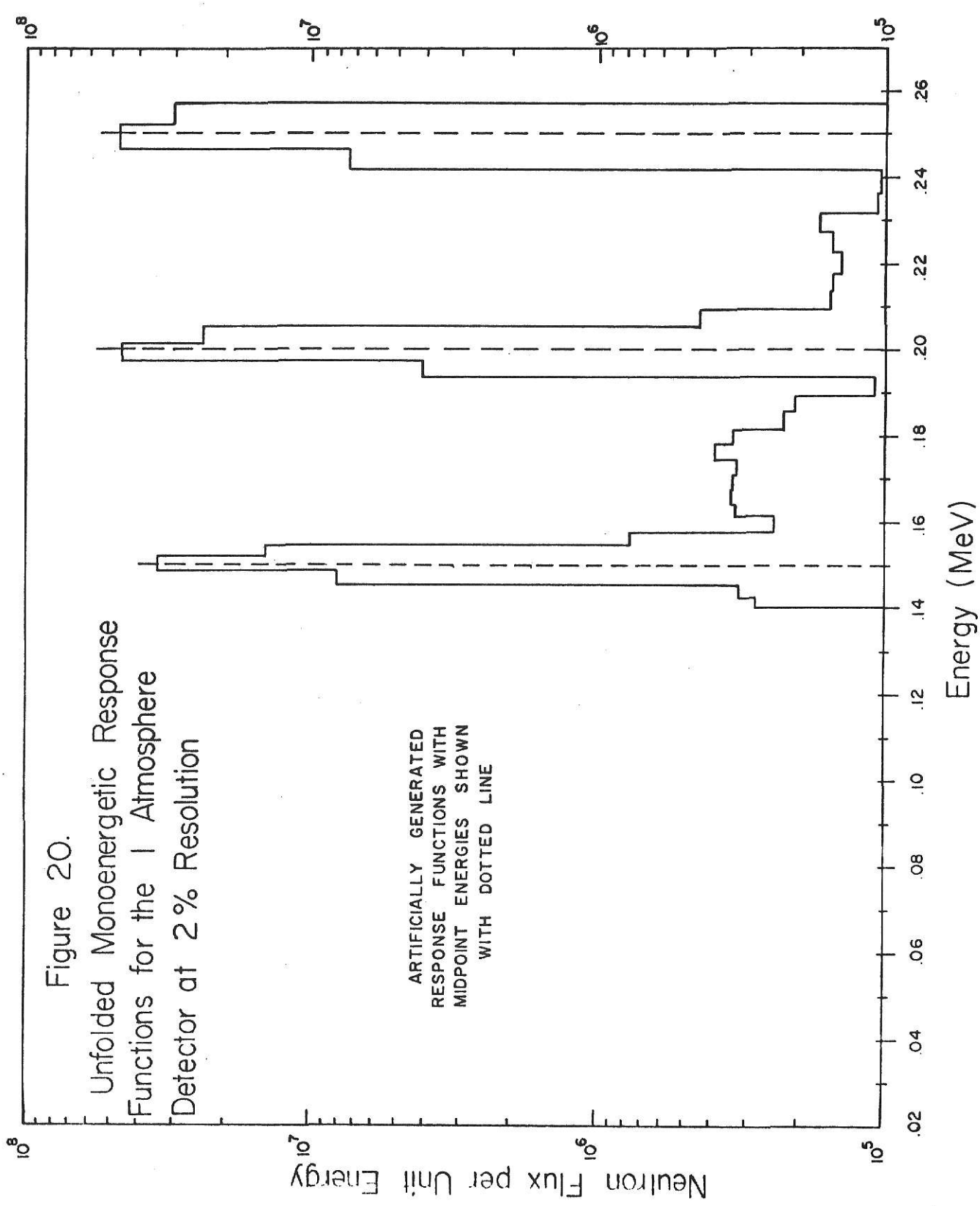


Figure 20.
Unfolded Monoenergetic Response
Functions for the 1 Atmosphere
Detector at 2% Resolution

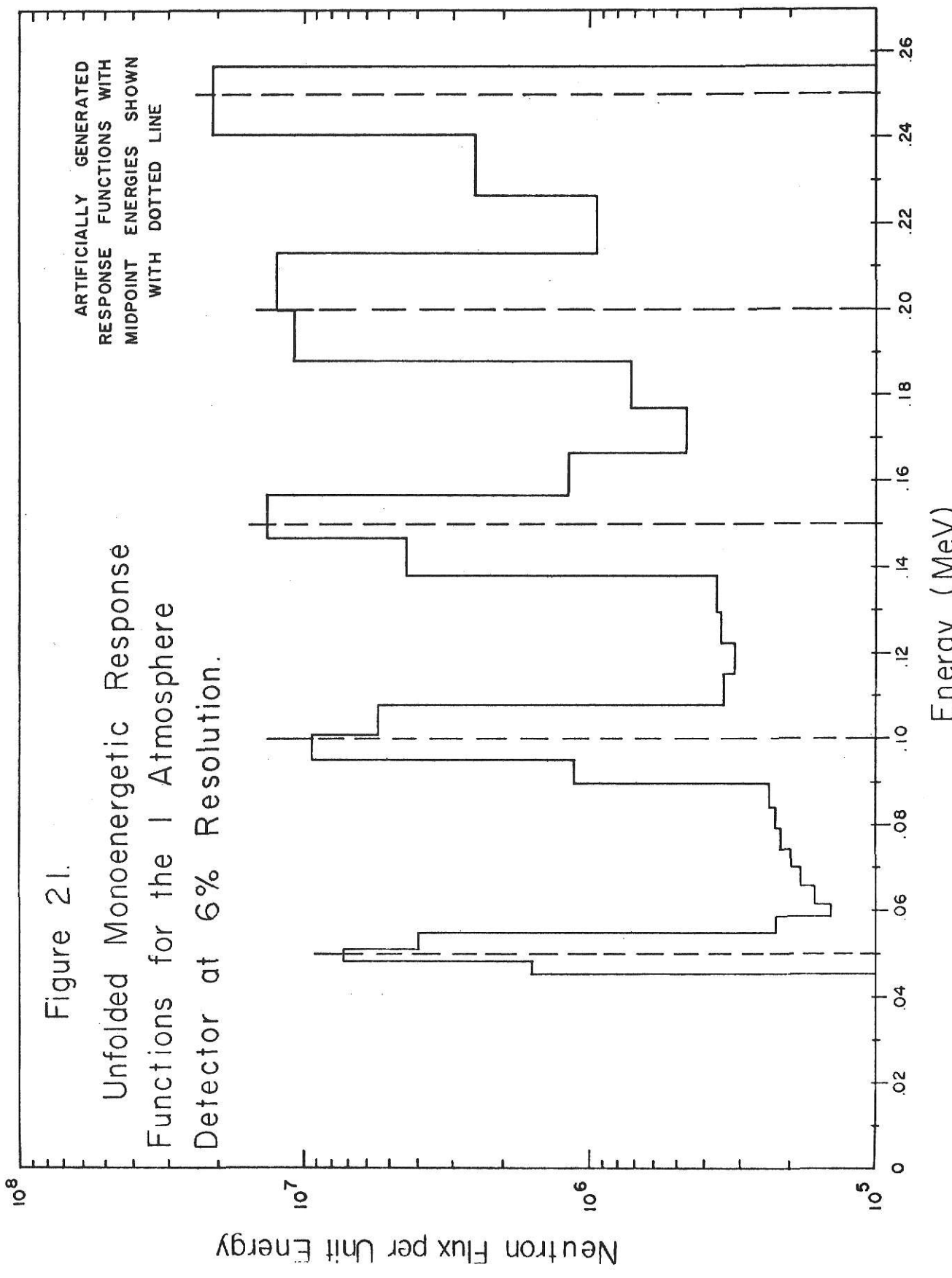


Figure 21.
Unfolded Monoenergetic Response Functions for the 1 Atmosphere Detector at 6% Resolution.

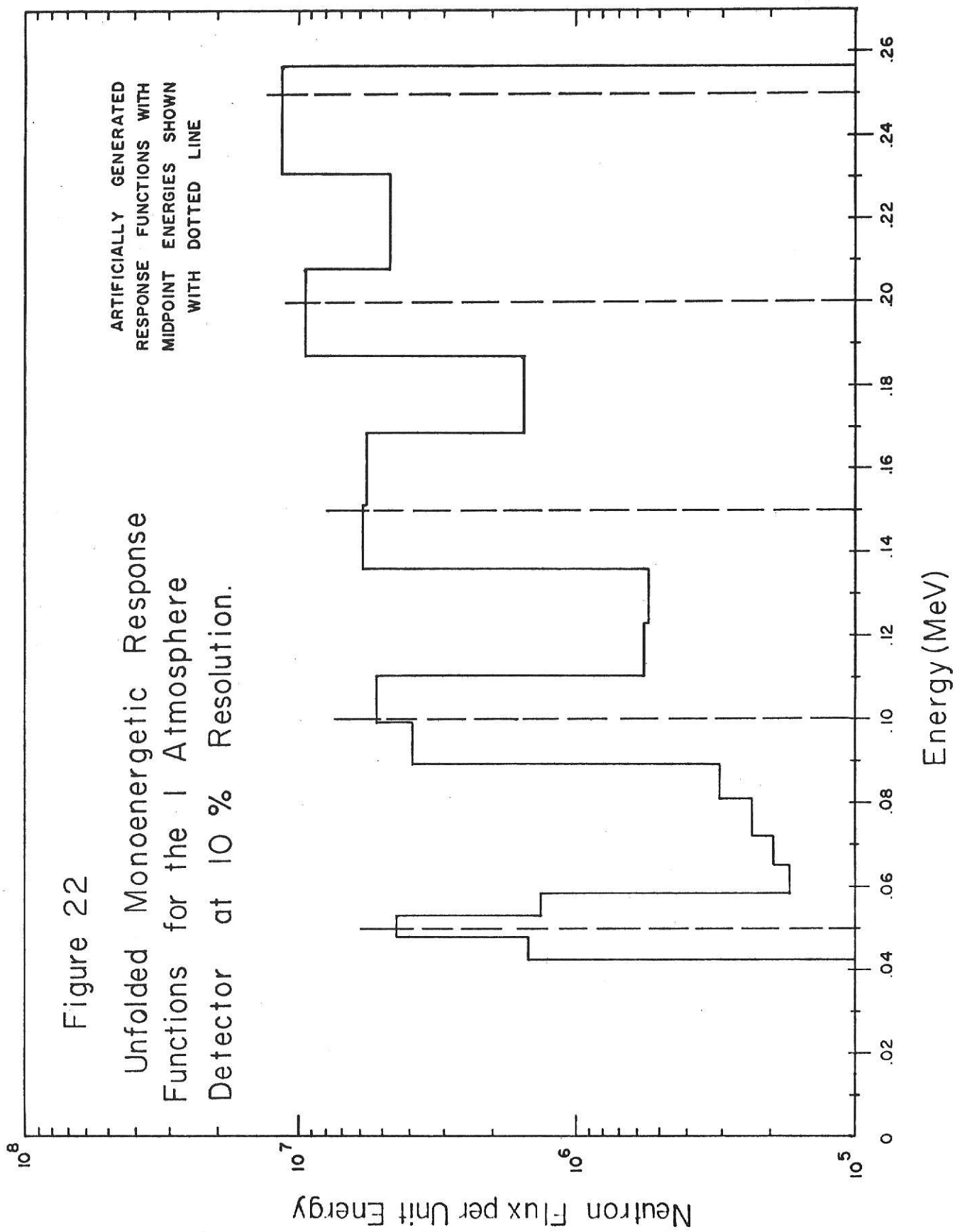


Figure 22

Unfolded Monoenergetic Response Functions for the 1 Atmosphere Detector at 10 % Resolution.

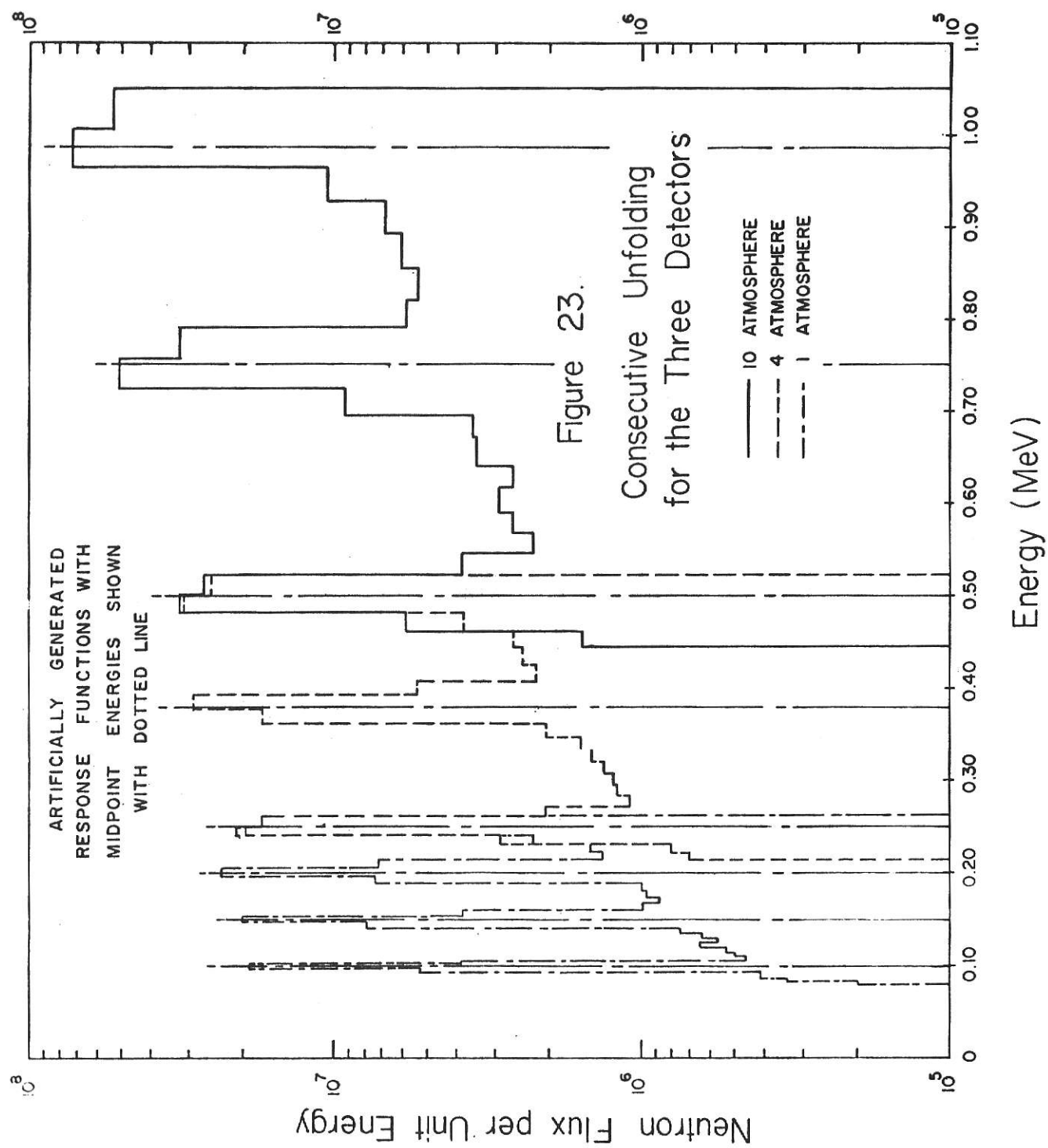


Figure 23. Consecutive Unfolding for the Three Detectors

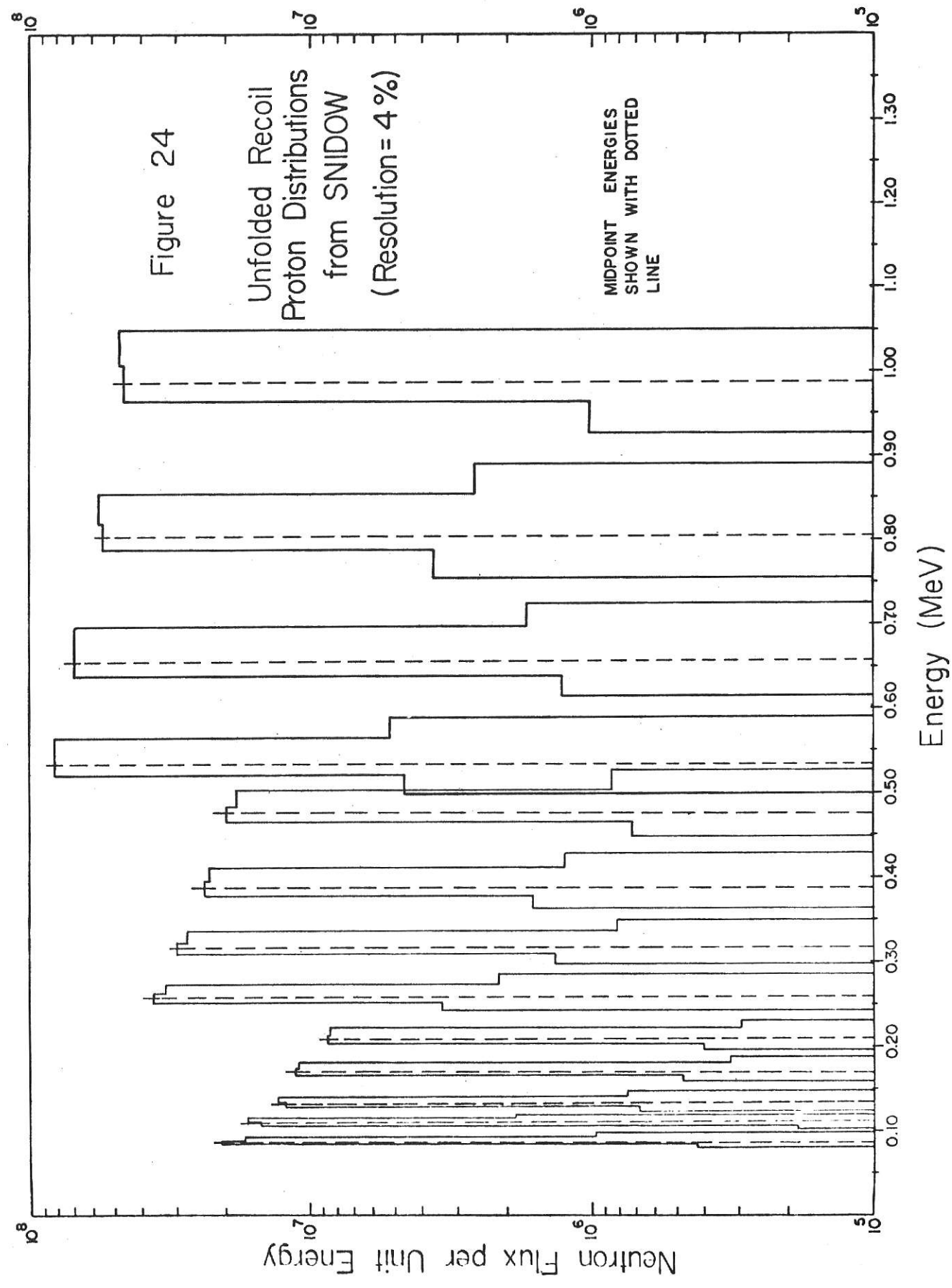


Figure 24
Unfolded Recoil Proton Distributions from SNIDOW (Resolution = 4%)
MIDPOINT ENERGIES SHOWN WITH DOTTED LINE
Neutron Flux per Unit Energy
Energy (MeV)
10^8
10^7
10^6
10^5
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30

5.0 MEASUREMENT OF COMPLEX NEUTRON SPECTRUMS FOR CALIBRATION

5.1 Calibration of the Benjamin-Type Neutron Spectrometer System by Neutron Penetration Studies

Ideally, calibration of the spectrometer system should be accomplished with a monoenergetic neutron source. This would consist of measuring the response of the system to monoenergetic neutrons and noting where the ^{239}Pu alpha peak occurred in the spectrum. This procedure could be carried out for several different monoenergetic neutron energies in the range of each detector and a plot of neutron energy vs. channel number constructed. The equivalent neutron energy could then be obtained for the alpha peak. The detector would be calibrated and the internal alpha source would be a quick means of calibrating the system. This was the procedure followed by Graf[8] during his study.

Unfortunately, a readily available source of monoenergetic neutrons does not exist at Kansas State University. As an alternative, it was decided to use a reactor spectrum transmitted through a thick sample of material which is characterized by deep minima in the total neutron cross section. The transmitted neutron spectrum is characterized by peaks at energies corresponding to the minima in the cross section.

The basis of the initial calibration of this system was to use the amount of energy deposited in each detector by the internal alpha source. The amount of energy that is deposited is obtained by integrating the empirical range-energy equations over the total path length traveled in the detector. This was done by Twentieth Century Electronics and reported to be 4.33 MeV, 1.49 MeV, and 0.36 MeV for the 10 atmosphere, 4 atmosphere, and 1 atmosphere detector, respectively. Using this alpha peak as a calibration point and assuming a total

of 1024 multichannel pulse height analyzer channels, the gain of the electronics was adjusted to that the calibration numbers would be 1.22 keV per channel, 0.63 keV per channel and 0.29 keV per channel for the 10 atmosphere, 4 atmosphere, and 1 atmosphere detectors, respectively.

An iron penetration experiment was chosen for calibration of the 10 atmosphere detector because of the minimums in the total neutron cross section at 400 keV, 600 keV, and 950 keV[16]. Aluminum was chosen for calibration of the 4 and 1 atmosphere detectors. The total neutron cross section for aluminum has prominent minimums at 25 keV, 65 keV, 129 keV, 190 keV, 270 keV, 350 keV, 380 keV[17] and 610 keV[18]. The thickness of the iron and aluminum samples was chosen to be approximately 3 mean free paths for the average cross-section of each sample. This resulted in the sample thickness being less than or equal to 1 mean free path at the minimums in the total neutron cross-section. This procedure was followed by Miller[19] and worked well.

Because of the need to know the neutron spectrum above the maximum energy to be analyzed for each detector, the KSU NE-213 neutron spectrometer system was used to obtain the neutron spectrum above 1.0 MeV. The experimental arrangement is shown in Figure 25. The KSU TRIGA MARK II nuclear reactor was used as a neutron source. A collimator described by Simons[1] collimates the neutron flux to 1.25 inches square through the beam port. A two inch bismuth plug was placed in the beam to attenuate the gamma-ray flux while little affecting the neutron flux or spectrum. The sample material was placed in the beam next to the end of the collimator. Another collimator used by Miller[19] was placed at the end of the sample to minimize the effect of multiple scattering in the sample. The detector was then placed 118 inches from the

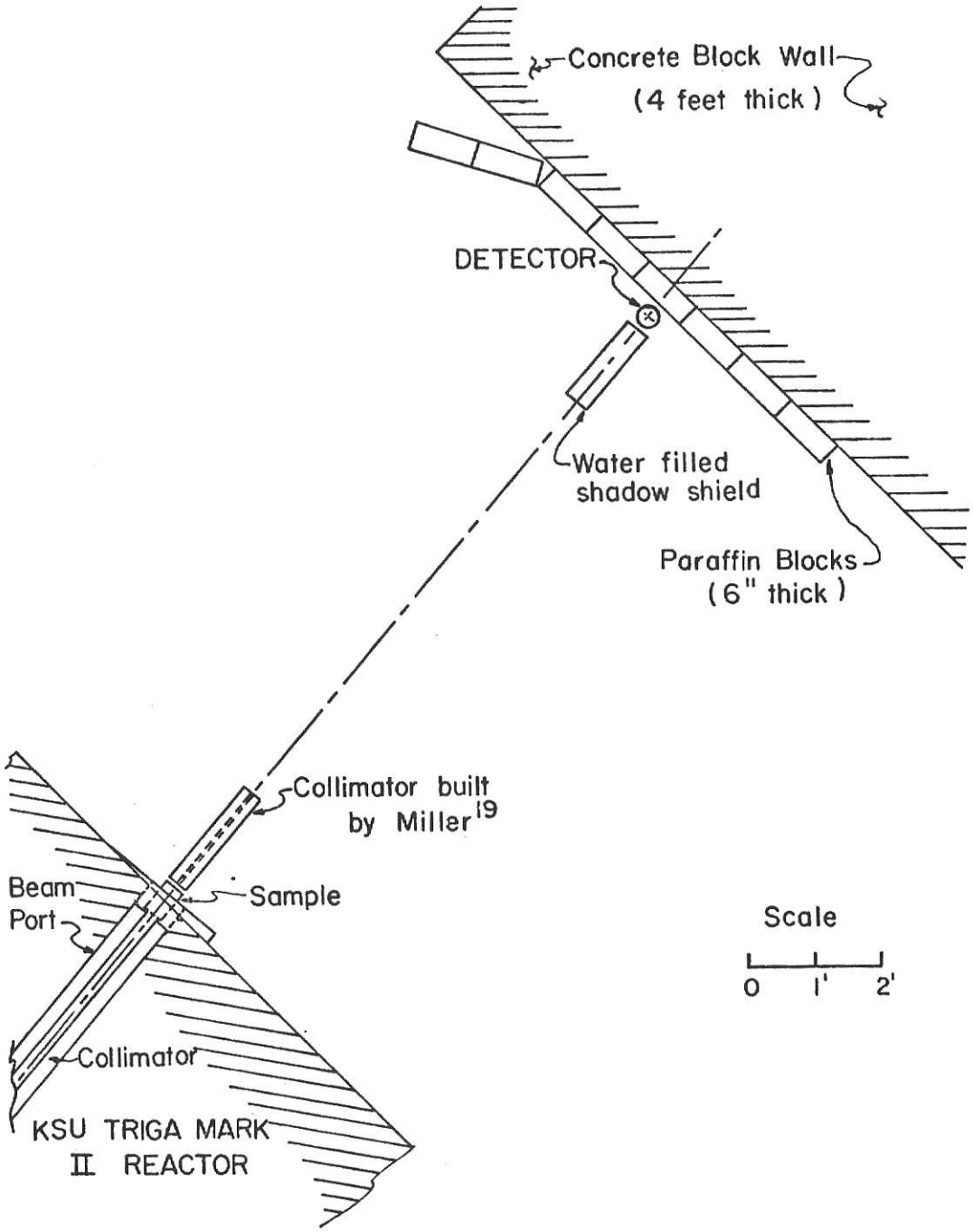


FIGURE 25. EXPERIMENTAL ARRANGEMENT FOR MEASURING TRANSMITTED NEUTRON SPECTRA

sample in the beam. This equipment arrangement was aligned with the neutron beam using a surveyor's transit. A background shadow shield (a 3-inch I.D. cylinder 24 inches long, filled with water) was placed in front of the detector as shown in Figure 25 for background measurements.

Since only the shape of the neutron spectrum above the maximum energy to be analyzed is needed (See Appendix C), Miller's measured iron penetration[19] spectrum was used. It was transformed to neutron flux per unit lethargy and used to unfold the iron penetration spectrum measured with the 10 atmosphere detector.

The NE-213 scintillation detector, and the 10, 4, and 1 atmosphere Benjamin-type detectors were used to measure the transmitted neutron spectrum through aluminum. The TMC 4096 Multichannel analyzer was used to accumulate the raw data in 1024 channels. These data were then binned down to 400 channels (to be compatible with SPEC 4) by a computer code, NUDASBIN, written by J. W. Thiesing and typically used for all NE-213 data reduction. The unfolded results of the iron and aluminum penetrations are shown in Figures 26 and 27, respectively.

As can be seen from Figure 27, the 10 atmosphere aluminum penetration spectrum must be shifted 0.0728 MeV to the left, for the 4 atmosphere detector the spectrum requires shifting 0.045 MeV to the right and a 0.100 MeV shift to the right is required for the 1 atmosphere detector. This results in an equivalent neutron energy for the alpha particle of 3.86 MeV, 1.83 MeV, and 0.362 MeV for the 10, 4, and 1 atmosphere detectors, respectively. The shifted spectrum for the iron penetration along with measured iron penetration data presented by Cerbone[16] are shown in Figure 28. Figure 29 shows the shifted aluminum penetration spectrums.

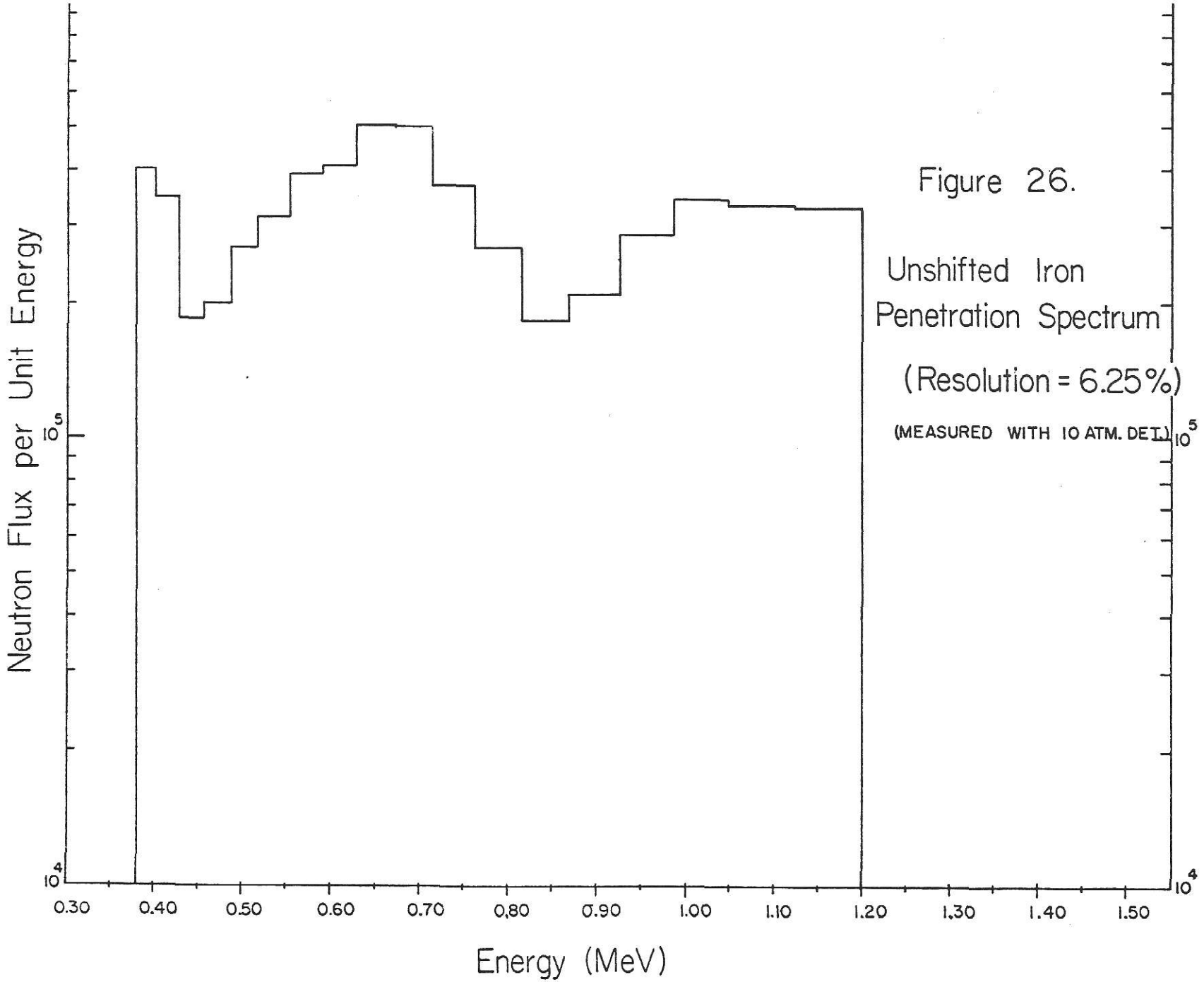

Neutron Flux per Unit Energy
10^5
10^4
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
Energy (MeV)
Unshifted Iron
Penetration Spectrum
(Resolution = 6.25%)
(MEASURED WITH 10 ATM. DET.)

Figure 26.

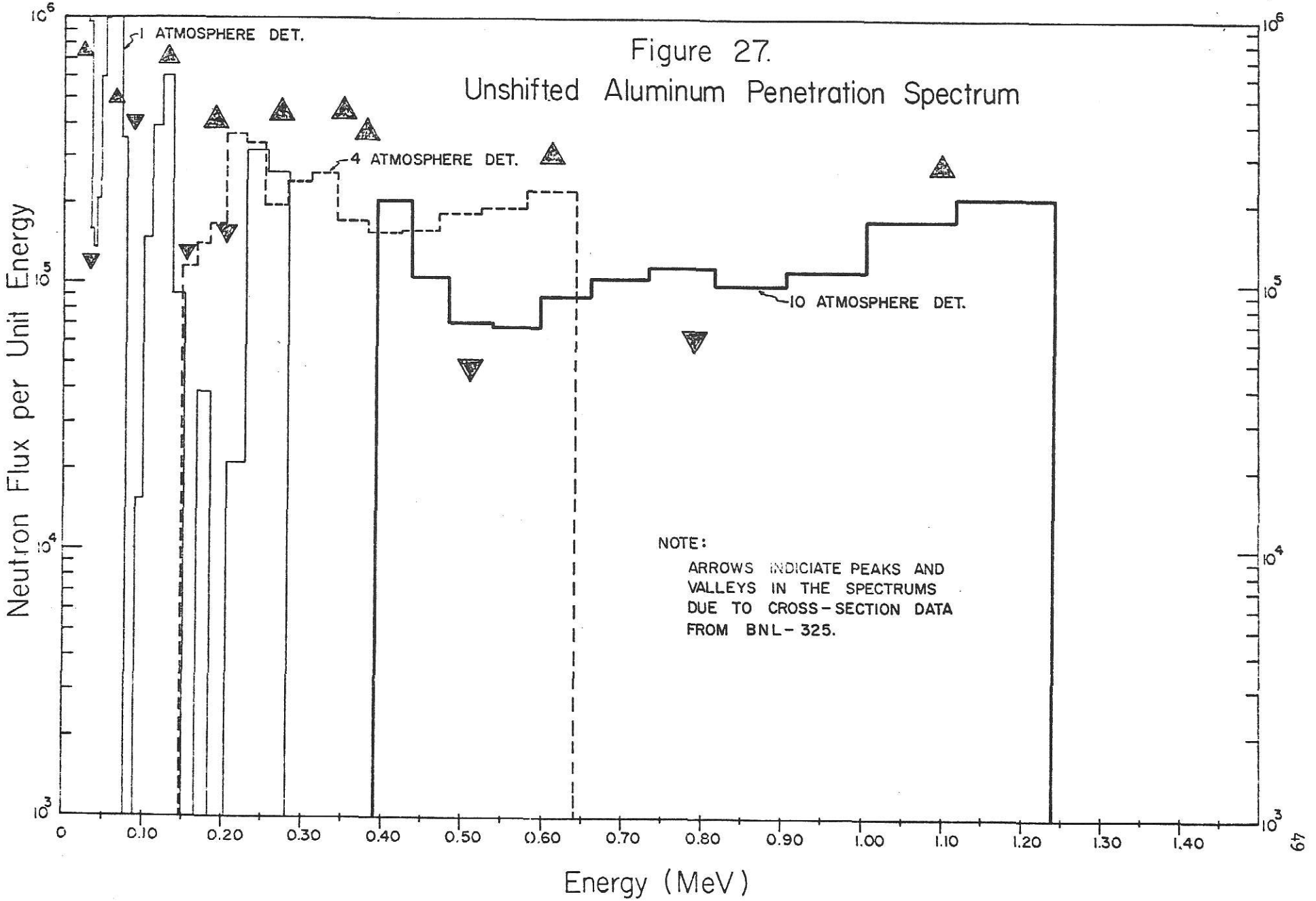


Figure 27.
Unshifted Aluminum Penetration Spectrum
1 ATMOSPHERE DET.
4 ATMOSPHERE DET.
10 ATMOSPHERE DET.
NOTE:
ARROWS INDICIATE PEAKS AND VALLEYS IN THE SPECTRUMS DUE TO CROSS-SECTION DATA FROM BNL-325.
Neutron Flux per Unit Energy
Energy (MeV)
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40

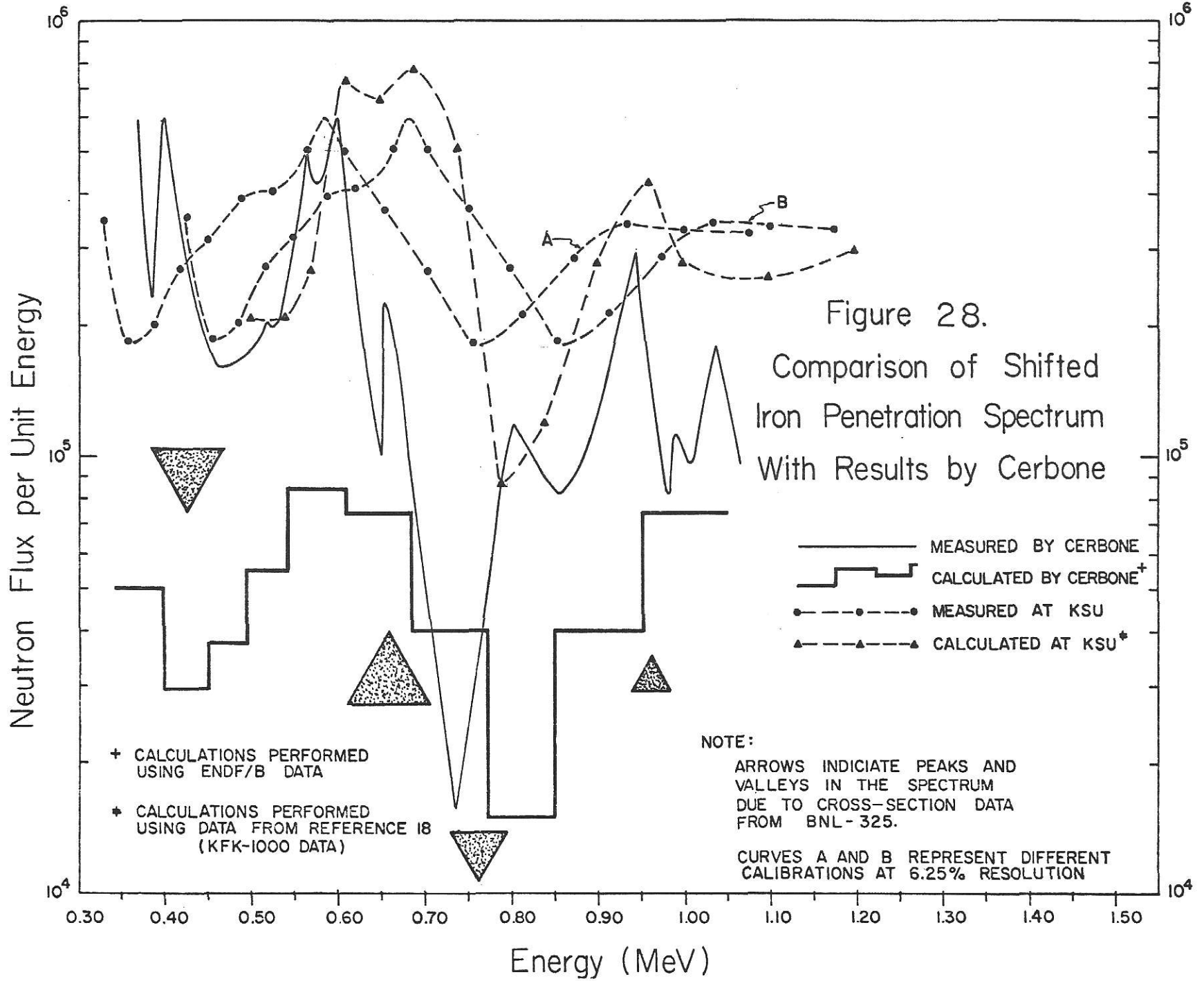


Figure 28.
Comparison of Shifted Iron Penetration Spectrum With Results by Cerbone

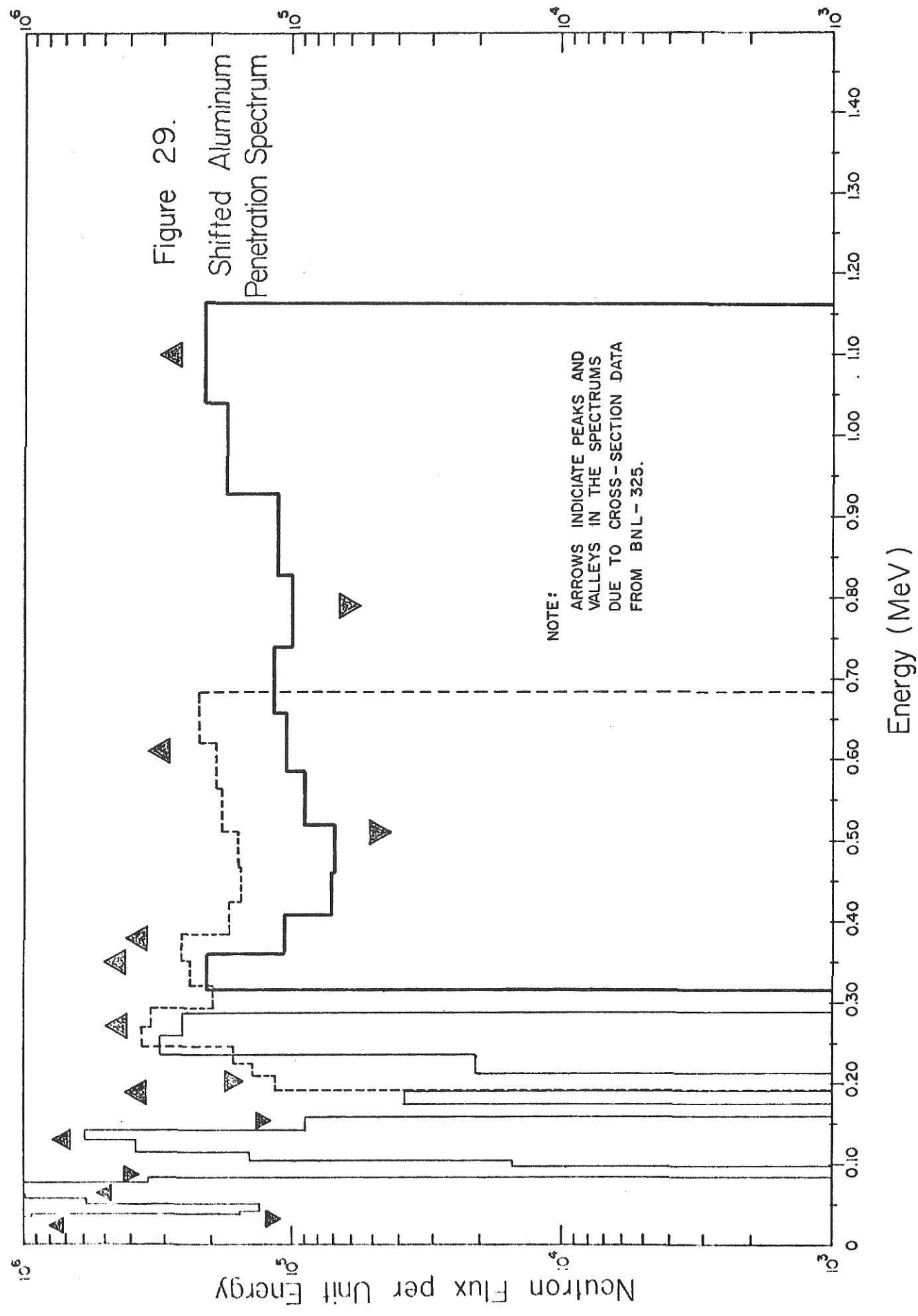


Figure 29.
Shifted Aluminum
Penetration Spectrum
NOTE:
ARROWS INDICIATE PEAKS AND
VALLEYS IN THE SPECTRUMS
DUE TO CROSS-SECTION DATA
FROM BNL-325.
Neutron Flux per Unit Energy
Energy (MeV)

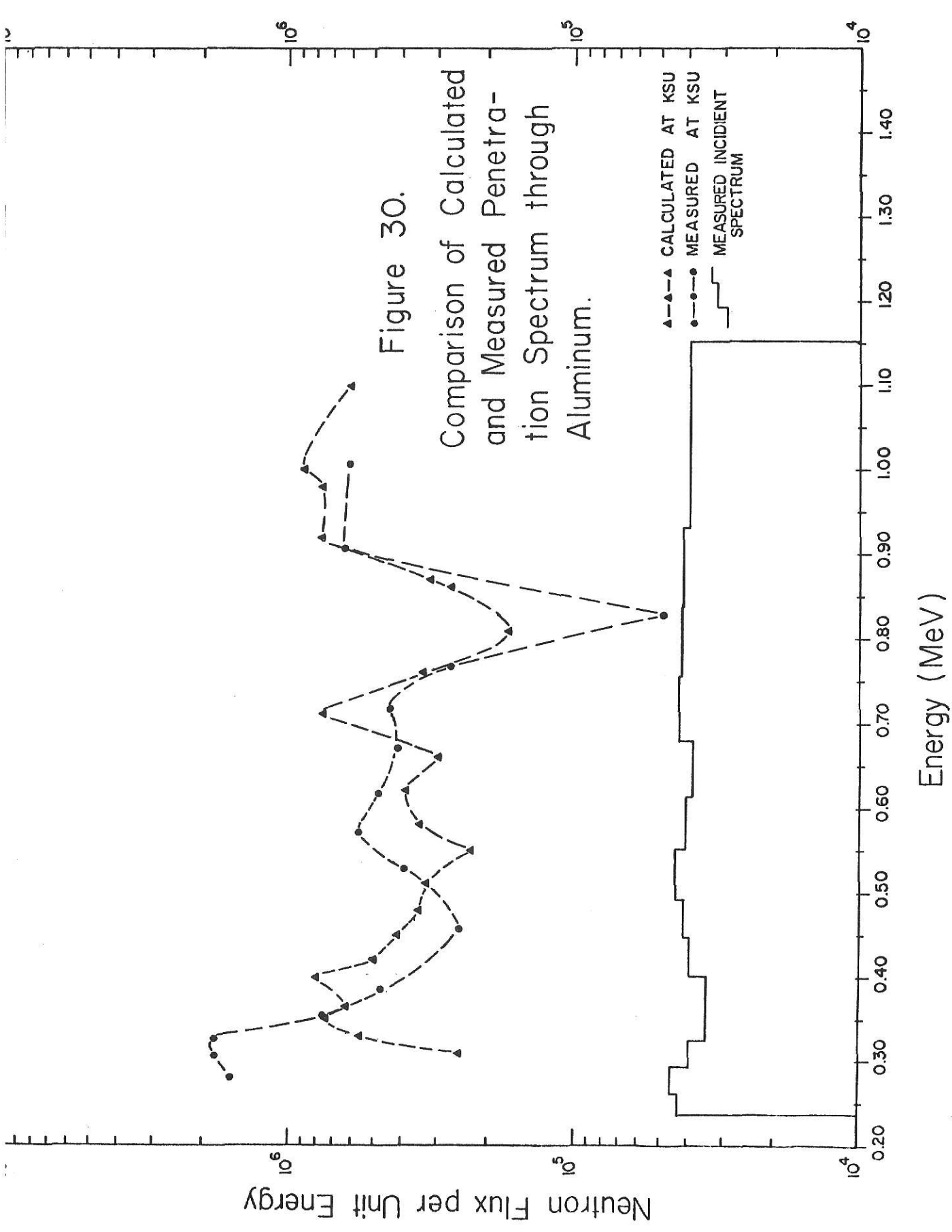


Figure 30.
Comparison of Calculated and Measured Penetration Spectrum through Aluminum.

As a further check on the calibration of this system, calculations were performed to obtain a calculated transmitted spectrum through aluminum and iron in the energy range of the 10 atmosphere detector. The transmitted spectrum can be calculated as:

$$\phi_{trans}(E) = \int_0^\infty \phi_I(E')\exp\,[-\Sigma_t(E')t]\; R(E,E')dE' \qquad (18)$$

where $\phi_I(E')$ = incident flux at E'

$\Sigma_t(E')$ = total neutron cross-section at E'

$R(E,E')$ = probability of a neutron of energy E' being detected at energy E.

Due to lack of resolution data for these detectors, the resolution function R(E,E') was assumed to be of the form of a gaussian:

$$R(E,E') = Y_o(E)\exp - \frac{(E - E')^2}{b_o(E)} \qquad (19)$$

where $Y_o = \frac{1}{\sqrt{b_o \pi}}$, which normalizes the function R(E,E') such that

$\int R(E,E')dE' = 1$

E = neutron energy detected

E' = actual neutron energy

b_o = $(FWHM)^2/4 \cdot \ln(2)$, where FWHM is the full width at half the maximum height of the gaussian peak.

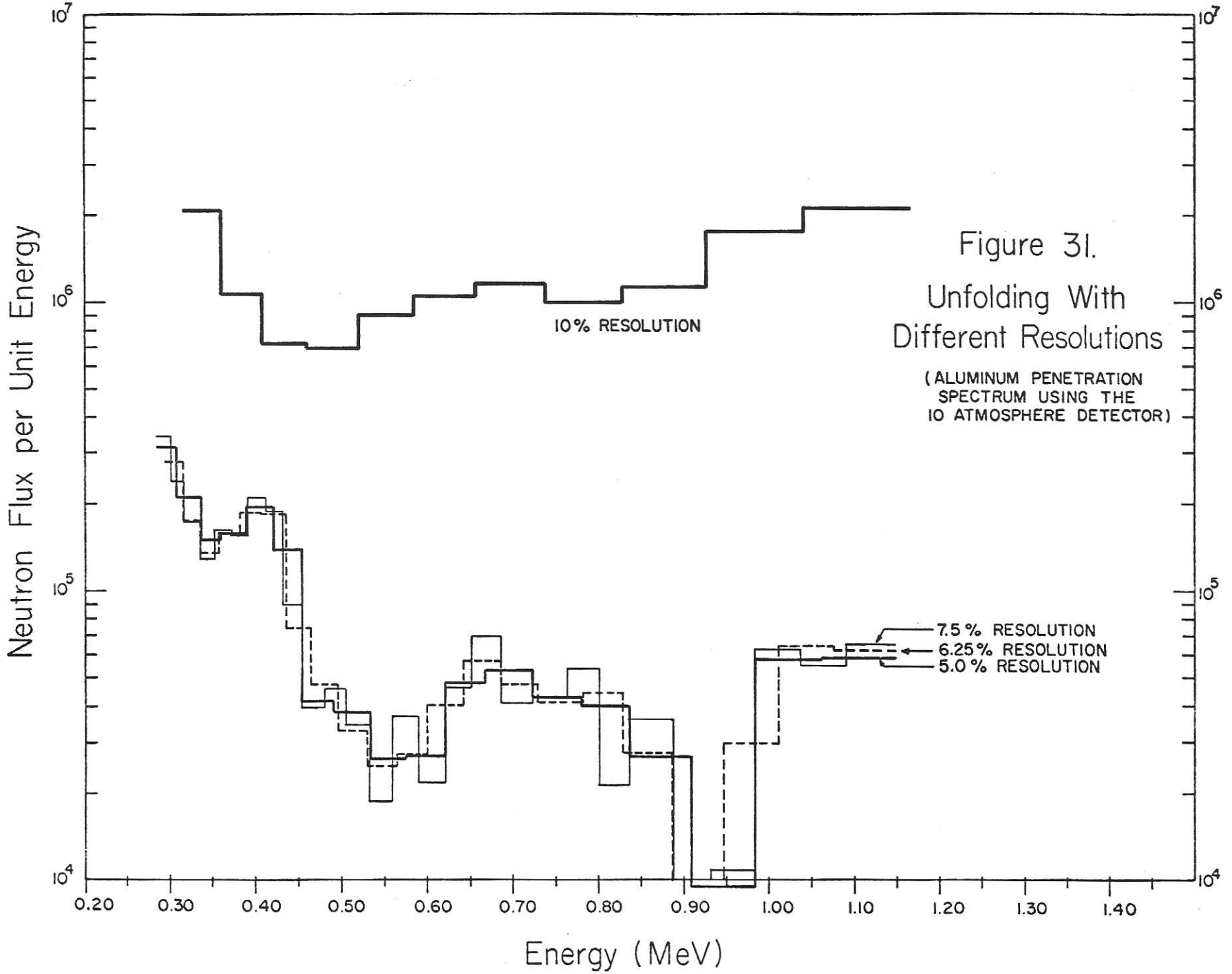
This procedure was also used by Miller[19] and yielded good agreement between measured and calculated neutron penetration spectrums. The results of the calculated and measured neutron penetration spectrums through aluminum in the energy range of the 10 atmosphere detector are shown in Figure 30.

The effect of resolution on the unfolding of complex recoil-proton spectrums was also considered. Since the resolution of these detectors was

not known, it was assumed to be a constant (not a function of energy) for each detector. It should be noted that the unfolding code used, SPEC 4, binned the input data according to a constant resolution. The aluminum penetration spectrum for the 10 atmosphere detector was unfolded using 10, 7.5, 6.25, and 5 per cent resolutions. These results are shown in Figure 31. A resolution of 6.25 per cent for the 10 atmosphere detector tends to yield a neutron spectrum with the most character and the least oscillations.

5.2 Measurement of a Californium-252 Neutron Spectrum

A neutron spectrum for Californium-252 was also measured. This spectrum peaks at approximately 0.80 MeV and is smoothly decreasing above and below this energy[20]. The calculated and measured Californium-252 neutron spectrums are shown in Figure 32.


Neutron Flux per Unit Energy
Energy (MeV)
10% RESOLUTION
7.5 % RESOLUTION
6.25% RESOLUTION
5.0 % RESOLUTION
Figure 31.
Unfolding With
Different Resolutions
(ALUMINUM PENETRATION
SPECTRUM USING THE
IO ATMOSPHERE DETECTOR)

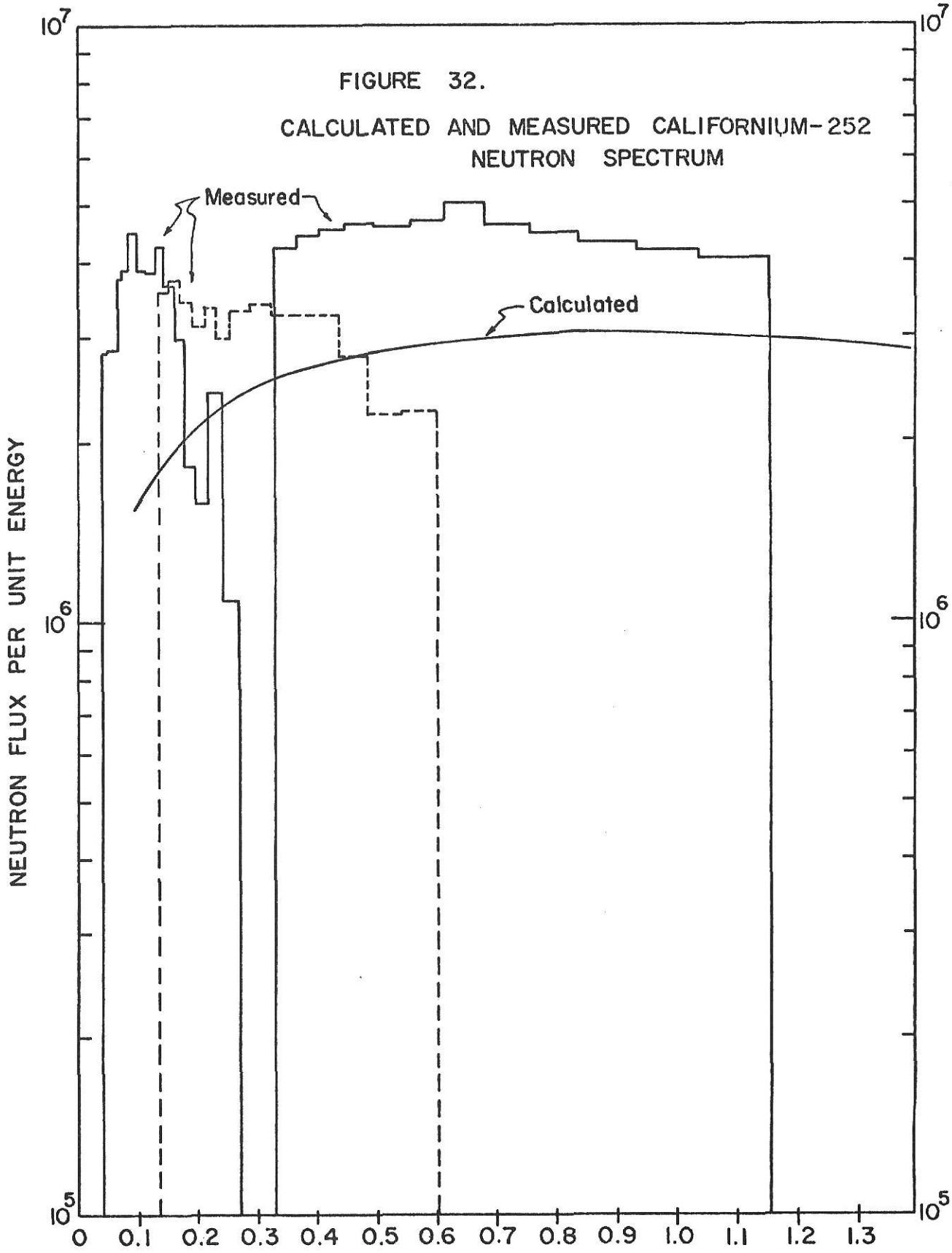


FIGURE 32.
CALCULATED AND MEASURED CALIFORNIUM-252
NEUTRON SPECTRUM
Measured
Calculated
NEUTRON FLUX PER UNIT ENERGY
10^7
10^6
10^5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3

6.0 DISCUSSION OF RESULTS AND CONCLUSIONS

The results of this study presented in the preceding pages may be summarized as follows:

1. A spectrum of the internal alpha calibration source was measured for each of the three detectors. Good resolution of the alpha peak was obtained for each detector, well within the technical specifications for each detector.

2. A linear pulse shaping electronic system was developed with a relatively high signal-to-noise ratio and good linearity.

3. An electronic pulse shape discrimination system was developed utilizing fast and slow components of the pulse. Performance of this system seemed to be very satisfactory, inasmuch as very few pulses from a pure gamma-ray source were gated through the system, while a continuous neutron spectrum was recorded. The ratio of counts without gamma-ray discrimination to counts with gamma-ray discrimination (the gamma-ray discrimination ratio) is approximately 1000 to 1.

4. The unfolding code SPEC 4 was brought to an operational status at KSU and synthetically checked using artificially generated monoenergetic response functions and monoenergetic response functions generated by the subroutine SNIDOW. These results were also satisfactory.

5. Calibration of the spectrometer system was accomplished using minima in the total neutron cross sections of iron and aluminum. Comparison of Figure 26 the unfolded iron penetration spectrum for the 10 atmosphere detector with Figure 28 showing the experimental and calculated penetrations spectra prepared both at KSU and by Cerbone[16], is informative. Curves A and B in Figure 28 are the measured penetration spectrum in Figure 26 shifted linearly

in energy and with the midpoints of the histogram connected with a dotted line to aid comparison. If the measured penetration spectrum at KSU is shifted to the position of curve A, the calculated KSU spectrum agrees well with the measured spectrum at the higher energy end with a gradually increasing difference in the peaks and valleys as lower energies are approached. Similarly, if the measured KSU penetration spectrum is shifted to the position of curve B, the calculated KSU spectrum agrees well from 600 keV to 750 keV with a shifting away from agreement of the peaks and valleys above and below this range. It should also be noted that a comparison of Cerbone's[16] calculated and measured penetration spectra show energy shifted differences above and below the energy range 600 keV to 750 keV. This suggests errors in the cross-section data for iron.

An aluminum penetration spectrum was also measured with all three detectors and unfolded as shown in Figure 27. The 10 atmosphere detector was calibrated as in Figure 26. The aluminum penetration spectra were then shifted linearly with energy as shown in Figure 29. The shape of the penetration spectra in the overlapping energy regions of the 10, 4, and 1 atmosphere detectors are conserved very well. However it is again apparent that there is a non-linear difference between the measured penetration spectra peaks and valleys and those indicated by BNL-325 cross-section data after linear energy shifting. Figure 30 confirms this result with a comparison of a KSU calculated aluminum penetration spectrum and a 10 atmosphere detector measured penetration spectrum. The two spectra match at the higher energy end (at 820 keV and 720 keV) with a gradually increasing difference in the position of the peaks and valleys as lower energies are approached.

SPEC 4 unfolding was also carried out assuming various detector energy resolutions with the results shown in Figure 31. The unfolded results obtained

with 10% and 7.5% resolutions seem too smooth; the spectrum is too flat from 650 keV to 850 keV. The unfolded results obtained with an assumed 5% resolution tend to oscillate (the data are binned on a too small energy grid). A resolution of 6.25% does not oscillate but still allows the two peaks to appear between 650 keV and 850 keV. It is also to be expected that again, the resolution will be a function of energy and not a constant as assumed by SPEC 4[19].

6. To represent better the resolution of the detector as a function of energy, KSU penetration calculations were performed for different resolutions by Richard Seck using CALFLUX[19]. Calculated penetration spectrums through aluminum were obtained for resolutions from 15% down to 5%. Calculated spectrums at 15% and 6.25% resolution are shown in Figure 33 with a measured penetration spectrum unfolded at 6.25% resolution. The low energy peak of the spectrum at about 380 keV, assumes a shape similar to that calculated for 15% resolution. The higher energy valley at about 800 keV to 900 keV assumes a shape similar to that calculated at 6.25% resolution. These results suggest a resolution varying with energy as shown in Figure 34.

7. *Measurements of a Californium-252* neutron source spectrum were performed. Good results were obtained with the 10 atmosphere Benjamin-type detector as compared to the calculated Californium-252 neutron spectrum. The 4 atmosphere and 1 atmosphere Benjamin-type detectors, however, *did not yield* the results expected. Two difficulties encountered were the relatively low activity of the Californium-252 source and the low efficiency of the 1 atmosphere and 4 atmosphere detectors. These effects resulted in poor statistics and large standard deviations in the unfolded neutron spectrums. Also the Californium-252 spectrum decreases sharply with energy in the energy range of the 4 and 1 atmosphere detectors. A different unfolding procedure, such as

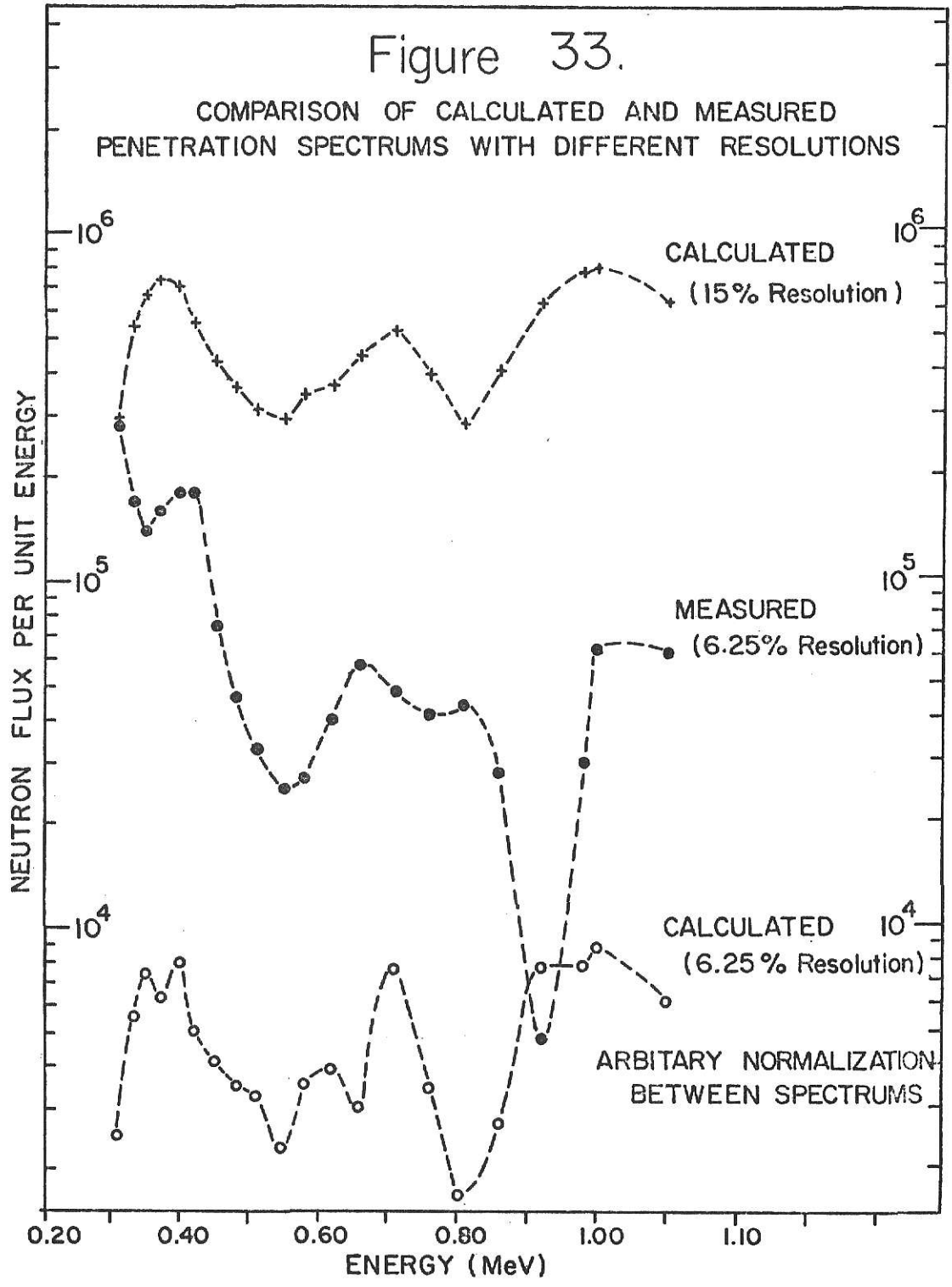


Figure 33.
COMPARISON OF CALCULATED AND MEASURED
PENETRATION SPECTRUMS WITH DIFFERENT RESOLUTIONS
NEUTRON FLUX PER UNIT ENERGY
10^6
10^5
10^4
CALCULATED
(15% Resolution)
MEASURED
(6.25% Resolution)
CALCULATED
(6.25 % Resolution)
ARBITARY NORMALIZATION
BETWEEN SPECTRUMS
0.20
0.40
0.60
0.80
1.00
1.10
ENERGY (MeV)

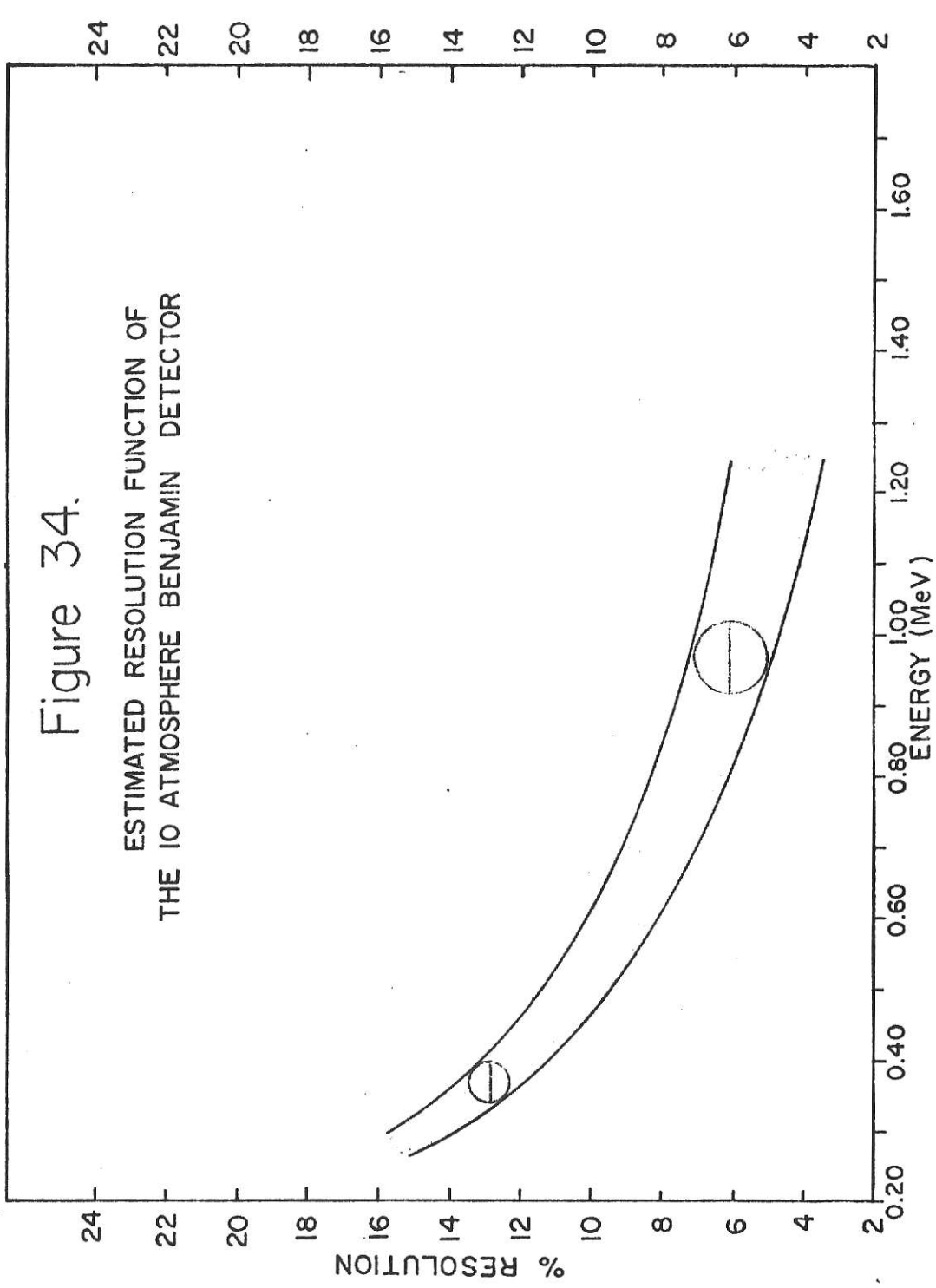


Figure 34.
ESTIMATED RESOLUTION FUNCTION OF
THE IO ATMOSPHERE BENJAMIN DETECTOR
% RESOLUTION
ENERGY (MeV)
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
2
4
6
8
10
12
14
16
18
20
22
24

that proposed by Mutone[20], may bring the problem into better perspective, but the author is, at this time, uncertain of the exact causes of differences between the calculated and measured Californium-252 spectra for the 4 and 1 atmosphere detectors.

In conclusion the Benjamin-type neutron spectrometer system developed appears to have potential application to the measurement of neutron spectral data in the energy range 1 keV to 1.1 MeV. Preliminary indications show the resolution of the system to be better than expected and to be a varying function of energy as indicated in Figure 34. The efficiency of the gas-filled detectors is, however, very low and will present problems in low flux fields. The calibration studies have yielded very promising results and indicate that only the 1 and 10 atmosphere detectors are needed to complement the NE-213 neutron spectrometer system from approximately 30 keV up to 1 MeV.

7.0 SUGGESTIONS FOR FUTURE STUDY

A number of areas require further study to improve the performance and reliability of this Benjamin-type neutron spectrometer system. Of primary importance are the following areas:

1. An improved energy calibration procedure is required to set the gain of the electronics more accurately. For this study the alpha peak was positioned in the TMC 4096 multichannel analyzer. The gain of the electronics was then adjusted according to the equivalent neutron energy of the alpha particle and the desired maximum energy to be analyzed. This adjustment then placed the alpha peak higher than the maximum energy that could actually be stored in the analyzer. The final gain adjustment was routinely made with a variable fine gain control for a reference. This procedure generally allowed a substantial deviation (50 keV tolerence or more) in the calibration.

2. Further study is also required to perfect the gamma-ray discrimination system to determine the exact discrimination levels for removing gamma-ray induced pulses. During this study, approximately 30 keV was the low energy neutron threshold for the one atmosphere detector. With further study energies approaching a 1 keV threshold may be obtained. Use of the ORTEC 458 Pulse Shape Analyzer may possibly improve the gamma ray discrimination system; it would reduce the number of components required and possibly enhance the difference between gamma-ray and neutron induced pulses to a greater extent than the system described here.

3. Energy resolution of the three detectors should be determined where possible using monoenergetic neutron beams. During such studies the energy calibration of the system could be studied in more detail than the penetration studies performed here permitted.

4. Absolute flux calibration would be straight forward if the absolute flux above E_{max} is known instead of just the shape of the flux. Since SPEC 4 normalizes the spectrum above E_{max} to the measured recoil proton distribution by a normalizing factor A, the unfolded neutron spectrum need only be multiplied by 1/A to obtain the absolute neutron spectrum.

5. The problem encountered in measuring a Californium-252 neutron spectrum with the 4 and 1 atmosphere detectors must be resolved. This is perhaps the most critical and disturbing problem encountered with the system. As mentioned previously, an unfolding procedure other than SPEC 4 such as that proposed by Mutone[14] may yield improved results or insight into the source of the substantial difference between the calculated and 1 and 4 atmosphere measured spectrums for Californium-252.

8.0 ACKNOWLEDGEMENTS

The author would like to express special appreciation to Dr. Walter Meyer, who assisted the author through his college career and under whose direction this study has been performed.

The author would like to express his gratitude to Dr. M. S. Krick for his advice and assistance regarding the electronic theory and equipment used in this study, to Dr. Hermann Donnert and Dr. Dean Eckhoff for their personal communications on various topics, to Dr. J. W. Thiesing for his private communications concerning transmission calculations and the theory of unfolding, to Richard Seck for his resolution studies, to Bill Starr and Dave Stallbaumer who diligently maintained the electronic equipment, and to the Atomic Energy Commission who supported this study under their traineeship program. The author would like to acknowledge his mother, Mrs. Charles H. Estes, Miss Maureen Beaudet, Mrs. Kathleen Scanlan, and the Engineering Experiment Station at Kansas State University for their typing of the several drafts of this thesis.

Finally, the author would like to express his love and appreciation to his wife, Karla, for her patience and understanding during this study.

9.0 REFERENCES

1. G. G. Simons, "Development, Calibration, and Utilization of the KSU NE-213 Fast-Neutron Spectrometer," Ph.D. Dissertation, Nuclear Engineering, Kansas State University (1968).

2. W. Meyer, et al., "Fast Neutron Transmission Measurements for Reactor Core and Shielding Materials," Technical Progress Report to Division of Research US/AEC (AEC Contract No. AT(11-1) 2049) COO-2049-1 Nuclear Engineering, Kansas State University (February, 1970).

3. R. E. Seck, Personal communications to Dr. Walter Meyer, Kansas State University (June 1969).

4. P. W. Benjamin, et al., "The Use of a Gas-Filled Spherical Proportional Counter for Neutron Spectrum Measurements in a Zero Energy Fast Reactor," Atomic Weapons Research Establishment, AWRE Report No. NR2/64.

5. J. M. Larson, "A Wide Band Charge-Sensitive Preamplifier for Proton-Recoil Proportional Counting," Argonne National Laboratory (1969).

6. ORTEC, "Instruments for Research," Catalog 1002.

7. Twentieth Century Electronics, Limited, "Spherical Proportional Counters."

8. R. G. Graf, "The Implementation and Calibration of a Benjamin-type Neutron Spectrometer for Energies Below 1.5 MeV," A Master's Thesis, University of Tennessee (1970).

9. E. F. Bennett, "Gamma-Ray Discrimination in a Proton-Recoil Proportional Counter, Argonne National Laboratory.

10. J. B. Parker, A Tabulated Range-Energy Table Generated by SPEC-4, Nuc. Instr. and Methods, 23, 61(1963).

11. R. E. Seck, "Development of an NE-213 Fast-Neutron TAC Spectrometer System Utilizing Off-Line Gamma-Ray Discrimination," A Master's Thesis, Kansas State University (1971).

12. ORTEC, "Pulse Shape Analyzer," Instruction Manual 458.

13. M. J. Coolbaugh, "Fast Neutron Spectroscopy in Aqueous Media Using an NE-213 Proton-Recoil Neutron Spectrometer System," Ph.D. Dissertation, Nuclear Engineering, Kansas State University (1971).

14. Mutone, J. Personal Communication - unpublished data (August, 1971).

15. P. W. Benjamin, et al., "The Analyses of Recoil Proton Spectra," Atomic Weapons Research Establishment, AWRE Report No. 0968.

16. Cerbone, R. J., "Neutron and Gamma Ray Spectra in an Iron Spherical Assembly," Gulf General Atomic, Inc., presented at the annual meeting of the American Nuclear Society in Seattle, June 15-19, 1969.

17. United States Atomic Energy Commission, "Neutron Cross Sections," BNL 325, Vol. 1 (May, 1964).

18. Cierjacks, S., P. Forti, D. Kopsch, J. Nebe, and H. Unseld, "High Resolution Total Neutron Cross-Sections Between 0.5-30.0 MeV," KFK-1000, Institut fur Angewandte Kernphysik, Karlsruhe (June, 1968).

19. Miller, H. W., "The Evaluation of Minima in Total Neutron Cross-Section by Transmission of Fission Spectra Through Thick Samples," A Master's Thesis, Kansas State University, (1971).

20. United States Atomic Energy Commission, "Californium-252, Its Use and Market Potential," (September, 1969).

10.0 APPENDICES

APPENDIX A

A-1.0 Operation of SPEC 4

SPEC 4 is an unfolding code used by Benjamin, Kemshall, and Buckshall[14], and Graf[8]. It calculates a complex neutron spectrum, ϕ^j, by back substitution (unfolding) in the following equation (see Chapter 4):

$$DM^i = \sum_{j=1}^{i} DM_o^{ij}\phi^j \qquad (1)$$

The following is a general list of operations, in chronological order, performed by SPEC 4:

1. Reads in range-energy data for hydrogen and carbon.

2. Reads in the number of points in the neutron spectrum present above that which is to be analyzed.

3. Reads in the neutron spectrum above the maximum to be analyzed and the corresponding energies.

4. Reads in the calibration, back bias of the analyzer, minimum neutron energy to be analyzed, maximum neutron energy to be analyzed, number of channels present, a data smoothing indicator, and a re-run indicator.

5. Reads in detector radius, hydrogen pressure, methane pressure, and resolution of the detector.

6. Bins the channels or energy groups according to the resolution of the detector.

7. Calculates a range-energy table according to types of gases present and gas pressures.

8. Generates a square matrix of recoil proton distributions according to the binning in 6 by calling subroutine SNIDOW.

9. SNIDOW calculates the number of protons (C(E)dE) which will deposit an energy between E and E + dE in a spherical counter according to the equation:

$$\frac{C(E)}{C_T} = \frac{F(E)}{E_n} + \frac{1}{E_n} \int_E^{E_n} \frac{dR(E' - E)}{dE} N[R(E') - R(E' - E)]\, dE' \qquad (2)$$

where C_T is the total number of recoil protons, E_n is the neutron energy, F(E) is the fraction of neutrons with energy E that will stop in the counter, and R(E) is the range of a proton having energy E.

SNIDOW calculates F(E) by defining N(L)dL as the probability that a proton will see a path length to the counter wall between L and L + dL which is given by:

$$N(L)dL = \frac{3}{4a}\left[1 - \frac{L^2}{4a^2}\right] dL, \qquad (3)$$

where a is the radius of the counter. F(E) is then defined as:

$$F(E) = \int_{R(E)}^{L_{max}} N(L)dL$$

$$= 1 - \frac{3R(E)}{4a} + \frac{R^3(E)}{16a^3} \qquad (4)$$

where L_{max} is just equal to 2a.

If the correction factor as mentioned in appendix B is less than 2.0, the range is essentially constant and the term N[R(E') - R(E' -E)] is replaced by N(R(E)) at the initial proton energy. SNIDOW then calculates the approximation to Equation (2), namely:

$$\frac{C(E)}{C_T} = \frac{F(E)}{E_n} + \frac{N(R(E))}{E_n} R(E - E) \qquad (5)$$

SNIDOW will first calculate $\bar{N}$ and check if the error is greater than 2%. If it is, Equation (2) is used to calculate $C(E)/C_T$ by the use of Simpson's rule.

10. The square monoenergetic response matrix from SNIDOW is then differentiated to obtain a differential monoenergetic response matrix.

11. The proton recoil spectrum due to neutrons above the maximum energy to be analyzed (E_{max}) is then calculated by calling the subroutine SPEC 2S, which repeatedly calls the subroutine SNIDOW.

12. The measured proton recoil spectrum is then read in by the subroutine CONTIN which normalizes background to foreground for counting times and distances and performs background subtraction.

13. The data are transferred to a smoothing subroutine called VSMTH which smooths the measured data transferred from CONTIN with gaussian shaped curves according to the resolution of the detector.

14. The calculated recoil proton spectrum due to neutrons above E_{max} is normalized to the measured recoil proton spectrum at the maximum energy group to be analyzed. This calculated recoil proton spectrum is then subtracted from the measured recoil proton spectrum.

15. This resulting spectrum is divided by the calibration number (to obtain cts/MeV) and normalized to an external monitor.

16. The measured recoil proton spectrum is binned according to the energy groups set up previously.

17. The neutron flux distribution is calculated by multiplying the differential of the measured recoil proton vector by the inverse matrix of the differential of the monoenergetic response function matrix according to the equation:

$$\left\{\phi^j\right\} = \left(\frac{\partial M_o^{ij}}{\partial E_j}\right)^{-1} \left(\frac{\partial M^i}{\partial E_p}\right) \qquad (6)$$

18. A neutron flux per unit energy and a neutron flux per unit lethargy are then calculated according to the previous binning.

19. Finally, a new neutron spectrum is calculated above E_{max} for the next lower pressure detector by using the previously calculated neutron spectrum.

The following is a list of input data and code listing for SPEC 4 and its subroutines taken from reference 14.

A1.1 INPUT DATA FORMATE FOR SPEC 4

A1.101 Hydrogen R-E data, R in cm at 1 atm and 15°C, E in keV.

Format 6E12.6, order E(I), R(I), I = 1, 92.

A1.102 Methane R-E data, R in cm at 1 atm and 15°C, E in keV.

Format 6E12.6, order E(I), R(I), I = 1, 92.

A1.103 Number of points on input neutron spectrum

Format I10.

A1.104 List of input neutron spectrum (flux per unit lethargy).

Format 6E12.5, order increasing energy.

A1.105 List of energies of points in A1.4, in MeV.

Format 6E12.5.

A1.106 Analyzer data:

CAL calibration in MeV per channel.
BBIAS back bias in channels (see Section 5.4).
EBOT lowest energy to be analyzed in MeV.
EMAX highest energy to be analyzed in MeV.
CH number of channels in the analyzer.
SMT smoothing indicator. SMT $\leq$ 0 - no smoothing.
SMT + ve - smoothing.
RTST $\leq$ 0 - program goes to read A1.03 on end of this run.
RTST + ve - program goes to read A1.06 on end of this run.

Format 7F10.0 Order CAL → RTST

A1.107 Counter parameters:

RAD radius in cm.
GPH hydrogen gas pressure in atmospheres.
GPC methane gas pressure in atmospheres.
RES counter resolution (%). This determines the width of the calculated neutron spectrum groups and is also used for smoothing.

A1.108 Number of runs at same counter and analyzer parameters and input neutron spectra. At end of each analysis the program jumps back to item A1.10 rather than item A1.3. This is useful if several short runs are recorded on an analyzer rather than one long one.

Format I2.

A1.109 Title card for this run.

Any alphanumeric characters in columns 1-72.

A1.11 Monitor count for this run.

Format F7.0.

A1.111 Analyzer spectrum.

Format 10F7.0, order - channels 1 to CH.

COMMENTS

If the input spectrum is normalized to a flux per unit lethargy per unit monitor count scale the normalizing factor printed out by SPEC 4 should equal the monitor count read in.

If smoothing is used the external errors are meaningless and so they are replaced by 0.5 times the internal errors.

A-1.2 SPEC 4 CODE LISTING

```
FORTRAN IV G LEVEL  18                  MAIN              DATE = 71251        12/20/05              PAGE 0001

            C       PROGRAM SPEC 4*****************************************
            C       PROGRAM SPEC 4*****************************************
0001                 DIMENSION ICH(32),ECH(32),EMID(31),SIGMA(31),RM(31,31),
                    1YMC(400),CTS(400),GSPEC(30),TLE(12),GFLX(30),EFLX(30),UFLX(30),
                    2CORF(100),DE(31),YCH(400),DSPEC(400),ERS(400),ER2(31),FER(31),
                    3ERI(31),FERI(31),EYCH(31),RMM(31,31),EHI(31),ELO(31),ECONS(31)
0002                 DIMENSION FU(75),U(75),ACH(31,31)
0003                 DIMENSION E(93),RH(93),RC(93),R(93)
            C       TYPE DOUBLE TLE  ***********************************
0004                 READ(1,177) (E(K),RH(K),K=2,93)
0005                 READ(1,177) (E(K),RC(K),K=2,93)
0006               177 FORMAT (6E12.6)
0007                 DO 73 I=2,93
0008                 E(I)=E(1)/1000.
0009                73 CONTINUE
0010               998 READ(1,101) NSPE
0011                  IF(NSPE) 666,666,667
0012               666 GO TO 69
0013               667 CONTINUE
0014               101 FORMAT (7I10)
0015                 NFLAG=0
0016                 READ(1,102) (FU(I),I=1,NSPE)
0017                 READ(1,102) ( U(I),I=1,NSPE)
0018               999 READ(1,100) CAL,BBIAS,EBOT,EMAX,CH,SMT,RTST
0019                 NCH=CH
0020                 ENORM=EMAX*1.05
0021               100 FORMAT (7F10.0)
0022                 READ(1,100) RAD,GPH,GPC,RES
            C*************************************************************
            C       ROUND CAL
            C
0023                 I=EMAX/CAL
0024                 A=I
0025                 CAL=EMAX/(A+0.5)
0026              2000 FORMAT(10X,I15,6F15.7)
0027              2001 FORMAT(10X,I40)
0028              2006 FORMAT(10X,7F15.7)
0029                 WRITE(3,2006) CAL,BBIAS,EBOT,EMAX,CH,SMT,RTST
0030                 WRITE(3,2006) RAD,GPH,GPC,RES
            C*************************************************************
            C       GENERATE ENERGY SCALE
            C
0031                 BBIAS=BBIAS-1.0
0032                 NN=31
0033                 I=31
0034                 RA=1.0-(RES/100.)
0035                 ICH(32)=0
0036                40 ICH(I)=A-BBIAS
0037                 IF(ICH(I)-ICH(I+1))62,63,62
0038                63 ICH(I)=ICH(I+1)-1
0039                 A=ICH(I)
0040                62 B=ICH(I)
0041                 ECH(I)=(B+BBIAS+0.5)*CAL
0042                 WRITE(3,2001) I
0043                 WRITE(3,2000) ICH(I),ECH(I)
0044                 I=I-1
0045                 A=A*RA
0046              2007 FORMAT(1H1)
```

```
FORTRAN IV G LEVEL  18                  MAIN                DATE = 71251          12/20/05              PAGE 0002

0047                  IF(I)2,2,1
0048                2 WRITE(3,2007)
0049                  WRITE(3,200) ICH(I+1)
0050              200 FORMAT (///40H LOWEST CHANNEL WHICH CAN BE ANALYSED IS,I40)
0051                  GO TO 6
0052                1 IF(ECH(I+1)-EBOT)3,3,4
0053                4 IF(ICH(I+1))39,39,40
0054               39 WRITE(3,2007)
0055                  WRITE(3,202)
0056              202 FORMAT (////50H CHANNEL 1 INDICATED REACHED BEFORE MINIMUM ENERGY)
0057                  GO TO 2008
0058                3 WRITE(3,2007)
0059             2008 NN=31-I
                 C*************************************************************
                 C      RENUMBER AND ADD ENORM (ROUNDING)
                 C
0060                  DO 5 J=1,NN
0061                  K=J+I
0062                  ICH(J)=ICH(K)
0063                  ECH(J)=ECH(K)
0064                5 CONTINUE
0065                6 K=NN+1
0066                  ICH(K)=ENORM/CAL-BBIAS
0067                  ECH(K)=(ICH(K)+BBIAS+0.5)*CAL
                 C*************************************************************
                 C      GENERATE MID ENERGY SCALE AND DE
                 C
0068                  N=NN-1
0069                  DO 7 J=1,N
0070                  K=J+1
0071                  EMID(J)=(ECH(J)+ECH(K))/2.0
0072                  DE(J)=ECH(K)-ECH(J)
0073                7 CONTINUE
                 C*************************************************************
                 C      CALCULATE NP
                 C
0074                  RA=RAD*RAD*RAD**4.1888
0075                  ANP=(GPH*2.0+GPC*4.0)*RA/3.9228/10**4
                 C*************************************************************
                 C      CALCULATE SIGMA
                 C
0076                  DO 8 I=1,N
0077                  SIGMA(I) = 9.42477/(1.206*EMID(I)+(0.09415*EMID(I)-1.86+ 0.00013*
                     1EMID(I)*EMID(I) )**2) + 3.14159/(1.206*EMID(I)+(0.4223 + 0.13*EMID
                     2(I) )**2)
0078                8 CONTINUE
                 C*************************************************************
                 C      CALCULATE RANGE-ENERGY TABLE
                 C
0079                  WRITE(3,207)
0080              207 FORMAT (1H1,23X,17HRANGE ENERGY DATA//19X,1HE,11X,2HRH,9X,4HRCH4,
                     17X,5HRANGE/)
0081                  E(1)=0.
0082                  R(1)=0.
0083                  DO 47 I=2,93
0084                  R(I)=1.0/(GPH/RH(I)+GPC/RC(I))
0085                  WRITE(3,208) E(I),RH(I),RC(I),R(I)
0086               47 CONTINUE
```

```
FORTRAN IV G LEVEL  18                  MAIN              DATE = 71251          12/20/05              PAGE 0003

0087          208 FORMAT (10X,4F12.4)
             C*************************************************************
             C      GENERATE MATRIX OF RESPONSE SLOPES
             C
0088               DO 9 I=1,N
0089               DO 10 J=1,N
0090               RM(I,J)=0.
0091            10 CONTINUE
0092             9 CONTINUE
0093               WRITE(3,2007)
0094               DO 2011 J=1,N
0095               DO 2011 I=1,N
0096          2011 ACH(I,J) = 0.0
0097               DO 11 J=1,N
0098               RA=SIGMA(J)*ANP
0099               K=J-1
0100               DO 13 I=1,J
0101               CALL SNIDOW (R,E,93,EMID(J),ECH(I),YCH(I),RAD,0,IM)
0102               IF(K)310,310,13
0103            13 CONTINUE
0104               DO 12 I=1,K
0105               RM(I,J)=(YCH(I)-YCH(I+1))*RA
0106            12 CONTINUE
0107           310 RM(J,J)=RA*YCH(J)
0108               DO 2010  I = 1,J
0109               ACH(I,J) = YCH(I)*RA
0110          2010 CONTINUE
0111            11 CONTINUE
0112               DO 2012 J=1,N
0113               WRITE(3,625) (ACH(I,J),I=1,N)
0114               WRITE(2,102) (ACH(I,J),I=1,N)
0115          2012 CONTINUE
0116               WRITE(3,621)
0117           621 FORMAT(1H1,10X,72HMATRIX OF MONOENERGETIC NEUTRON DIFFERENTIAL REC
                  1OIL PROTON DISTRIBUTIONS//)
0118               DO 616 J=1,N
0119               WRITE(3,625) (RM(I,J),I=1,N)
0120            616 CONTINUE
0121            625 FORMAT (5X,1P10E11.4)
             C*************************************************************
             C      GENERATE RECOIL SPECTRUM DUE TO NEUTRONS ABOVE EMAX
             C
0122               CALL SPEC 2S (FU,U,R,E,YCH,CAL,EMAX,RAD,ANP,NSPE,93,NCH,BBIAS)
0123            102 FORMAT(6E12.5)
0124               L=ICH(NN+1)
0125               WRITE(3,635)
0126            635 FORMAT (1H1,10X,17HOUTPUT OF SPEC 2S/)
0127               WRITE(3,525) (YCH(I),I=1,L)
0128               I=ICH(NN)+1
0129               AR=0.
0130               DO 14 J=I,L
0131               AR=AR+YCH(J)
0132            14 CONTINUE
             C*************************************************************
             C      READ IN COUNTS, SUBTRACT SPECTRUM DUE TO NEUTRONS ABOVE EMAX
             C
0133           1000 READ(1,170) ITIMES
0134            170 FORMAT (I2)
```

```
FORTRAN IV G LEVEL  18                  MAIN              DATE = 71251          12/20/05              PAGE 0004

0135                DO 95 KK=1,ITIMES
0136             28 READ(1,110) (TLE(I),I=1,12)
0137            110 FORMAT (12A6)
0138                READ(1,103) UMON
0139                CALL CONTIN(CTS,NCH)
0140            103 FORMAT ( F12.0)
0141                IF(SMT)739,739,740
0142            740 CALL VSMTH(CTS,1,NCH,RES)
0143            739 I=ICH(NN)+1
0144                L=ICH(NN+1)
0145                SCTS=0.
0146                DO 15 J=I,L
0147                SCTS=SCTS+CTS(J)
0148             15 CONTINUE
0149                IF(AR.LE.0.0) GO TO 2002
0150                A=SCTS/AR
0151                GO TO 2003
0152           2002 A = 1.0
0153           2003 WRITE(3,223) A
0154            223 FORMAT(////20X,25HDSPEC PER MEV PER MONITOR/10X,21HNORMALISING FAC
                   1TOR = ,1PE12.4/)
0155                DO 269 J=1,NCH
0156                YMC(J)=YCH(J)*A
0157            269 CONTINUE
0158                DO 16 J=1,I
0159                DSPEC(J)=(CTS(J)-YMC(J)  )/CAL/UMON
0160                ERS(J)=CTS(J)**0.5/CAL/UMON
0161             16 CONTINUE
0162                WRITE(3,224) (DSPEC(J),J=1,I)
0163            224 FORMAT(10X,10F10.3)
                C*************************************************************
                C      FIND SPECTRUM OF SLOPES
                C
0164                DO 17 I=1,N
0165                J=ICH(I)
0166                K=ICH(I+1)+1
0167                AJ=FLOAT(J+K)/2.0
0168                AL=K-J+1
0169                SXY=0.
0170                E2XY=0.
0171                SXX=0.
0172                SY=0.
0173                DO 18 M=J,K
0174                AM=M-AJ
0175                SXY=SXY+DSPEC(M)*AM
0176                E2XY=E2XY+(AM*ERS(M))**2
0177                SY=SY+DSPEC(M)
0178                SXX=SXX+AM*AM
0179             18 CONTINUE
0180                B=ICH(I+1)-ICH(I)
0181                A=SXY/SXX
0182                RA=SY/AL
0183                GSPEC(I)=-A*B
0184                ER2(I)=E2XY/SXX/SXX*B*B
0185                DD=0.
0186                DO 188 M=J,K
0187                AM=M-AJ
0188                DD=DD+(AM*A+RA-DSPEC(M))**2
```

```
FORTRAN IV G LEVEL  18                  MAIN                DATE = 71251          12/20/05                PAGE 0005

0189          188 CONTINUE
0190              ERI(I)=DD/(AL-2.0)/SXX*B*B
0191           17 CONTINUE
              C*************************************************************
              C      PRINT OUT GROUPED SPECTRUM OF SLOPES
              C
0192              WRITE(3,210)
0193          210 FORMAT (1H1)
0194              WRITE(3,1111) (TLE(I),I=1,20)
0195         1111 FORMAT(5X,20A4)
0196              WRITE(3,400) BBIAS,CH,SMT,GPH,GPC,RES
0197          400 FORMAT(//5X,6HBBIAS=,F5.2,3X,9HCHANNELS=,F5.0,3X,7HSMOOTH=,F3.0/
                 119H HYDROGEN PRESSURE=,F5.2,3X,16HCARBON PRESSURE=,F5.2,3X,
                 211HRESOLUTION=,F5.2,//)
0198              WRITE(3,203) UMON,CAL
0199          203 FORMAT (/////20X,45HGROUPED SPECTRUM OF SLOPES  PER MONITOR COUNT/
                 1/20X,15HMONITOR COUNT =,F9.2/22X,13HCALIBRATION =,F9.6//13X,9HINDI
                 2CATED,8X,6HENERGY,13X,3HMID,11X,5HSIGMA,7X,7HGROUPED,12X,8HERROR**
                 32/14X,7HCHANNEL,8X,8HBOUNDARY,11X,6HENERGY,21X,8HSPECTRUM,4X,8HINT
                 4ERNAL,6X,8HEXTERNAL/)
0200              DO 24 I=1,N
0201              J=I+1
0202              JJ=ICH(I)+1
0203              WRITE(3,204) JJ,ICH(J),ECH(I),ECH(J),EMID(I),SIGMA(I),GSPEC(I),ER2
                 1(I),ERI(I)
0204           24 CONTINUE
0205          204 FORMAT (I16,I6,F10.4,F8.4,F14.4,F14.2,F14.3,2E14.4)
              C*************************************************************
              C      UNFOLD RESPONSE FUNCTION MATRIX
              C
0206              GFLX(N)=GSPEC(N)/RM(N,N)
0207              FER(N)=ER2(N)**0.5/GSPEC(N)
0208              FERI(N)=ERI(N)**0.5/GSPEC(N)
0209              DO 25 I=2,N
0210              K=N-I+1
0211              L=K+1
0212              DO 26 J=1,K
0213              A=RM(J,L)*GFLX(L)
0214              GSPEC(J)=GSPEC(J)-A
0215              B=RM(J,L)/RM(L,L)
0216              ER2(J)=ER2(J)+ER2(L)*B*B
0217              ERI(J)=ERI(J)+ERI(L)*B*B
0218           26 CONTINUE
0219              GFLX(K)=GSPEC(K)/RM(K,K)
0220              FER(K)=ER2(K)**0.5/GSPEC(K)
0221              FERI(K)=ERI(K)**0.5/GSPEC(K)
0222           25 CONTINUE
              C*************************************************************
              C      CALCULATE FLUXES AND PRINT ANSWER
              C
0223              WRITE(3,205)
0224          205 FORMAT (1H1///20X,27HCALCULATED NEUTRON SPECTRUM//18X,6HENERGY,14X
                 1,6HFLUX /,12X,6HFLUX /,12X,6HFLUX /,16X,9H0/0 ERROR/17X,8HBOUNDARY
                 2,13X,5HGROUP,14X,3HMEV,13X,8HLETHARGY,9X,8HINTERNAL,6X,8HEXTERNAL/
                 3)
0225              SUMFLX=0.
0226              DO 27 I=1,N
0227              J=I+1
```

```
0228              EFLX(I)=GFLX(I)/DE(I)
0229              UFLX(I)=GFLX(I)/ALOG(ECH(J)/ECH(I))
0230              SUMFLX=SUMFLX+GFLX(I)
0231              IF(SMT)741,741,742
0232            742 FERI(I)=FER(I)*0.5
0233            741 EYCH(I)=UFLX(I)*FERI(I)
0234              WRITE(3,206) ECH(I),ECH(J),GFLX(I),EFLX(I),UFLX(I),FER(I),FERI(I)
0235              ECONS(I) = 0.5*(FER(I)+FERI(I))*EFLX(I)
0236              EHI(I) = EFLX(I) + ECONS(I)
0237              ELO(I) = EFLX(I) - ECONS(I)
0238              WRITE(2,555) ECH(I),ECH(J),EMID(I),EFLX(I),EHI(I),ELO(I),I
0239            555 FORMAT (5E12.5,I8)
0240             27 CONTINUE
0241              WRITE(3,7777) SUMFLX
0242           7777 FORMAT (5X,12HSUMMED FLUX=,E15.4//)
0243            206 FORMAT (F20.4,F8.4,1P3E18.4,2P2F14.2)
                C*************************************************************
                C       PUNCH AND PRINT OUTPUT SPECTRUM FOR NEXT RUN
                C
0244              DO 51 I=1,NSPE
0245              IF (EMID(N)-U(I) )52,51,51
0246             51 CONTINUE
0247              I=NSPE
0248             52 SLOPE=(EFLX(N)-EFLX(N-1))/(EMID(N)-EMID(N-1))
0249              ENUFLX=(U(I)-EMID(N))*SLOPE+EFLX(N)
0250              ANEWFU=ENUFLX*U(I)
0251              IF(FU(I).EQ.0.0) GO TO 2004
0252              RATIOU=ANEWFU/FU(I)
0253              GO TO 2005
0254           2004 RATIOU = 1.0
0255           2005 K = N + 1
0256              J=N+NSPE-I+1
0257              NSPE=J
0258              I=I+J-K
0259             57 IF(NFLAG)556,554,556
0260            554 FU(I)=FU(I)*RATIOU
0261            556 CONTINUE
0262              FU(J)=FU(I)
0263              U(J)=U(I)
0264              J=J-1
0265              I=I-1
0266              IF(K-J)57,57,53
0267             53 NFLAG=1
0268              DO 50 I=1,N
0269              FU(I)=UFLX(I)
0270              U(I)=EMID(I)
0271             50 CONTINUE
0272              WRITE(2,101) NSPE
0273              WRITE(2,102) (FU(I),I=1,NSPE)
0274              WRITE(2,102) ( U(I),I=1,NSPE)
0275              WRITE(3,610) NSPE
0276            610 FORMAT (1H1///10X,59HOUTPUT SPECTRUM READY FOR NEXT SPEC 4 RUN AT
                   1LOWER PRESSURE//10X,6HNSPE =,I5//15X,6HE(MEV),8X,6HPHI(U)/)
0277              WRITE(3,611) (U(I),FU(I),I=1,NSPE)
0278            611 FORMAT (10X,1P2E14.4)
0279             95 CONTINUE
0280              IF(RTST)998,998,999
0281             69 CONTINUE
```

```
0282                STOP
0283                END
```

A-2.0 CALLING SEQUENCE OF SUBROUTINE SNIDOW

This is:

CALL SNIDOW (R, E, N, EN, EP, C, A, IF, IM),

where R is table of proton ranges in the counter gas.

First point 0 range.

E is a table of energies (in MeV) corresponding to the range points.

First point 0 energy.

N is the number of points in the R-E table.

EN is the neutron energy (MeV).

EP is the proton energy (MeV).

C is $C(E)/C_T$ returned by the subroutine.

A is the counter radius in cm.

IF indicator for forcing method.

IF = 0 subroutine will use best method.
IF = 1 subroutine will use full integration.
IF = 2 subroutine will use approximation.

IM indicator for method used returned by subroutine.
IM = 0 returned if EP > EN.
IM = 1 returned if integration used.
IM = 2 returned if approximation used.

NOTES

Listing given is for an accuracy of 2%. To change accuracy recompile with ERT = X, where X is the fractional accuracy required.

The integration will be carried on for 257 terms, if accuracy is still not sufficient subroutine will print out accuracy.

A-2.1 SNIDOW CODE LISTING

```
FORTRAN IV G LEVEL  18                  SNIDOW              DATE = 71251          12/20/05              PAGE 0001

0001                  SUBROUTINE SNIDOW (R,E,N,EN,EP,C,A,IF,IM)
0002                  DIMENSION R(93),E(93),AINT(257),ENS(5)
                C*************************************************************
                C     FIND FRACTION OF RECOILS STOPPED
                C
0003                  ERT=0.02
0004                  IF(EN-EP)21,61,61
0005               61 DO11I=1,N
0006                  IF(E(I)-EP)1,1,2
0007                1 CONTINUE
0008                2 RU=R(I)-(R(I)-R(I-1))*(E(I)-EP)/(E(I)-E(I-1))
0009                  RU=RU/A
0010                  IF(RU-2.0)20,21,21
0011               21 C=0.
0012                  IM=0
0013                  RETURN
0014               20 FS=1.0-0.75*RU+RU*RU*RU/16.0
0015                  IF(IF-2)22,82,22
                C*************************************************************
                C     GENERATE ENERGY SCALE AND TERMS FOR INTEGRATION
                C
0016               22 ITEST=1
0017                  AS=0.
0018                  DINT=1.0
0019                  JJ=5
0020                  DE=(EN-EP)/4.0
0021               72 DO 40 K=1,JJ
0022                  AINT(K)=0.
0023               40 CONTINUE
0024                  DO 3 J=1,JJ
0025                  AJ=J-1
0026                  ES=EP+DE*(AS+AJ*DINT)
0027                  ESMEP=ES-EP
0028                  DO 4 K=1,N
0029                  IF(E(K)-ESMEP)4,4,5
0030                4 CONTINUE
0031                5 DO 6L=K,N
0032                  IF(E(L)-ES)6,6,7
0033                6 CONTINUE
0034                7 L1=L-1
0035                  K1=K-1
0036                  RES=R(L)-(R(L)-R(L1))*(E(L)-ES)/(E(L)-E(L1))
0037                  RESMEP=R(K)-(R(K)-R(K1))*(E(K)-ESMEP)/(E(K)-E(K1))
0038                  DRDE    =(R(K)-R(K1))/(E(K)-E(K1))
0039                  R0=(RES-RESMEP)/A
                C*************************************************************
                C     STORE NS IF FIRST TIME ROUND
                C
0040                  IF(ITEST)81,81,80
0041               80 ENS(J)=1.0-R0*R0*0.25
0042               81 IF(R0-2.0)30,31,31
0043               30 AINT(J)=DRDE*0.75/A*(1.0-R0*R0*0.25)
0044                3 CONTINUE
                C*************************************************************
                C     TEST IF APPROXIMATION IS SUFFICIENTLY ACCURATE
                C
0045               31 IF(ITEST)71,71,70
0046               70 IF(IF-1)700,83,700
```

```
FORTRAN IV G LEVEL  18                  SNIDOW              DATE = 71251          12/20/05              PAGE 0002

0047          700 ERROR=1.0-ENS(1)/ENS(5)
0048              ERROR= ABS(ERROR)
0049              IF(ERROR-ERT )82,82,83
              C*************************************************************
              C     TEST IF ANY TERMS EXCEPT LAST ARE ZERO
              C
0050           83 DO 87 J=2,4
0051              IF(AINT(J))87,88,87
0052           87 CONTINUE
0053              GO TO 830
0054           88 AJ=J-1
0055              DE=DE*AJ/4.0
0056              GO TO 72
              C*************************************************************
              C     PERFORM INTEGRATION
              C
0057          830 SEN=AINT(1)+AINT(5)
0058              SE=AINT(2)+AINT(4)
0059              SO=AINT(3)
0060              C=(SEN+4.0*SE+2.0*SO)/3.0*DE+FS
0061              ITEST=0
0062              JJ=4
0063              AS=1.0
0064              DINT=2.0
0065              DE=DE/2.0
0066              GO TO 72
0067           71 SO=SO+SE
0068              SE=0.
0069              DO 73 J=1,JJ
0070              SE=SE+AINT(J)
0071           73 CONTINUE
0072              CKEEP=(SEN+4.0*SE+2.0*SO)/3.0*DE+FS
              C*************************************************************
              C     TEST IF MORE TERMS ARE NECESSARY
              C
0073              ERROR=1.0-C/CKEEP
0074              ERROR= ABS(ERROR)
0075              C=CKEEP
0076              IF(ERROR-ERT )74,74,75
0077           75 DE=DE/2.0
0078              JJ=JJ*2
0079              IF(JJ-258)72,76,76
0080           76 WRITE(3,221) EP,EN,ERROR
0081          221 FORMAT (/10X,38HACCURACY OF SUBROUTINE SNIDOW AT EP = ,F6.0,14H KE
                 1V AND EN = ,F6.0,9H IS ONLY ,F8.6/)
0082           74 C=C/EN
0083              IM=1
0084              RETURN
              C*************************************************************
              C     APPROXIMATE CALCULATION
              C
0085           82 ES=EN-EP
0086              DO 85 L=1,N
0087              IF(E(L)-ES)85,85,86
0088           85 CONTINUE
0089              L=N
0090           86 L1=L-1
0091              RES=R(L)-(R(L)-R(L1))*(E(L)-ES)/(E(L)-E(L1))
```

```
0092              RU=(1.0-0.25*RU*RU)*0.75/A
0093              C=(FS+RU*RES)/EN
0094              IM=2
0095              RETURN
0096              END
```

A-3.0 CALLING SEQUENCE OF SUBROUTINE SPEC 2S

This is:

CALL SPEC 2S (FU, EU, R, E, YS, CAL, EMAX, RS, VNP, NE, NRE, NCH, BBIAS)

where FU and EU are tables of flux per lethargy and energy (MeV) with NE points on the input neutron spectrum.

R and E are tables of proton range and energy having NRE points.

YS is a table of counts per channel returned by SPEC 2S.

CAL is the energy width of each channel (MeV).

EMAX is the minimum neutron energy (MeV).

RS is the counter radius (cm).

VNP is the number of hydrogen atoms in the counter (in units of 10^{24}).

NCH is the number of channels.

BBIAS is the analyzer back bias in channels.

NOTES

The subroutine divides the energy scale into KK equal points with EMAX at point N. The recoil proton spectrum is tabulated in these KK points. The neutron spectrum above EMAX is divided into the (KK - N) equal energy intervals and a further M equal lethargy intervals up to the maximum neutron energy specified (which must be less than 10 MeV). Subroutine SNIDOW is called KK. (M + KK - N) times and so the running time of the subroutine depends on the values of these quantities. In the listing given N = 20, KK = 25 and M = 30 and so SNIDOW is called 875 times. These values can be halved without serious loss in accuracy.

Having generated KK points on the recoil proton spectrum the subroutine carries out a linear interpolation to give NCH points with an energy spacing of CAL. If EMAX. KK/N is on the analyzer higher channels will be returned with zeros.

A-3.1 SPEC 2S CODE LISTING

```
FORTRAN IV G LEVEL  18                  SPEC2S              DATE = 71251          12/20/05              PAGE 0001

0001                  SUBROUTINE SPEC2S (FU,EU,R,E,YS,CAL,EMAX,RS,VNP,NE,NRE,NCH,BBIAS)
0002                  DIMENSION U(80),ES(80),FS(80),EM(80),FM(80),FU(75),EU(75),R(93),
                     1E(93),YS(400),DDU(50)
0003                  N=20
0004                  M=30
0005                  KK=25
0006                  DO 1 I=1,NE
0007                  U(I)=ALOG(EU(I))
0008                1 CONTINUE
                  C*****************************************************************
                  C     GENERATE ENERGY SCALE
                  C
0009                  DE=EMAX/(N-1)
0010                  AANCH=NCH
0011                  AJ=CAL*AANCH/EMAX
0012                  IF(AJ-1.0)22,22,23
0013               22 WRITE(3,101)
0014              101 FORMAT (///10X,44HEMAX NOT ON KICKSORTER. SPEC2S WILL NOT WORK)
0015               23 DO  2 I=1,80
0016                  AJ=I-1
0017                  ES(I)=AJ*DE
0018                  FS(I)=0.
0019                2 CONTINUE
                  C*****************************************************************
                  C     GENERATE TABLE OF ENERGIES AND FLUXES ABOVE EMAX
                  C
0020                  EMU=(KK-1)*DE
0021                  EMU=ALOG(EMU)
0022                  DU=(U(NE)-EMU)/M
0023                  KKKK=KK-N
0024                  DO 20 I=1,KKKK
0025                  AJ=I-0.5
0026                  C=EMAX+AJ*DE
0027                  EM(I)=ALOG(C)
0028                  DDU(I)=ALOG((C+DE/2.0)/(C-DE/2.0))
0029               20 CONTINUE
0030                  MM=M+KKKK
0031              801 K=KKKK+1
0032                  DO 21 I=K,MM
0033                  AJ=I+0.5-K
0034                  EM(I)=EMU+AJ*DU
0035                  DDU(I)=DU
0036               21 CONTINUE
0037                  J=1
0038                  DO 3 I=1,MM
0039                  DO 4 K=J,NE
0040                  IF(U(K)-EM(I))4,5,5
0041               4  CONTINUE
0042                  K=NE
0043               5  J=K
0044                  FM(I)=FU(K-1)+(FU(K)-FU(K-1))*(EM(I)-U(K-1))/(U(K)-U(K-1))
0045                  EM(I)=EXP(EM(I))
0046               3  CONTINUE
                  C*****************************************************************
                  C     CALCULATE RECOIL PROTON SPECTRUM
                  C
0047                  DO 6 I=1,MM
0048                  SIG=9.42477/(1.206*EM(I)+(0.09415*EM(I)-1.86+0.00013*EM(I)*EM(I))
```

```
     1**2)+3.14159/(1.206*EM(I)+(0.4223+0.13*EM(I))**2)
0049          SIG=SIG*VNP*CAL*FM(I)*CDU(I)
0050          DO 25 J=1,80
0051          IF(ES(J)-EM(I))25,26,26
0052       25 CONTINUE
0053       26 KKK=J-1
0054          DO 7 J=1,KKK
0055          CALL SNIDOW (R,E,NRE,EM(I),ES(J),C,RS,0,IM)
0056          FS(J)=FS(J)+C*SIG
0057        7 CONTINUE
0058        6 CONTINUE
           C*************************************************************
           C     INTERPOLATE FS TO GIVE 400 POINTS ON YS
           C
0059          J=1
0060          DO 8 I=1,NCH
0061          AJ=I
0062          EY=CAL*(AJ+BBIAS)
0063          DO 9 K=J,KK
0064          IF(ES(K)-EY)9,10,10
0065        9 CONTINUE
0066          K=KK
0067       10 J=K
0068          IF (J-1.)11,11,37
0069       37 YS(I)=FS(J-1)+(FS(K)-FS(K-1))*(EY-ES(K-1))/(ES(K)-ES(K-1))
0070          IF(YS(I).LE.0.0) GO TO 11
0071          GO TO 8
0072       11 YS(I)=0.0
0073        8 CONTINUE
0074          RETURN
0075          END
```

A-4.0 CALLING SEQUENCE OF SUBROUTINE VSMTH

This is:

CALL VSMTH (X, N1, N2, RES),

where X is the array of points to be smoothed.

N1 and N2 define the lower and upper limits of points in X to be smoothed.

RES is the smoothing (or counter) resolution in per cent.

NOTES

X is overwritten by the smoothed data.

A-4.1 VSMTH CODE LISTING

```
FORTRAN IV G LEVEL  18                  VSMTH               DATE = 71251        12/20/05              PAGE 0001

0001                SUBROUTINE VSMTH (X,N1,N2,RES)
0002                DIMENSION X(400), SMX (400), II (400)
0003                DO 200 I = N1,N2
0004                II(I) = I* RES/200. +. 5
0005                II(I) = II (I)/2
0006            200 CONTINUE
0007                KM = N1 + II (N1)
0008                KN = N2 - II (N2)
0009                DO 99 I = N1, N2
0010                SMX (I) = X(I)
0011             99 CONTINUE
0012                DO 100 I = 1, 8
0013                DO 101 J = KM, KN
0014                K1 = J - II (J)
0015                K2 = J + II (J)
0016                TOTN = 0
0017                DO 102 K = K1, K2
0018                TOTN = TOTN + X (K)
0019            102 CONTINUE
0020                SMX (J) = TOTN/(2*II(J) + 1)
0021            101 CONTINUE
0022                DO 103 J = N1, N2
0023                X (J) = SMX (J)
0024            103 CONTINUE
0025            100 CONTINUE
0026                RETURN
0027                END
```

A-5.0 CALLING SEQUENCE OF SUBROUTINE CONTIN

This is:

CALL CONTIN (CT, NCH)

where CTS is the analyzer spectrum

NCH is the number of channels in the analyzer

NOTES

This subroutine reads in the analyzer spectrum, normalizes background to foreground for counting times and distances and subtracts the background spectrum from the foreground.

A-5.1 CONTIN CODE LISTING

```
FORTRAN IV G LEVEL  18                  CONTIN              DATE = 71251        12/20/05              PAGE 0001

0001                  SUBROUTINE  CONTIN(CTS,NCH)
0002                  DIMENSION CTS(400),BCNT(400)
0003                  READ(1,101) FTIME,BTIME,FDIST,BDIST
0004              101 FORMAT(4F12.5)
0005                  WRITE(3,105) FTIME,BTIME,FDIST,BDIST
0006              105 FORMAT(/17H FOREGROUND TIME=,F12.2,2X,16HBACKGROUND TIME=,
                     1 F12.2/21H FOREGROUND DISTANCE=,F14.2,2X,20HBACKGROUND DISTANCE=,
                     2 F14.2//)
0007                  TRATIO=FTIME/BTIME
0008                  DRATIO=(BDIST*BDIST)/(FDIST*FDIST)
0009                  WRITE(3,100)
0010              100 FORMAT (//18H FOREGROUND COUNTS,//)
0011                  READ(1,102) (CTS(I),I=1,NCH)
0012                  WRITE(3,103) (CTS(I),I=1,NCH)
0013              103 FORMAT (10X,10F8.0)
0014                  WRITE(3,104)
0015              104 FORMAT (//18H BACKGROUND COUNTS//)
0016                  READ(1,102) (BCNT(I),I=1,NCH)
0017              102 FORMAT (12X,10F6.0)
0018                  WRITE(3,103) (BCNT(I),I=1,NCH)
0019                  DO 10 I=1,NCH
0020                  CTS(I)=CTS(I)-BCNT(I)*TRATIO
0021                  IF(CTS(I))110,10,10
0022              110 CTS(I)=0.
0023               10 CONTINUE
0024                  WRITE(3,106)
0025              106 FORMAT(///16H ADJUSTED COUNTS//)
0026                  WRITE(3,103) (CTS(I),I=1,NCH)
0027             1001 CONTINUE
0028                  RETURN
0029                  END
```

APPENDIX B

Typical Output of SPEC 4

```
0.0031293     1.0000000     0.3000000     1.1499996   400.0000000     1.0000000    -1.0000000
2.0000000    10.0000000     0.0           6.2500000
                                  31
          367     1.1499987
                                  30
          344     1.0780268
                                  29
          322     1.0091829
                                  28
          302     0.9465983
                                  27
          283     0.8871425
                                  26
          265     0.8308160
                                  25
          249     0.7807480
                                  24
          233     0.7306800
                                  23
          218     0.6837412
                                  22
          205     0.6430610
                                  21
          192     0.6023807
                                  20
          180     0.5648297
                                  19
          169     0.5304080
                                  18
          158     0.4959862
                                  17
          148     0.4646937
                                  16
          139     0.4365304
                                  15
          130     0.4083672
                                  14
          122     0.3833331
                                  13
          114     0.3582991
                                  12
          107     0.3363944
                                  11
          100     0.3144897
                                  10
           94     0.2957141
```

RANGE ENERGY DATA

E	RH	RCH4	RANGE
0.0010	0.0147	0.0050	0.0015
0.0015	0.0195	0.0070	0.0020
0.0020	0.0235	0.0082	0.0024
0.0025	0.0272	0.0097	0.0027
0.0030	0.0310	0.0101	0.0031
0.0040	0.0375	0.0130	0.0038
0.0050	0.0435	0.0155	0.0043
0.0060	0.0490	0.0170	0.0049
0.0070	0.0545	0.0190	0.0054
0.0080	0.0595	0.0205	0.0059
0.0090	0.0645	0.0220	0.0064
0.0100	0.0690	0.0235	0.0069
0.0125	0.0800	0.0275	0.0080
0.0150	0.0910	0.0307	0.0091
0.0175	0.1010	0.0340	0.0101
0.0200	0.1100	0.0367	0.0110
0.0250	0.1280	0.0420	0.0128
0.0300	0.1440	0.0470	0.0144
0.0350	0.1600	0.0515	0.0160
0.0400	0.1740	0.0565	0.0174
0.0450	0.1900	0.0610	0.0190
0.0500	0.2050	0.0660	0.0205
0.0550	0.2200	0.0710	0.0220
0.0600	0.2360	0.0760	0.0236
0.0650	0.2510	0.0805	0.0251
0.0700	0.2660	0.0850	0.0266
0.0750	0.2820	0.0905	0.0282
0.0800	0.2970	0.0950	0.0297
0.0850	0.3130	0.1000	0.0313
0.0900	0.3290	0.1050	0.0329
0.0950	0.3460	0.1100	0.0346
0.1000	0.3620	0.1150	0.0362
0.1100	0.4000	0.1250	0.0400
0.1200	0.4380	0.1350	0.0438
0.1250	0.4550	0.1400	0.0455
0.1300	0.4750	0.1450	0.0475
0.1400	0.5140	0.1550	0.0514
0.1500	0.5510	0.1650	0.0551
0.1600	0.5980	0.1750	0.0598
0.1700	0.6400	0.1850	0.0640
0.1750	0.6620	0.1900	0.0662
0.1800	0.6820	0.1950	0.0682
0.1900	0.7300	0.2050	0.0730
0.2000	0.7800	0.2180	0.0780
0.2250	0.9200	0.2550	0.0920
0.2500	1.0500	0.2900	0.1050
0.2750	1.2200	0.3300	0.1220
0.3000	1.3700	0.3750	0.1370
0.3500	1.7300	0.4700	0.1730
0.4000	2.1300	0.5750	0.2130
0.4500	2.5700	0.6900	0.2570
0.5000	3.0500	0.8100	0.3050
0.5500	3.5700	0.9400	0.3570
0.6000	4.1200	1.0700	0.4120
0.6500	4.7200	1.2200	0.4720
0.7000	5.3500	1.3900	0.5350

0.7500	6.0200	1.5500	0.6020
0.8000	6.7200	1.7200	0.6720
0.8500	7.4600	1.9200	0.7460
0.9000	8.2400	2.1200	0.8240
0.9500	9.0600	2.3200	0.9060
1.0000	9.9100	2.5000	0.9910
1.1000	11.7000	3.0000	1.1700
1.2000	13.6000	3.4500	1.3600
1.2500	14.6000	3.7000	1.4600
1.3000	15.6000	3.9500	1.5600
1.4000	17.6000	4.4500	1.7600
1.5000	20.2000	5.0200	2.0200
1.6000	22.5000	5.6000	2.2500
1.7000	25.0000	6.1500	2.5000
1.7500	26.4000	6.4500	2.6400
1.8000	27.8000	6.8500	2.7800
1.9000	31.0000	7.5000	3.1000
2.0000	33.8000	8.2400	3.3800
2.2500	41.3000	10.0000	4.1300
2.5000	50.6000	12.2000	5.0600
2.7500	59.0000	14.4000	5.9000
3.0000	70.3000	16.7000	7.0300
3.5000	92.8000	22.0000	9.2800
4.0000	118.0000	27.9000	11.8000
4.5000	146.0000	34.5000	14.6000
5.0000	177.0000	41.6000	17.7000
5.5000	210.0000	49.4000	21.0000
6.0000	246.0000	57.8000	24.6000
6.5000	285.0000	66.7000	28.5000
7.0000	326.0000	76.3000	32.6000
7.5000	370.0000	86.5000	37.0000
8.0000	417.0000	97.2000	41.7000
8.5000	466.0000	108.0000	46.6000
9.0000	518.0000	120.0000	51.8000
9.5000	628.0000	132.2000	62.8000
10.0000	752.0000	143.0000	75.2000

4.2312E-01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
3.8527E-01 3.8225E-01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
3.5023E-01 3.4767E-01 3.4441E-01 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
3.1824E-01 3.1590E-01 3.1312E-01 3.1011E-01 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
2.8920E-01 2.8704E-01 2.8452E-01 2.8191E-01 2.7869E-01 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
2.6305E-01 2.6102E-01 2.5864E-01 2.5627E-01 2.5345E-01 2.5048E-01 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
2.3952E-01 2.3762E+01 2.3540E-01 2.3315E-01 2.3057E-01 2.2796E-01 2.2480E-01 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
2.1842E-01 2.1664E-01 2.1453E-01 2.1245E-01 2.1000E-01 2.0760E-01 2.0480E-01 2.0186E-01 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
1.9878E-01 1.9700E-01 1.9501E-01 1.9305E-01 1.9078E-01 1.8850E-01 1.8591E-01 1.8330E-01 1.8027E-01 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
1.8129E-01 1.7971E-01 1.7781E-01 1.7588E-01 1.7375E-01 1.7161E-01 1.6917E-01 1.6673E-01 1.6401E-01 1.6084E-01
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
1.6595E-01 1.6441E-01 1.6252E-01 1.6079E-01 1.5867E-01 1.5664E-01 1.5434E-01 1.5206E-01 1.4950E-01 1.4664E-01
1.4369E-01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
1.5178E-01 1.5028E-01 1.4859E-01 1.4687E-01 1.4488E-01 1.4295E-01 1.4072E-01 1.3857E-01 1.3616E-01 1.3347E-01
1.3081E-01 1.2782E-01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
1.3933E-01 1.3790E-01 1.3628E-01 1.3463E-01 1.3281E-01 1.3090E-01 1.2884E-01 1.2671E-01 1.2444E-01 1.2190E-01
1.1938E-01 1.1667E-01 1.1355E-01 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
1.2799E-01 1.2665E-01 1.2510E-01 1.2353E-01 1.2176E-01 1.1997E-01 1.1802E-01 1.1598E-01 1.1381E-01 1.1137E-01
1.0900E-01 1.0643E-01 1.0358E-01 1.0067E-01 0.0 0.0 0.0 0.0 0.0 0.0
0.0
1.1743E-01 1.1616E-01 1.1469E-01 1.1320E-01 1.1152E-01 1.0982E-01 1.0793E-01 1.0604E-01 1.0394E-01 1.0165E-01
9.9334E-02 9.6905E-02 9.4226E-02 9.1551E-02 8.8417E-02 0.0 0.0 0.0 0.0 0.0
0.0
1.0828E-01 1.0707E-01 1.0567E-01 1.0425E-01 1.0265E-01 1.0103E-01 9.9234E-02 9.7419E-02 9.5423E-02 9.3251E-02
9.1032E-02 8.8693E-02 8.6140E-02 8.3613E-02 8.0701E-02 7.7564E-02 0.0 0.0 0.0 0.0
0.0
1.0009E-01 9.8936E-02 9.7605E-02 9.6252E-02 9.4730E-02 9.3187E-02 9.1477E-02 8.9744E-02 8.7848E-02 8.5740E-02
8.3654E-02 8.1407E-02 7.8967E-02 7.6533E-02 7.3782E-02 7.0860E-02 6.7913E-02 0.0 0.0 0.0
0.0
9.2589E-02 9.1479E-02 9.0227E-02 8.8961E-02 8.7507E-02 8.6048E-02 8.4409E-02 8.2757E-02 8.0957E-02 7.8943E-02
7.7398E-02 7.4993E-02 7.2687E-02 7.0151E-02 6.7488E-02 6.4730E-02 6.1973E-02 5.8852E-02 0.0 0.0
0.0
8.5973E-02 8.4936E-02 8.3723E-02 8.2514E-02 8.1113E-02 7.9749E-02 7.8186E-02 7.7106E-02 7.5334E-02 7.3179E-02
7.1779E-02 6.9138E-02 6.7091E-02 6.4842E-02 6.2247E-02 5.9441E-02 5.6737E-02 5.3810E-02 5.0707E-02 0.0
0.0
7.9992E-02 7.9015E-02 7.7859E-02 7.6717E-02 7.5396E-02 7.4417E-02 7.3086E-02 7.1608E-02 6.9932E-02 6.8040E-02
6.5903E-02 6.4081E-02 6.2410E-02 5.9889E-02 5.7409E-02 5.4709E-02 5.2221E-02 4.9360E-02 4.6371E-02 4.3316E-02

0.0
7.4641E-02 7.3697E-02 7.2621E-02 7.1530E-02 7.0999E-02 6.9644E-02 6.8142E-02 6.6485E-02 6.4919E-02 6.3255E-02
6.1537E-02 5.9644E-02 5.7356E-02 5.5561E-02 5.2903E-02 5.0508E-02 4.8028E-02 4.5411E-02 4.2610E-02 3.9683E-02
3.6530E-02

MATRIX OF MONOENERGETIC NEUTRON DIFFERENTIAL RECOIL PROTON DISTRIBUTIONS

```
4.2312E-01 0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
3.0221E-03 3.8225E-01 0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
2.5597E-03 3.2556E-03 3.4441E-01 0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
2.3356E-03 2.7783E-03 3.0080E-03 3.1011E-01 0.0        0.0        0.0        0.0        0.0        0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
2.1510E-03 2.5282E-03 2.6022E-03 3.2286E-03 2.7869E-01 0.0        0.0        0.0        0.0        0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
2.0361E-03 2.3806E-03 2.3664E-03 2.8227E-03 2.9667E-03 2.5048E-01 0.0        0.0        0.0        0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.8965E-03 2.2230E-03 2.2495E-03 2.5788E-03 2.6171E-03 3.1539E-03 2.2480E-01 0.0        0.0        0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.7755E-03 2.1105E-03 2.0789E-03 2.4532E-03 2.4040E-03 2.7945E-03 2.9444E-03 2.0186E-01 0.0        0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.7776E-03 1.9868E-03 1.9672E-03 2.2716E-03 2.2796E-03 2.5817E-03 2.6163E-03 3.0286E-03 1.8027E-01 0.0
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.5850E-03 1.9032E-03 1.9256E-03 2.1343E-03 2.1392E-03 2.4317E-03 2.4473E-03 2.7149E-03 3.1751E-03 1.6084E-01
0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.5423E-03 1.8832E-03 1.7337E-03 2.1195E-03 2.0264E-03 2.3053E-03 2.2742E-03 2.5634E-03 2.8616E-03 2.9450E-03
1.4369E-01 0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.4972E-03 1.6878E-03 1.7169E-03 1.9941E-03 1.9248E-03 2.2340E-03 2.1538E-03 2.4025E-03 2.6948E-03 2.6600E-03
2.9843E-03 1.2782E-01 0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.4318E-03 1.6163E-03 1.6499E-03 1.8262E-03 1.9099E-03 2.0583E-03 2.1252E-03 2.2713E-03 2.5357E-03 2.5255E-03
2.7117E-03 3.1206E-03 1.1355E-01 0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.3453E-03 1.5472E-03 1.5735E-03 1.7674E-03 1.7910E-03 1.9501E-03 2.0357E-03 2.1706E-03 2.4441E-03 2.3702E-03
2.5709E-03 2.8496E-03 2.9056E-03 1.0067E-01 0.0        0.0        0.0        0.0        0.0        0.0
0.0
1.2735E-03 1.4715E-03 1.4904E-03 1.6808E-03 1.6994E-03 1.8893E-03 1.8920E-03 2.0944E-03 2.2965E-03 2.3123E-03
2.4290E-03 2.6783E-03 2.6753E-03 3.1340E-03 8.8417E-02 0.0        0.0        0.0        0.0        0.0
0.0
1.2118E-03 1.4006E-03 1.4179E-03 1.6001E-03 1.6170E-03 1.7985E-03 1.8150E-03 1.9952E-03 2.1725E-03 2.2184E-03
2.3393E-03 2.5534E-03 2.5268E-03 2.9115E-03 3.1371E-03 7.7564E-02 0.0        0.0        0.0        0.0
0.0
1.1502E-03 1.3305E-03 1.3533E-03 1.5220E-03 1.5426E-03 1.7106E-03 1.7326E-03 1.8960E-03 2.1080E-03 2.0854E-03
2.2461E-03 2.4402E-03 2.4346E-03 2.7508E-03 2.9220E-03 2.9472E-03 6.7913E-02 0.0        0.0        0.0
0.0
1.1097E-03 1.2526E-03 1.2657E-03 1.4544E-03 1.4588E-03 1.6383E-03 1.6527E-03 1.7999E-03 2.0139E-03 1.9453E-03
2.4053E-03 2.3057E-03 2.5360E-03 2.6628E-03 2.7576E-03 2.7574E-03 3.1213E-03 5.8852E-02 0.0        0.0
0.0
1.0373E-03 1.2126E-03 1.2088E-03 1.4011E-03 1.3644E-03 1.5623E-03 1.0804E-03 1.7717E-03 2.1556E-03 1.4003E-03
2.6404E-03 2.0475E-03 2.2488E-03 2.5956E-03 2.8054E-03 2.7037E-03 2.9278E-03 3.1022E-03 5.0707E-02 0.0
0.0
```

9.7736E-04 1.1556E-03 1.1425E-03 1.3208E-03 9.7919E-04 1.3309E-03 1.4783E-03 1.6761E-03 1.8916E-03 2.1374E-03
1.8219E-03 1.6705E-03 2.5215E-03 2.4801E-03 2.6998E-03 2.4875E-03 2.8617E-03 2.9382E-03 3.0550E-03 4.3316E-02
0.0
9.4409E-04 1.0759E-03 1.0914E-03 5.3046E-04 1.3555E-03 1.5016E-03 1.6575E-03 1.5657E-03 1.6641E-03 1.7177E-03
1.8932E-03 2.2878E-03 1.7954E-03 2.6574E-03 2.3955E-03 2.4798E-03 2.6168E-03 2.8009E-03 2.9270E-03 3.1533E-03
3.6530E-02

OUTPUT OF SPEC 2S

5.6996E 01 5.6911E 01 5.6825E 01 5.674CE 01 5.6655E 01 5.6570E 01 5.6485E 01 5.6399E 01 5.6314E 01 5.6229E 01
5.6144E 01 5.6059E 01 5.5973E 01 5.588ØE 01 5.5803E 01 5.5718E 01 5.5632E 01 5.5547E 01 5.5462E 01 5.5377E 01
5.5279E 01 5.5187E 01 5.5094E 01 5.5002E 01 5.4909E 01 5.4817E 01 5.4724E 01 5.4632E 01 5.4539E 01 5.4446E 01
5.4354E 01 5.4261E 01 5.4169E 01 5.4076E 01 5.3984E 01 5.3891E 01 5.3799E 01 5.3706E 01 5.3612E 01 5.3519E 01
5.3418E 01 5.3320E 01 5.3223E 01 5.3126E 01 5.3029E 01 5.2931E 01 5.2834E 01 5.2737E 01 5.2640E 01 5.2542E 01
5.2445E 01 5.2348E 01 5.2251E 01 5.2153E 01 5.2056E 01 5.1959E 01 5.1862E 01 5.1764E 01 5.1649E 01 5.1533E 01
5.1416E 01 5.1300E 01 5.1184E 01 5.1068E 01 5.0952E 01 5.0836E 01 5.0719E 01 5.0603E 01 5.0487E 01 5.0371E 01
5.0255E 01 5.0139E 01 5.0022E 01 4.9906E 01 4.9790E 01 4.9674E 01 4.9558E 01 4.9427E 01 4.9288E 01 4.9149E 01
4.9010E 01 4.8870E 01 4.3731E 01 4.8592E 01 4.8453E 01 4.8314E 01 4.8175E 01 4.8035E 01 4.7896E 01 4.7757E 01
4.7618E 01 4.7479E 01 4.7340E 01 4.7200E 01 4.7061E 01 4.6922E 01 4.6788E 01 4.6666E 01 4.6544E 01 4.6421E 01
4.6299E 01 4.6177E 01 4.6055E 01 4.5933E 01 4.5811E 01 4.5689E 01 4.5567E 01 4.5445E 01 4.5322E 01 4.5200E 01
4.5078E 01 4.4956E 01 4.4834E 01 4.4712E 01 4.4590E 01 4.4468E 01 4.4327E 01 4.4185E 01 4.4044E 01 4.3902E 01
4.3760E 01 4.3619E 01 4.3477E 01 4.3335E 01 4.3193E 01 4.3052E 01 4.2910E 01 4.2768E 01 4.2627E 01 4.2485E 01
4.2343E 01 4.2202E 01 4.2060E 01 4.1918E 01 4.1776E 01 4.1626E 01 4.1469E 01 4.1312E 01 4.1155E 01 4.0998E 01
4.0841E 01 4.0684E 01 4.0527E 01 4.0370E 01 4.0213E 01 4.0056E 01 3.9899E 01 3.9742E 01 3.9585E 01 3.9428E 01
3.9271E 01 3.9114E 01 3.8957E 01 3.8800E 01 3.8647E 01 3.8506E 01 3.8365E 01 3.8224E 01 3.8083E 01 3.7942E 01
3.7801E 01 3.7661E 01 3.7520E 01 3.7379E 01 3.7238E 01 3.7097E 01 3.6956E 01 3.6815E 01 3.6674E 01 3.6533E 01
3.6392E 01 3.6251E 01 3.6110E 01 3.5969E 01 3.5825E 01 3.5681E 01 3.5537E 01 3.5393E 01 3.5249E 01 3.5105E 01
3.4961E 01 3.4816E 01 3.4672E 01 3.4528E 01 3.4384E 01 3.4240E 01 3.4096E 01 3.3952E 01 3.3808E 01 3.3663E 01
3.3519E 01 3.3375E 01 3.3231E 01 3.3092E 01 3.2957E 01 3.2822E 01 3.2687E 01 3.2552E 01 3.2417E 01 3.2282E 01
3.2147E 01 3.2012E 01 3.1877E 01 3.1742E 01 3.1607E 01 3.1472E 01 3.1337E 01 3.1202E 01 3.1067E 01 3.0932E 01
3.0797E 01 3.0662E 01 3.0529E 01 3.0404E 01 3.0278E 01 3.0152E 01 3.0027E 01 2.9901E 01 2.9775E 01 2.9650E 01
2.9524E 01 2.9399E 01 2.9273E 01 2.9147E 01 2.9022E 01 2.8896E 01 2.8770E 01 2.8645E 01 2.8519E 01 2.8394E 01
2.8268E 01 2.8142E 01 2.8012E 01 2.7882E 01 2.7752E 01 2.7621E 01 2.7491E 01 2.7350E 01 2.7230E 01 2.7090E 01
2.6969E 01 2.6839E 01 2.6708E 01 2.6578E 01 2.6447E 01 2.6317E 01 2.6186E 01 2.6056E 01 2.5926E 01 2.5795E 01
2.5665E 01 2.5542E 01 2.5426E 01 2.5310E 01 2.5194E 01 2.5078E 01 2.4961E 01 2.4845E 01 2.4729E 01 2.4613E 01
2.4497E 01 2.4380E 01 2.4264E 01 2.4148E 01 2.4032E 01 2.3916E 01 2.3800E 01 2.3683E 01 2.3567E 01 2.3451E 01
2.3338E 01 2.3239E 01 2.3139E 01 2.3040E 01 2.2940E 01 2.2841E 01 2.2741E 01 2.2642E 01 2.2542E 01 2.2443E 01
2.2343E 01 2.2244E 01 2.2144E 01 2.2045E 01 2.1945E 01 2.1846E 01 2.1746E 01 2.1647E 01 2.1547E 01 2.1448E 01
2.1348E 01 2.1249E 01 2.1150E 01 2.1051E 01 2.0952E 01 2.0853E 01 2.0754E 01 2.0655E 01 2.0555E 01 2.0456E 01
2.0357E 01 2.0258E 01 2.0159E 01 2.0060E 01 1.9961E 01 1.9862E 01 1.9763E 01 1.9663E 01 1.9564E 01 1.9465E 01
1.9374E 01 1.9280E 01 1.9186E 01 1.9092E 01 1.8998E 01 1.8905E 01 1.8811E 01 1.8717E 01 1.8623E 01 1.8529E 01
1.8435E 01 1.8341E 01 1.8247E 01 1.8153E 01 1.8060E 01 1.7966E 01 1.7872E 01 1.7778E 01 1.7686E 01 1.7600E 01
1.7515E 01 1.7429E 01 1.7344E 01 1.7258E 01 1.7173E 01 1.7087E 01 1.7002E 01 1.6916E 01 1.6831E 01 1.6745E 01
1.6660E 01 1.6574E 01 1.6489E 01 1.6403E 01 1.6318E 01 1.6232E 01 1.6147E 01 1.6061E 01 1.5979E 01 1.5897E 01
1.5815E 01 1.5733E 01 1.5651E 01 1.5569E 01 1.5488E 01 1.5406E 01 1.5324E 01 1.5242E 01 1.5160E 01 1.5078E 01
1.4996E 01 1.4914E 01 1.4832E 01 1.475CE 01 1.4669E 01 1.4587E 01 1.4505E 01 1.4411E 01 1.4304E 01 1.4196E 01
1.4092E 01 1.3986E 01 1.3880E 01 1.3773E 01 1.3667E 01 1.3561E 01 1.3455E 01 1.3348E 01 1.3242E 01 1.3135E 01
1.3030E 01 1.2924E 01 1.2817E 01 1.2711E 01 1.2605E 01

FOREGROUND TIME= 1.00 BACKGROUND TIME= 1.00
FOREGROUND DISTANCE= 1.00 BACKGROUND DISTANCE= 1.00

FOREGROUND COUNTS

27535. 3542. 54383. 34975. 273. 6573. 150923. 181934. 127250. 192920.
142528. 104130. 68984. 36450. 45975. 234549. 209868. 189124. 169696. 153679.
138108. 124454. 112125. 99672. 90303. 80838. 73767. 66809. 60359. 54931.
49621. 45632. 41980. 38222. 35363. 32680. 29774. 27958. 25711. 23763.
22366. 20322. 18820. 17550. 16219. 15425. 14122. 13468. 12799. 12317.
12142. 11703. 11411. 11227. 11058. 10745. 10536. 10632. 10354. 10212.
10329. 10074. 10170. 9901. 9885. 9885. 10017. 9834. 9707. 9632.
9709. 9653. 9434. 9552. 9563. 9361. 9359. 9478. 9235. 9225.
9143. 8884. 8866. 8681. 8702. 8543. 8550. 8252. 8128. 7814.

7737.	7584.	7392.	7180.	7202.	6725.	6682.	6687.	6493.	6354.
6201.	6211.	6349.	6130.	5968.	5980.	5868.	5727.	5649.	5746.
5589.	5638.	5579.	5449.	5384.	5354.	5234.	5339.	5090.	5086.
4996.	4907.	4872.	4891.	4877.	4782.	4622.	4678.	4589.	4530.
4294.	4347.	4214.	4134.	4211.	4134.	3988.	3946.	3940.	3854.
3985.	3800.	3649.	3669.	3735.	3714.	3730.	3713.	3613.	3655.
3733.	3572.	3508.	3583.	3518.	3451.	3526.	3507.	3401.	3455.
3287.	3420.	3361.	3375.	3389.	3329.	3359.	3335.	3208.	3274.
3184.	3247.	3215.	3082.	3177.	3175.	3148.	3125.	3206.	3171.
3022.	3122.	3044.	3069.	2977.	3034.	2936.	2930.	2928.	2996.
2922.	2945.	2924.	2856.	2869.	2924.	2880.	2811.	2813.	2839.
2770.	2777.	2661.	2724.	2734.	2718.	2653.	2644.	2668.	2705.
2675.	2597.	2583.	2648.	2470.	2444.	2463.	2464.	2576.	2454.
2501.	2464.	2463.	2370.	2382.	2289.	2415.	2368.	2326.	2355.
2345.	2362.	2292.	2276.	2265.	2196.	2126.	2234.	2184.	2198.
2142.	2202.	2169.	2134.	2160.	2091.	2105.	2095.	2115.	2037.
2023.	2010.	2058.	1997.	2012.	1906.	1982.	1900.	1943.	1918.
1958.	1870.	1807.	1842.	1903.	1840.	1877.	1805.	1897.	1868.
1850.	1779.	1742.	1829.	1808.	1790.	1743.	1703.	1730.	1776.
1762.	1666.	1733.	1633.	1684.	1648.	1665.	1715.	1607.	1597.
1570.	1624.	1679.	1593.	1643.	1638.	1591.	1492.	1554.	1581.
1607.	1610.	1558.	1448.	1507.	1568.	1585.	1515.	1473.	1501.
1524.	1415.	1434.	1428.	1424.	1441.	1523.	1437.	1415.	1420.
1448.	1372.	1366.	1397.	1350.	1316.	1300.	1298.	1294.	1356.
1278.	1254.	1282.	1288.	1224.	1237.	1274.	1283.	1237.	1179.
1160.	1201.	1162.	1171.	1202.	1196.	1168.	1129.	1201.	1156.
1081.	1141.	1126.	1081.	1134.	1071.	1060.	1091.	1115.	1006.
988.	1008.	1003.	996.	1071.	1022.	1023.	975.	985.	997.
987.	997.	947.	925.	961.	935.	938.	897.	937.	868.
905.	909.	902.	913.	856.	944.	850.	857.	877.	846.
826.	833.	865.	855.	829.	824.	781.	815.	783.	765.

BACKGROUND COUNTS

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

ADJUSTED COUNTS

27535.	3542.	54383.	34975.	273.	6573.	150923.	181934.	127250.	192920.
142528.	104130.	68984.	36450.	45975.	234549.	209868.	189124.	169696.	153679.
138108.	124454.	112125.	99672.	90303.	80838.	73767.	66809.	60359.	54931.
49621.	45632.	41980.	38222.	35363.	32680.	29774.	27958.	25711.	23763.
22366.	20322.	18820.	17550.	16219.	15425.	14122.	13468.	12799.	12317.
12142.	11703.	11411.	11227.	11058.	10745.	10536.	10632.	10354.	10212.
10329.	10074.	10170.	9901.	9885.	9885.	10017.	9834.	9707.	9632.
9709.	9653.	9434.	9552.	9563.	9361.	9359.	9478.	9235.	9225.
9143.	8884.	8866.	8681.	8702.	8543.	8550.	8252.	8128.	7814.
7737.	7584.	7392.	7180.	7202.	6725.	6682.	6687.	6493.	6354.
6201.	6211.	6349.	6130.	5968.	5980.	5868.	5727.	5649.	5746.
5589.	5638.	5579.	5449.	5384.	5354.	5234.	5339.	5090.	5086.
4996.	4907.	4872.	4891.	4877.	4782.	4622.	4678.	4589.	4530.
4294.	4347.	4214.	4134.	4211.	4134.	3988.	3946.	3940.	3854.
3985.	3800.	3549.	3669.	3735.	3714.	3730.	3713.	3613.	3655.
3733.	3572.	3508.	3583.	3518.	3451.	3526.	3507.	3401.	3455.
3287.	3420.	3361.	3375.	3389.	3329.	3359.	3335.	3208.	3274.
3184.	3247.	3215.	3082.	3177.	3175.	3148.	3125.	3206.	3171.
3022.	3122.	3044.	3069.	2977.	3034.	2936.	2930.	2928.	2996.
2922.	2945.	2924.	2856.	2869.	2924.	2880.	2811.	2813.	2839.
2770.	2777.	2661.	2724.	2734.	2718.	2653.	2644.	2668.	2705.
2675.	2597.	2583.	2648.	2470.	2444.	2463.	2464.	2576.	2454.
2501.	2464.	2463.	2370.	2382.	2289.	2415.	2368.	2326.	2355.
2345.	2362.	2292.	2276.	2265.	2196.	2126.	2234.	2184.	2198.
2142.	2202.	2169.	2134.	2160.	2091.	2105.	2095.	2115.	2037.
2023.	2010.	2058.	1997.	2012.	1906.	1982.	1900.	1943.	1918.
1958.	1870.	1907.	1842.	1903.	1840.	1877.	1805.	1897.	1868.
1850.	1779.	1742.	1829.	1808.	1790.	1743.	1703.	1730.	1776.
1762.	1666.	1733.	1633.	1684.	1648.	1665.	1715.	1607.	1597.
1570.	1624.	1679.	1593.	1643.	1638.	1591.	1492.	1554.	1581.
1607.	1610.	1558.	1448.	1507.	1568.	1585.	1515.	1473.	1501.
1524.	1415.	1434.	1428.	1424.	1441.	1523.	1437.	1415.	1420.
1448.	1372.	1366.	1397.	1350.	1316.	1300.	1298.	1294.	1356.
1278.	1254.	1282.	1288.	1224.	1237.	1274.	1283.	1237.	1179.
1160.	1201.	1162.	1171.	1202.	1196.	1168.	1129.	1201.	1156.
1081.	1141.	1126.	1081.	1134.	1071.	1060.	1091.	1115.	1006.
988.	1008.	1003.	996.	1071.	1022.	1023.	975.	985.	997.
987.	997.	947.	925.	961.	935.	938.	897.	937.	868.

905.	909.	902.	913.	856.	944.	850.	857.	877.	846.
826.	833.	865.	855.	829.	824.	781.	815.	783.	765.

DSPEC PER MEV PER MONITOR
NORMALISING FACTOR = 6.9573E 01

75320.250	-1334.057	161155.063	99152.750	-11723.809	8427.746	469739.000	568858.375	394126.188	604003.625
442987.313	320299.625	208004.125	104055.813	134513.313	737149.250	658296.313	592024.625	529958.375	478793.563
429054.688	385441.875	346063.188	306288.313	276368.750	246142.500	223566.500	201352.000	180760.625	163435.188
146486.813	133759.938	122110.000	110121.313	101005.500	92452.188	83186.188	77403.438	70243.750	64040.238
59597.527	53087.238	48308.988	44272.129	40040.328	37524.598	33382.289	31666.367	30043.477	28580.738
27306.590	26214.840	25280.328	24475.020	23777.828	23176.059	22661.719	22226.617	21863.816	21555.297
21287.277	21050.180	20841.059	20660.656	20507.559	20373.109	20243.930	20109.008	19966.207	19821.297
19682.258	19553.707	19435.508	19324.117	19213.906	19096.938	18962.328	18800.770	18600.559	18356.797
18076.738	17775.387	17467.520	17158.359	16839.250	16491.508	16097.688	15651.719	15162.949	14649.789
14130.129	13613.637	13103.129	12599.930	12109.969	11643.629	11211.207	10819.668	10476.797	10183.684
9935.570	9719.223	9515.176	9305.395	9082.324	8851.836	8628.449	8426.098	8250.250	8095.707
7950.328	7802.156	7651.816	7496.266	7335.871	7170.832	7006.785	6841.492	6676.551	6513.371
6352.723	6194.484	6037.668	5880.621	5721.332	5558.023	5389.547	5215.758	5037.609	4857.066
4676.680	4499.207	4327.125	4162.320	4006.006	3860.808	3726.224	3601.006	3485.408	3379.945
3285.336	3202.286	3131.165	3071.736	3022.944	2982.935	2949.275	2919.285	2890.485	2860.962
2829.567	2795.957	2760.482	2723.952	2686.444	2647.346	2610.256	2575.959	2544.984	2517.529
2493.385	2471.901	2452.035	2432.504	2412.021	2389.597	2364.780	2337.780	2309.423	2280.975
2253.835	2229.204	2207.752	2189.669	2174.781	2162.272	2148.946	2135.714	2121.933	2107.046
2091.260	2074.439	2056.833	2038.774	2020.634	2002.775	1985.504	1969.009	1953.357	1938.463
1924.120	1910.046	1895.905	1880.202	1862.980	1844.910	1825.917	1806.034	1785.396	1764.197
1742.662	1720.990	1699.340	1677.785	1656.310	1634.829	1613.204	1591.286	1568.947	1546.125
1522.837	1499.191	1474.895	1449.095	1423.665	1398.865	1374.929	1352.010	1330.194	1309.479
1289.799	1271.036	1253.019	1235.654	1218.436	1201.457	1184.418	1167.141	1149.500	1131.422
1112.910	1094.050	1075.953	1058.027	1040.402	1023.309	1007.122	991.753	977.237	964.440
951.132	938.285	925.750	913.352	900.798	888.111	875.200	862.014	848.536	834.830
820.980	805.349	788.429	771.801	755.645	740.135	725.439	711.696	699.013	687.466
677.089	667.874	659.772	652.693	646.515	641.099	636.284	631.900	627.784	623.782
618.986	611.141	603.094	594.801	586.246	577.456	568.477	559.383	550.264	541.233
532.401	523.877	515.776	508.198	501.221	494.909	489.308	484.433	480.275	476.804
473.896	471.540	469.669	468.184	466.986	465.965	465.025	464.073	463.038	461.787
460.328	458.618	456.630	453.841	451.261	448.377	445.183	441.672	437.835	433.191
427.479	421.509	415.184	408.498	401.443	394.023	386.230	378.081	369.595	360.717
351.715	342.397	332.896	323.254	313.534	303.797	294.115	284.533	274.775	263.795
252.909	242.409	232.235	222.413	212.953	203.847	195.089	186.659	178.533	170.573
163.042	155.603	148.323	141.143	134.040	126.975	119.926	112.866	105.112	97.266
89.288	81.355	73.436	65.562	57.757	50.060	42.510	35.155	28.017	21.135
14.533	8.240	2.312	-3.296	-8.582	-13.543	-18.199	-19.304		

*** RCTORPECTM TH 6.5 ALUNUM PHA 4.33V 84/71 0 . P E P

BBIAS= 0.0 CHANNELS= 400. SMOOTH= 1.
HYDROGEN PRESSURE=10.00 CARBON PRESSURE= 0.0 RESOLUTION= 6.25

GROUPED SPECTRUM OF SLOPES PER MONITOR COUNT

MONITOR COUNT = 100.00
CALIBRATION = 0.003129

INDICATED CHANNEL		ENERGY BOUNDARY		MID ENERGY	SIGMA	GROUPED SPECTRUM	ERROR**2 INTERNAL	EXTERNAL
95	100	0.2957	0.3145	0.3051	7.94	2298.113	0.5916E 05	0.1064E 05
101	107	0.3145	0.3364	0.3254	7.68	1530.573	0.5091E 05	0.1079E 03
108	114	0.3364	0.3583	0.3473	7.44	1102.517	0.4696E 05	0.3333E 03
115	122	0.3583	0.3833	0.3708	7.19	1301.939	0.4108E 05	0.1334E 02
123	130	0.3833	0.4084	0.3959	6.96	1349.072	0.3719E 05	0.1883E 03
131	139	0.4084	0.4365	0.4224	6.73	1337.610	0.3146E 05	0.1415E 04
140	148	0.4365	0.4647	0.4506	6.51	521.375	0.2855E 05	0.1540E 04
149	158	0.4647	0.4960	0.4803	6.29	348.920	0.2544E 05	0.1978E 02
159	169	0.4960	0.5304	0.5132	6.08	257.300	0.2282E 05	0.1999E 02
170	180	0.5304	0.5648	0.5476	5.87	189.263	0.2158E 05	0.7395E 02
181	192	0.5648	0.6024	0.5836	5.68	198.318	0.1941E 05	0.6147E 01
193	205	0.6024	0.6431	0.6227	5.49	260.502	0.1733E 05	0.1470E 02
206	218	0.6431	0.6837	0.6634	5.31	307.293	0.1604E 05	0.4514E 01
219	233	0.6837	0.7307	0.7072	5.13	270.162	0.1344E 05	0.2904E 01
234	249	0.7307	0.7807	0.7557	4.95	220.364	0.1171E 05	0.1050E 02
250	265	0.7807	0.8308	0.8058	4.78	204.189	0.1060E 05	0.5194E 02
266	283	0.8308	0.8871	0.8590	4.62	136.256	0.8873E 04	0.1501E 02
284	302	0.8871	0.9466	0.9169	4.46	48.531	0.7766E 04	0.1774E 02
303	322	0.9466	1.0092	0.9779	4.31	120.759	0.6759E 04	0.2816E 02
323	344	1.0092	1.0780	1.0436	4.16	203.992	0.5495E 04	0.6721E 01
345	367	1.0780	1.1500	1.1140	4.02	162.263	0.4528E 04	0.6349E 01

CALCULATED NEUTRON SPECTRUM

ENERGY BOUNDARY		FLUX / GROUP	FLUX / MEV	FLUX / LETHARGY	O/O ERROR INTERNAL	O/O ERROR EXTERNAL
0.2957	0.3145	5.2266E 03	2.7837E 05	8.4905E 04	11.00	5.50
0.3145	0.3364	3.7724E 03	1.7222E 05	5.6026E 04	15.66	7.83
0.3364	0.3583	2.9681E 03	1.3550E 05	4.7050E 04	21.21	10.61
0.3583	0.3833	3.9506E 03	1.5781E 05	5.8497E 04	16.56	8.28
0.3833	0.4084	4.6079E 03	1.8406E 05	7.2838E 04	15.03	7.52
0.4084	0.4365	5.1118E 03	1.8151E 05	7.6649E 04	13.87	6.94
0.4365	0.4647	2.0898E 03	7.4203E 04	3.3426E 04	36.01	18.01
0.4647	0.4960	1.4702E 03	4.6983E 04	2.2560E 04	53.84	26.92
0.4960	0.5304	1.1254E 03	3.2694E 04	1.6772E 04	74.63	37.31
0.5304	0.5648	8.5705E 02	2.4898E 04	1.3630E 04	106.79	53.40
0.5648	0.6024	1.0144E 03	2.7014E 04	1.5760E 04	95.85	47.93
0.6024	0.6431	1.6432E 03	4.0394E 04	2.5146E 04	62.86	31.43
0.6431	0.6837	2.3074E 03	5.6721E 04	3.7617E 04	48.49	24.25
0.6837	0.7307	2.2325E 03	4.7562E 04	3.3624E 04	51.82	25.91
0.7307	0.7807	2.0398E 03	4.0741E 04	3.0778E 04	60.28	30.14
0.7807	0.8308	2.2154E 03	4.4248E 04	3.5643E 04	60.17	30.08
0.8308	0.8871	1.5567E 03	2.7637E 04	2.3731E 04	89.56	44.78
0.8871	0.9466	2.9244E 02	4.9186E 03	4.5082E 03	514.62	257.31
0.9466	1.0092	1.8608E 03	2.9733E 04	2.9066E 04	87.49	43.75
1.0092	1.0780	4.3860E 03	6.3710E 04	6.6464E 04	39.14	19.57
1.0780	1.1500	4.4419E 03	6.1717E 04	6.8730E 04	41.47	20.74

SUMMED FLUX= 0.5517E 05

OUTPUT SPECTRUM READY FOR NEXT SPEC 4 RUN AT LOWER PRESSURE

NSPE = 46

E(MEV)	PHI(U)
3.0510E-01	8.4905E 04
3.2544E-01	5.6026E 04
3.4735E-01	4.7050E 04
3.7082E-01	5.8497E 04
3.9585E-01	7.2838E 04
4.2245E-01	7.6649E 04
4.5061E-01	3.3426E 04
4.8034E-01	2.2560E 04
5.1320E-01	1.6772E 04
5.4762E-01	1.3630E 04
5.8360E-01	1.5760E 04
6.2272E-01	2.5146E 04
6.6340E-01	3.7617E 04
7.0721E-01	3.3624E 04
7.5571E-01	3.0778E 04
8.0578E-01	3.5643E 04
8.5898E-01	2.3731E 04
9.1687E-01	4.5082E 03
9.7789E-01	2.9066E 04
1.0436E 00	6.6464E 04
1.1140E 00	6.8730E 04
1.2000E 00	7.1139E 04
1.4000E 00	7.5193E 04
1.6000E 00	8.5935E 04
1.8000E 00	9.8501E 04
2.0000E 00	9.8095E 04
2.2000E 00	9.4548E 04
2.4000E 00	1.0144E 05
2.6000E 00	1.0671E 05
2.8000E 00	1.0782E 05
3.0000E 00	1.0732E 05
3.2000E 00	1.0590E 05
3.4000E 00	1.0372E 05
3.6000E 00	1.0453E 05
3.8000E 00	1.1188E 05
4.0000E 00	1.2181E 05
4.2000E 00	1.2576E 05
4.4000E 00	1.2373E 05
4.6000E 00	1.1745E 05
4.8000E 00	1.0752E 05
5.0000E 00	9.8298E 04
6.0000E 00	7.5396E 04
7.0000E 00	5.0365E 04
8.0000E 00	3.1567E 04
9.0000E 00	1.8900E 04
1.0000E 01	1.1806E 04

IHC215I CONVERT - ILLEGAL DECIMAL CHARACTER .

.001625 1.0 0.15 0.55 400. 1. 1.

APPENDIX C

Measured Raw Pulse Height Spectra

Presented in this section are the raw pulse height spectra measured for complex neutron distributions during this study.

***** DIRECT BEAM 10 ATM. ./1/71 *****

44129. 51. 624. 1968. 2871.10763.24420.41870. 7659. 2630. 234. 383.
653. 1481. 4259.14613.79563. 5130.21224.72482.49664.30815.17581. 6352.
96768.88691.80607.72982.65647.59141.52626.45505.39436.32940.26829.20786.
16152.10321. 5358. 30.95052.90233.86890.82157.77972.75233.71948.67944.
64718.61819.59659.56823.54176.52039.49937.47837.46165.45061.42691.41365.
39400.38012.37174.35914.35052.33980.32925.31776.30935.30073.28979.28036.
27319.26915.26318.25415.24976.24036.23873.23024.22533.22239.22007.21403.
21097.20749.20109.19867.19613.19480.19063.19274.18653.18898.18486.18354.
17897.17904.17878.17659.17433.17412.17338.17102.17270.16946.16680.16933.
16650.16421.16548.16193.16248.16088.16004.16122.15776.15704.15666.15292.
15252.15192.15162.15038.14842.15207.14605.14637.14775.14618.14449.14434.
14528.14293.14262.14319.14347.14167.14154.13836.13609.13847.13764.13403.
13565.13501.13632.13064.13057.13150.12992.12867.12829.12757.12812.12647.
12730.12705.12254.12354.12261.12226.12138.12014.11968.11911.12008.11897.
11718.11669.11420.11752.11439.11441.11521.11238.11079.11239.11168.10937.
10939.10754.10807.10606.10557.10671.10693.10417.10641.10472.10507.10429.
10365.10423.10140.10260.10086.10143.10148.10158.10017.10199. 9859. 9832.
10020. 9809. 9877. 9819. 9719. 9634. 9560. 9534. 9271. 9420. 9514. 9400.
9372. 9341. 9384. 9175. 9005. 8974. 9008. 8966. 9280. 8858. 9034. 8969.
8871. 8789. 8778. 8843. 8740. 8635. 8669. 8662. 8340. 8408. 8463. 8513.
8489. 8307. 8386. 8375. 8282. 8273. 8170. 8090. 8159. 7992. 8172. 8062.
7889. 8053. 7943. 7949. 8071. 7832. 7942. 7772. 7945. 7889. 7753. 7710.
7662. 7750. 7547. 7722. 7501. 7569. 7567. 7604. 7513. 7482. 7347. 7503.
7278. 7330. 7388. 7291. 7319. 7221. 7272. 7139. 7147. 7287. 7038. 7013.
7192. 7011. 7062. 7101. 7026. 7159. 7055. 6937. 7070. 6909. 7080. 6956.
6927. 6824. 6793. 6909. 6922. 6744. 6860. 6828. 6596. 6608. 6717. 6694.
6596. 6620. 6690. 6621. 6446. 6476. 6539. 6601. 6531. 6463. 6303. 6358.
6384. 6392. 6493. 6355. 6316. 6230. 6394. 6336. 6233. 6141. 6185. 6103.
6209. 6129. 6023. 6076. 6030. 5990. 6134. 5948. 6203. 6042. 5954. 6103.
5880. 5891. 5928. 5782. 5670. 5740. 5917. 5711. 5759. 5839. 5717. 5692.
5720. 5792. 5650. 5650. 5561. 5618. 5546. 5532. 5509. 5547. 5473. 5444.
5429. 5296. 5473. 5401. 5383. 5392. 5310. 5346. 5407. 5229. 5235. 5163.
5358. 5141. 5250. 5139. 5197. 5167. 5250. 5047. 5335. 5164. 5215. 5175.
5052. 5085. 4973. 4972. 4802. 4962. 4867. 4856. 4925. 4890. 4744. 4794.
4727. 4770. 4837. 4809. 4722. 4753. 4851. 4598. 4734. 4733. 4669. 4636.
4485. 4441. 4571. 4564. 4486. 4658. 4557. 4651. 4491. 4551. 4559. 4448.
4481. 4432. 4357. 4452. 4334. 4331. 4369. 4548. 4392. 4296. 4314. 4302.
4262. 4336. 4249. 4238. 4132. 4139. 4137. 4088. 4071. 4000. 4171. 4223.
4078. 4113. 4003. 4007. 3956. 4054. 4140. 3904. 3906. 4024. 4020. 3959.
3821. 3891. 3857. 3838. 3852. 3763. 3872. 3956. 3787. 3840. 3838. 3829.
3614. 3774. 3834. 3612. 3782. 3688. 3683. 3615. 3638. 3656. 3700. 3627.
3666. 3625. 3687. 3599. 3596. 3598. 3619. 3475. 3571. 3538. 3534. 3453.
3520. 3562. 3639. 3509. 3372. 3377. 3282. 3471. 3435. 3364. 3371. 3355.
3356. 3404. 3387. 3247. 3196. 3408. 3249. 3291. 3357. 3229. 3242. 3313.
3349. 3273. 3150. 3224. 3116. 3090. 3229. 3242. 3249. 3202. 3085. 3179.
3095. 3059. 2958. 2993. 3119. 3066. 3027. 3082. 3086. 3053. 3074. 3009.
3076. 2953. 2966. 3006. 3011. 3021. 3028. 2953. 2912. 2928. 2927. 2874.
2892. 2857. 2780. 2853. 2877. 2958. 2801. 2876. 2815. 2801. 2715. 2808.
2708. 2803. 2779. 2798. 2681. 2670. 2648. 2702. 2704. 2705. 2672. 2706.
2629. 2572. 2721. 2557. 2586. 2612. 2539. 2627. 2515. 2661. 2631. 2582.
2508. 2480. 2467. 2517. 2503. 2410. 2477. 2550. 2476. 2488. 2471. 2413.
2363. 2385. 2362. 2468. 2304. 2380. 2404. 2388. 2343. 2314. 2441. 2367.
2266. 2314. 2334. 2311. 2194. 2291. 2221. 2264. 2312. 2274. 2291. 2253.
2185. 2114. 2179. 2228. 2158. 2200. 2173. 2153. 2196. 2173. 2156. 2162.

2114. 2183. 2203. 2052. 2063. 2069. 2046. 2172. 2131. 2167. 2087. 2001.
2026. 2015. 2000. 2061. 2054. 1997. 2027. 1976. 2014. 1992. 1970. 1971.
1884. 1888. 1942. 1943. 1909. 1915. 1910. 1892. 1911. 1879. 1863. 1880.
1832. 1851. 1845. 1805. 1858. 1814. 1825. 1811. 1851. 1796. 1853. 1827.
1835. 1782. 1813. 1721. 1766. 1670. 1858. 1713. 1682. 1739. 1630. 1753.
1710. 1700. 1714. 1749. 1647. 1655. 1625. 1585. 1663. 1670. 1651. 1608.
1683. 1647. 1653. 1576. 1644. 1586. 1642. 1494. 1551. 1513. 1617. 1634.
1518. 1594. 1545. 1565. 1576. 1505. 1497. 1542. 1513. 1486. 1549. 1472.
1510. 1484. 1494. 1468. 1450. 1412. 1506. 1464. 1470. 1492. 1378. 1404.
1375. 1397. 1367. 1413. 1424. 1411. 1421. 1412. 1346. 1382. 1402. 1340.
1378. 1334. 1383. 1328. 1377. 1377. 1334. 1262. 1264. 1252. 1326. 1292.
1269. 1251. 1293. 1244. 1288. 1205. 1268. 1267. 1270. 1209. 1209. 1197.
1221. 1222. 1208. 1268. 1206. 1199. 1214. 1206. 1184. 1201. 1147. 1162.
1113. 1158. 1142. 1247. 1072. 1101. 1183. 1118. 1180. 1145. 1101. 1143.
1108. 1096. 1138. 1139. 1132. 1119. 1119. 1104. 1040. 1093. 1057. 1096.
1081. 1092. 1049. 1067. 1045. 1077. 1022. 956. 1003. 1009. 1041. 1066.
982. 1020. 1013. 1009. 980. 1005. 975. 962. 975. 950. 964. 931.
913. 922. 979. 951. 946. 942. 969. 965. 947. 895. 939. 889.
940. 901. 890. 904. 925. 915. 902. 860. 860. 880. 877. 858.
899. 900. 844. 794. 867. 853. 828. 846. 858. 853. 847. 830.
784. 777. 803. 807. 788. 808. 789. 773. 750. 791. 764. 756.
786. 734. 796. 757. 727. 697. 757. 705. 710. 737. 744. 745.
721. 736. 713. 705. 707. 726. 740. 693. 672. 658. 670. 752.
659. 754. 686. 666. 680. 626. 675. 642. 663. 700. 672. 636.
674. 679. 634. 631. 631. 654. 641. 658. 635. 618. 639. 635.
651. 610. 634. 597. 601. 583. 623. 601. 611. 586. 531. 597.
539. 569. 552. 604. 539. 589. 554. 574. 575. 576. 539. 562.
562. 528. 561. 587. 526. 526. 566. 516. 534. 555. 490. 538.
525. 503. 493. 502. 478. 479. 534. 489. 487. 503. 501. 484.
479. 502. 455. 498. 486. 480. 463. 464. 452. 466. 474. 507.
428. 438. 428. 446. 473. 422. 424. 448. 421. 432. 411. 423.
423. 412. 441. 414.

***** REACTOR SPECTRUM THRU 6'' IRON ALPHA = 4.33 MEV 8/18/71 *****
30680. 34. 470. 1431. 2145. 6624.16977.35899.10742. 95. 132. 212.
319. 571. 1071. 2246.72542.69563.98473.80012.67373.57323.51573.47528.
44194.41444.40067.38174.36519.35720.34941.34177.33727.32615.32312.31279.
31154.30416.30015.29573.29092.28664.28153.27367.27104.26848.26760.26201.
25942.25614.25429.24849.24644.24590.23967.23700.23039.22838.22203.21900.
21388.20803.20787.20384.20094.19869.19745.19523.19327.18880.18908.18576.
18277.17951.17990.17755.17190.17589.17380.17364.17012.16786.16697.16822.
16585.16568.16530.15908.16035.15967.15667.15605.15597.15337.15476.15263.
15009.14981.14973.14773.14423.14076.14123.14301.13875.13932.13793.13445.
13137.13120.12911.12704.12439.12147.12206.11720.11552.11462.11419.11070.
11006.10797.10744.10728.10465.10497.10406.10332.10456.10271.10171.10312.
10109.10072. 9905. 9930. 9891.10043. 9893. 9883. 9701. 9764. 9826. 9499.
9764. 9577. 9618. 9533. 9303. 9234. 9332. 9183. 9030. 9240. 9033. 9251.
9086. 9118. 9060. 8973. 9159. 9015. 8791. 8790. 8879. 8665. 8640. 8752.
8664. 8663. 8587. 8530. 8530. 8455. 8569. 8349. 8594. 8171. 8361. 8527.
8289. 8273. 8327. 8150. 8037. 8300. 8246. 8159. 8163. 8191. 8058. 8145.
8039. 8103. 8017. 8130. 7935. 8034. 8057. 8066. 7930. 7905. 7779. 7915.

7975. 7795. 7746. 7583. 7658. 7631. 7682. 7542. 7599. 7694. 7691. 7493.
7348. 7358. 7398. 7421. 7260. 7280. 7273. 7073. 7145. 7143. 7142. 7185.
6983. 7033. 7020. 6935. 6949. 6807. 6733. 6722. 6717. 6639. 6629. 6516.
6515. 6545. 6453. 6391. 6328. 6223. 6102. 6185. 6174. 6092. 6280. 6039.
5909. 6150. 5900. 5960. 5830. 5901. 5974. 5774. 5949. 5626. 5709. 5770.
5693. 5598. 5836. 5595. 5492. 5618. 5533. 5475. 5359. 5371. 5319. 5359.
5389. 5271. 5280. 5404. 5193. 5158. 5275. 5160. 5081. 5246. 5082. 5103.
5019. 5014. 4855. 5007. 4998. 4895. 4909. 4928. 4821. 4852. 4824. 4731.
4742. 4804. 4844. 4487. 4701. 4675. 4533. 4559. 4608. 4584. 4432. 4504.
4544. 4463. 4349. 4342. 4282. 4296. 4339. 4233. 4348. 4275. 4243. 4205.
4204. 4152. 4156. 4133. 4059. 4110. 4050. 4100. 4049. 4049. 3985. 3963.
3864. 4012. 3864. 3914. 3869. 3775. 3869. 3823. 3875. 3824. 3828. 3767.
3844. 3821. 3817. 3776. 3637. 3866. 3769. 3704. 3704. 3752. 3741. 3630.
3742. 3694. 3640. 3721. 3682. 3704. 3750. 3591. 3673. 3572. 3646. 3566.
3662. 3689. 3621. 3586. 3541. 3514. 3465. 3418. 3542. 3533. 3507. 3599.
3496. 3480. 3559. 3391. 3604. 3511. 3488. 3387. 3513. 3431. 3465. 3410.
3322. 3381. 3389. 3443. 3440. 3319. 3292. 3333. 3228. 3384. 3333. 3275.
3295. 3321. 3210. 3216. 3143. 3289. 3227. 3154. 3260. 3221. 3221. 3179.
3190. 3104. 3096. 3198. 3147. 3192. 3147. 3051. 3152. 3090. 3144. 2946.
2954. 2989. 3024. 3074. 3000. 2925. 3106. 2974. 3031. 2865. 3018. 3028.
2871. 2987. 2910. 2874. 2934. 2745. 2859. 2869. 2823. 2832. 2892. 2819.
2958. 2794. 2827. 2720. 2724. 2690. 2788. 2775. 2726. 2659. 2652. 2719.
2732. 2647. 2609. 2666. 2594. 2619. 2644. 2587. 2548. 2585. 2650. 2592.
2569. 2520. 2477. 2525. 2473. 2584. 2545. 2417. 2487. 2410. 2412. 2349.
2380. 2357. 2438. 2386. 2411. 2396. 2377. 2349. 2383. 2376. 2383. 2331.
2334. 2269. 2291. 2286. 2274. 2299. 2269. 2200. 2184. 2186. 2168. 2186.
2295. 2190. 2285. 2244. 2140. 2187. 2106. 2045. 2125. 2120. 2049. 2164.
1982. 2052. 2084. 2082. 2051. 2011. 2071. 1983. 1958. 1986. 1972. 1942.
1953. 1874. 1911. 1889. 1965. 1854. 1972. 1823. 1936. 1868. 1870. 1819.
1798. 1850. 1857. 1781. 1723. 1746. 1704. 1742. 1722. 1812. 1696. 1668.
1716. 1676. 1645. 1685. 1615. 1679. 1665. 1636. 1628. 1640. 1595. 1579.
1653. 1618. 1573. 1599. 1558. 1512. 1505. 1551. 1550. 1500. 1533. 1607.
1474. 1495. 1461. 1475. 1500. 1472. 1486. 1501. 1441. 1405. 1507. 1476.
1396. 1327. 1403. 1417. 1314. 1488. 1410. 1412. 1366. 1341. 1377. 1354.
1348. 1368. 1351. 1310. 1398. 1357. 1404. 1315. 1336. 1271. 1315. 1278.
1298. 1259. 1268. 1302. 1333. 1294. 1332. 1230. 1185. 1278. 1232. 1227.
1216. 1271. 1192. 1233. 1211. 1196. 1207. 1146. 1218. 1186. 1191. 1240.
1157. 1205. 1191. 1232. 1160. 1165. 1183. 1156. 1143. 1132. 1250. 1121.
1140. 1224. 1092. 1134. 1081. 1167. 1075. 1134. 1111. 1081. 1091. 1090.
1084. 1101. 1134. 1119. 1134. 1079. 1145. 1128. 1094. 1071. 1089. 1093.
1057. 1070. 1043. 1108. 1084. 1117. 1044. 1045. 1022. 1101. 1032. 1030.
1022. 1025. 1047. 952. 1021. 1028. 1064. 1056. 1014. 1061. 1094. 1023.
989. 1012. 1009. 1039. 1035. 995. 982. 958. 976. 1002. 1037. 1023.
963. 1026. 1016. 958. 990. 968. 967. 963. 956. 964. 934. 903.
1011. 939. 992. 991. 1003. 931. 903. 981. 962. 953. 910. 947.
943. 889. 860. 924. 894. 922. 921. 884. 901. 908. 913. 856.
896. 874. 913. 897. 838. 880. 868. 918. 867. 869. 893. 855.
855. 850. 875. 856. 858. 837. 823. 867. 814. 794. 830. 838.
819. 883. 798. 835. 809. 862. 781. 781. 768. 789. 783. 818.
786. 804. 854. 791. 757. 819. 777. 775. 740. 798. 737. 753.
773. 744. 710. 760. 753. 777. 767. 720. 793. 728. 717. 737.
718. 699. 682. 707. 719. 690. 686. 676. 700. 683. 679. 709.
753. 653. 676. 665. 706. 676. 670. 665. 636. 628. 669. 678.
649. 659. 735. 626. 651. 659. 638. 645. 632. 597. 621. 601.
602. 656. 633. 591. 650. 625. 607. 627. 619. 578. 571. 629.
628. 582. 588. 600. 576. 592. 578. 547. 575. 549. 586. 581.
565. 543. 573. 540. 524. 541. 575. 512. 555. 582. 555. 551.
514. 521. 546. 519. 540. 549. 544. 533. 565. 553. 479. 528.
533. 551. 507. 511. 509. 453. 518. 518. 463. 541. 517. 480.
487. 443. 528. 489. 503. 509. 473. 458. 477. 476. 453. 508.

441. 490. 490. 442. 450. 493. 434. 440. 437. 469. 447. 451.
434. 450. 468. 465. 446. 458. 474. 424. 438. 433. 421. 435.
457. 434. 427. 420. 419. 408. 443. 432. 433. 417. 441. 380.
428. 410. 403. 397. 371. 423. 420. 373. 420. 408. 366. 399.
411. 386. 380. 385. 385. 399. 362. 372. 381. 388. 359. 395.
358. 394. 363. 427. 387. 363. 374. 372. 371. 390. 378. 335.
382. 372. 332. 375. 382. 331. 341. 346. 377. 336. 332. 377.
356. 327. 336. 345. 343. 346. 345. 339. 339. 348. 339. 338.
331. 328. 323. 337.

*** 8/22/71 NE 213 AL. PENETRATION ***

0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1.
1. 1. 13. 5050. 12911. 21225. 22158. 21893. 21363. 20728. 20055. 19230.
18819. 18153. 17858. 16849. 16530. 16067. 15705. 15418. 15062. 14704. 14169. 13762.
13279. 12866. 12737. 11988. 11771. 11344. 11037. 10631. 10297. 9994. 9846. 9466.
9273. 9246. 9125. 8830. 8841. 8578. 8554. 8299. 8137. 7952. 7811. 7506.
7495. 7178. 7001. 6720. 6696. 6652. 6626. 6399. 6339. 6090. 6026. 6042.
5866. 5794. 5783. 5488. 5490. 5316. 5297. 5111. 5108. 5167. 5016. 4781.
4733. 4559. 4608. 4642. 4410. 4320. 4235. 4340. 4073. 4014. 3982. 3986.
3901. 3774. 3688. 3722. 3801. 3604. 3533. 3521. 3560. 3454. 3325. 3326.
3321. 3237. 3316. 3221. 3176. 3214. 3152. 2977. 3034. 2983. 2923. 2832.
2962. 2832. 2735. 2814. 2759. 2744. 2686. 2633. 2664. 2568. 2583. 2514.
2458. 2478. 2435. 2395. 2364. 2323. 2278. 2298. 2226. 2272. 2215. 2198.
2219. 2112. 2111. 2156. 2023. 2060. 2020. 1994. 2025. 1930. 1977. 1996.
1900. 1897. 1905. 1808. 1890. 1808. 1781. 1835. 1761. 1744. 1725. 1682.
1679. 1683. 1647. 1640. 1595. 1602. 1601. 1639. 1597. 1546. 1565. 1551.
1509. 1505. 1472. 1476. 1430. 1495. 1430. 1408. 1456. 1372. 1302. 1352.
1323. 1278. 1330. 1349. 1348. 1259. 1167. 1252. 1251. 1274. 1262. 1221.
1236. 1190. 1190. 1201. 1177. 1207. 1186. 1142. 1044. 1085. 1074. 1110.
1100. 1020. 1083. 1090. 1040. 1007. 1003. 999. 961. 993. 975. 956.
960. 1016. 992. 969. 962. 987. 963. 902. 922. 903. 894. 929.
912. 857. 914. 871. 914. 771. 818. 852. 792. 824. 860. 810.
805. 787. 765. 808. 813. 749. 810. 733. 728. 806. 701. 692.
767. 718. 763. 702. 711. 763. 718. 674. 728. 647. 639. 708.
690. 665. 662. 618. 590. 612. 683. 605. 582. 597. 642. 618.
578. 570. 612. 571. 597. 549. 531. 482. 563. 547. 573. 532.
510. 537. 543. 509. 539. 525. 516. 518. 500. 467. 475. 476.
507. 481. 480. 468. 495. 449. 429. 474. 439. 476. 424. 398.
445. 413. 434. 410. 400. 397. 418. 433. 378. 434. 424. 396.
374. 383. 371. 366. 377. 360. 336. 352. 359. 365. 378. 382.
333. 347. 349. 337. 302. 330. 333. 293. 312. 296. 342. 293.
311. 318. 310. 305. 298. 318. 308. 291. 270. 294. 306. 301.
301. 250. 255. 247. 290. 275. 256. 283. 246. 291. 269. 254.
258. 281. 279. 252. 258. 235. 220. 252. 242. 237. 256. 244.
210. 256. 217. 217. 225. 215. 232. 234. 194. 226. 203. 228.
188. 216. 204. 192. 210. 186. 237. 185. 193. 203. 191. 191.
190. 188. 205. 194. 161. 163. 178. 185. 187. 175. 159. 155.
182. 172. 142. 157. 164. 180. 171. 145. 168. 140. 163. 146.
129. 153. 160. 165. 136. 153. 161. 143. 146. 125. 137. 142.
144. 136. 125. 134. 140. 141. 127. 112. 139. 130. 132. 116.
121. 137. 130. 128. 126. 126. 118. 118. 104. 105. 96. 112.

142.	111.	117.	113.	105.	117.	114.	116.	105.	120.	102.	117.
120.	109.	102.	95.	119.	104.	103.	99.	107.	88.	104.	97.
105.	92.	86.	100.	89.	97.	88.	88.	96.	86.	87.	96.
69.	74.	91.	76.	91.	72.	72.	102.	77.	82.	93.	77.
71.	66.	74.	74.	71.	80.	69.	77.	78.	80.	71.	76.
67.	58.	71.	74.	74.	68.	69.	77.	54.	59.	56.	75.
78.	73.	60.	44.	75.	62.	67.	73.	75.	62.	48.	66.
62.	57.	56.	52.	51.	50.	58.	59.	54.	57.	52.	62.
55.	63.	52.	57.	62.	48.	64.	56.	58.	55.	48.	55.
52.	45.	58.	44.	44.	49.	54.	44.	62.	40.	39.	54.
43.	57.	50.	44.	35.	40.	32.	50.	34.	47.	42.	45.
46.	32.	37.	50.	59.	39.	27.	41.	38.	40.	41.	45.
35.	25.	35.	31.	36.	23.	35.	32.	40.	37.	50.	40.
27.	35.	28.	37.	33.	27.	31.	30.	34.	35.	40.	30.
32.	28.	33.	37.	26.	33.	33.	39.	32.	41.	26.	30.
27.	24.	30.	26.	35.	38.	31.	32.	30.	37.	24.	28.
31.	30.	26.	25.	28.	31.	29.	25.	28.	19.	23.	27.
22.	37.	25.	24.	22.	26.	20.	19.	25.	23.	26.	25.
26.	29.	15.	23.	20.	23.	27.	17.	26.	19.	29.	22.
19.	25.	25.	18.	19.	16.	17.	20.	24.	24.	19.	20.
13.	14.	22.	21.	16.	14.	17.	21.	18.	15.	23.	20.
19.	20.	10.	19.	20.	22.	18.	18.	18.	22.	18.	17.
22.	16.	16.	18.	21.	20.	17.	20.	18.	27.	8.	19.
13.	15.	12.	12.	11.	14.	17.	13.	15.	15.	21.	18.
10.	13.	12.	7.	13.	10.	8.	12.	12.	6.	8.	14.
13.	15.	13.	13.	7.	17.	9.	12.	15.	10.	10.	12.
9.	9.	9.	9.	6.	9.	12.	8.	22.	6.	12.	6.
6.	11.	14.	9.	10.	8.	13.	10.	7.	7.	6.	6.
11.	14.	9.	6.	3.	6.	5.	14.	8.	13.	12.	5.
7.	2.	7.	6.	7.	9.	6.	7.	4.	6.	10.	8.
4.	10.	7.	4.	12.	6.	8.	3.	9.	5.	6.	16.
2.	10.	8.	9.	7.	7.	9.	4.	6.	3.	11.	8.
11.	5.	5.	6.	2.	4.	8.	7.	6.	4.	7.	8.
11.	4.	6.	3.	11.	4.	4.	8.	7.	9.	6.	3.
8.	1.	7.	6.	1.	7.	3.	5.	5.	5.	8.	4.
6.	5.	7.	8.	3.	6.	3.	4.	8.	4.	4.	6.
9.	3.	4.	5.	5.	5.	4.	3.	3.	5.	5.	4.
6.	7.	4.	3.	3.	2.	2.	2.	4.	3.	1.	1.
4.	4.	2.	2.	4.	10.	2.	8.	4.	6.	4.	2.
1.	4.	2.	1.	5.	1.	7.	3.	2.	5.	1.	4.
5.	1.	2.	2.	3.	7.	4.	5.	3.	3.	2.	3.
5.	3.	7.	4.	4.	2.	2.	3.	5.	2.	2.	4.
4.	4.	3.	0.	5.	2.	2.	5.	4.	4.	4.	5.
2.	2.	1.	4.	2.	1.	3.	1.	2.	6.	1.	1.
1.	4.	0.	1.	4.	4.	5.	4.	6.	2.	4.	1.
3.	3.	2.	1.								

***** REACTOR SPECTRUM THRU 6.5'' ALUMINUM ALPHA = 4.33MEV 8/24/71 *****

27344. 20. 307. 738. 1922. 6227.17130.46726.19949. 60. 58. 81.
185. 583. 2397. 9878.71050.79949.9E687.60240.34604.10547.95368.83545.
73635.65137.58369.50854.45316.40301.35784.29684.23964.18988.14273.10126.

5340. 479.96344.92250.88012.84721.81144.77850.74417.71828.68892.65854.
63221.60952.58702.56326.53731.51732.49656.47696.45895.44070.41871.40460.
38033.36713.35635.34109.32574.31468.29993.29173.28139.27149.25882.25053.
23931.23079.22216.21541.20632.19769.19106.18390.17922.17326.16825.16280.
15601.15163.14380.14158.13851.13201.12892.12594.11961.11576.11321.11093.
10816.10282.10204. 9647. 9443. 9183. 8984. 8790. 8527. 8187. 7877. 7532.
7385. 7257. 7038. 6923. 6487. 6430. 6231. 6113. 6041. 5913. 5512. 5453.
5431. 5261. 5129. 5007. 5022. 4898. 4853. 4721. 4794. 4744. 4649. 4583.
4532. 4519. 4435. 4412. 4335. 4438. 4341. 4319. 4300. 4164. 4212. 4191.
4122. 4056. 4168. 4163. 4119. 3995. 4058. 3957. 3985. 4048. 4111. 3962.
3979. 3908. 3922. 4059. 3897. 3984. 3812. 3834. 3936. 3790. 3865. 3908.
3810. 3926. 3938. 3848. 3861. 3821. 3804. 3831. 3713. 3721. 3819. 3780.
3781. 3821. 3814. 3750. 3661. 3674. 3717. 3748. 3698. 3772. 3792. 3659.
3735. 3596. 3625. 3669. 3649. 3712. 3707. 3683. 3551. 3635. 3626. 3582.
3609. 3602. 3538. 3561. 3383. 3502. 3452. 3482. 3441. 3353. 3403. 3383.
3434. 3367. 3283. 3389. 3277. 3389. 3345. 3221. 3186. 3246. 3177. 3111.
3049. 3070. 2995. 3080. 2979. 3057. 2884. 2931. 2910. 2850. 2814. 2872.
2686. 2864. 2827. 2718. 2578. 2596. 2649. 2585. 2576. 2643. 2605. 2528.
2539. 2530. 2534. 2404. 2377. 2451. 2452. 2387. 2445. 2495. 2467. 2480.
2473. 2319. 2272. 2367. 2342. 2306. 2382. 2287. 2337. 2247. 2256. 2214.
2245. 2215. 2177. 2259. 2220. 2262. 2204. 2132. 2171. 2281. 2130. 2222.
2166. 2124. 2157. 2099. 2115. 2064. 2172. 2080. 2053. 2030. 2040. 2081.
2103. 2075. 2019. 1950. 2004. 1984. 1989. 1961. 1946. 1949. 1865. 1966.
1899. 1903. 1906. 1880. 1915. 1972. 1899. 1874. 1863. 1878. 1858. 1791.
1791. 1856. 1827. 1791. 1780. 1797. 1831. 1811. 1659. 1696. 1663. 1675.
1755. 1652. 1646. 1658. 1620. 1646. 1580. 1638. 1631. 1679. 1579. 1633.
1568. 1577. 1520. 1548. 1538. 1551. 1566. 1496. 1477. 1512. 1565. 1542.
1567. 1514. 1475. 1439. 1435. 1402. 1509. 1362. 1435. 1479. 1451. 1446.
1459. 1445. 1484. 1429. 1468. 1463. 1422. 1388. 1447. 1382. 1426. 1455.
1480. 1509. 1329. 1449. 1378. 1329. 1386. 1401. 1412. 1385. 1409. 1347.
1375. 1351. 1324. 1390. 1344. 1405. 1372. 1368. 1364. 1282. 1357. 1328.
1395. 1308. 1302. 1245. 1354. 1314. 1345. 1334. 1265. 1377. 1278. 1316.
1352. 1296. 1327. 1272. 1313. 1337. 1250. 1384. 1284. 1286. 1254. 1200.
1335. 1239. 1306. 1245. 1211. 1285. 1240. 1291. 1275. 1276. 1218. 1187.
1209. 1228. 1262. 1227. 1228. 1235. 1271. 1250. 1189. 1248. 1213. 1197.
1276. 1247. 1250. 1234. 1234. 1172. 1172. 1195. 1224. 1233. 1171. 1225.
1143. 1229. 1198. 1202. 1148. 1125. 1187. 1213. 1149. 1162. 1124. 1157.
1137. 1146. 1139. 1147. 1176. 1175. 1155. 1173. 1100. 1166. 1120. 1183.
1117. 1146. 1160. 1103. 1072. 1138. 1124. 1104. 1156. 1164. 1151. 1098.
1100. 1112. 1080. 1111. 1115. 1040. 1083. 1174. 1063. 1116. 1055. 1069.
1121. 1025. 1061. 1026. 1084. 1058. 1059. 1068. 1076. 1059. 1045. 1106.
1028. 998. 1018. 1035. 1065. 1009. 1062. 1076. 1048. 1039. 1061. 1032.
1040. 997. 1010. 979. 1037. 1015. 1020. 1068. 1018. 910. 928. 988.
936. 932. 974. 1000. 950. 952. 1019. 1012. 980. 980. 928. 966.
993. 967. 935. 969. 1025. 947. 931. 924. 935. 907. 961. 913.
864. 894. 948. 949. 937. 932. 933. 904. 919. 914. 850. 913.
995. 915. 915. 877. 945. 930. 891. 893. 903. 859. 913. 865.
904. 885. 837. 870. 842. 826. 823. 930. 833. 859. 867. 832.
852. 879. 835. 842. 832. 883. 856. 827. 820. 884. 843. 804.
867. 831. 851. 829. 801. 824. 808. 838. 819. 826. 809. 799.
841. 859. 769. 787. 837. 737. 801. 778. 782. 814. 774. 835.
784. 756. 791. 776. 793. 708. 765. 763. 774. 782. 752. 727.
748. 758. 765. 758. 747. 740. 771. 770. 753. 756. 669. 700.
712. 742. 698. 726. 755. 742. 724. 714. 721. 731. 730. 743.
692. 697. 748. 743. 727. 709. 751. 735. 728. 702. 700. 700.
657. 722. 652. 739. 706. 695. 711. 708. 707. 693. 695. 676.
680. 683. 665. 642. 668. 693. 684. 712. 680. 703. 688. 653.
662. 637. 704. 668. 646. 623. 647. 654. 662. 658. 603. 679.
644. 649. 659. 683. 680. 599. 635. 643. 638. 608. 621. 626.
596. 626. 624. 672. 618. 690. 603. 617. 659. 640. 630. 680.

```
 616.  628.  6C5.  648.  586.  598.  563.  614.  609.  599.  646.  600.
 623.  633.  626.  613.  648.  612.  621.  587.  577.  542.  586.  574.
 609.  608.  627.  589.  623.  636.  623.  553.  600.  565.  572.  591.
 568.  609.  568.  623.  558.  544.  559.  576.  545.  558.  547.  571.
 552.  557.  558.  589.  539.  612.  580.  595.  554.  552.  574.  532.
 554.  566.  534.  602.  543.  557.  556.  511.  536.  526.  541.  558.
 539.  533.  517.  535.  522.  519.  491.  483.  542.  492.  518.  510.
 494.  513.  517.  559.  505.  524.  482.  474.  480.  512.  462.  531.
 515.  518.  483.  500.  462.  469.  529.  447.  458.  557.  462.  498.
 511.  516.  466.  476.  464.  459.  448.  467.  442.  497.  447.  460.
 456.  449.  463.  457.  449.  449.  499.  462.  485.  450.  511.  406.
 445.  461.  415.  459.  475.  495.  454.  425.  406.  428.  441.  462.
 432.  438.  441.  441.  437.  394.  452.  443.  435.  419.  409.  433.
 416.  399.  443.  411.  426.  450.  428.  379.  393.  416.  387.  369.
 412.  386.  383.  378.  417.  359.  408.  392.  441.  400.  420.  392.
 393.  405.  401.  387.  373.  386.  388.  381.  386.  368.  414.  378.
 365.  420.  405.  365.  396.  358.  363.  348.  358.  399.  357.  381.
 361.  371.  362.  404.  334.  335.  371.  340.  379.  372.  324.  354.
 335.  352.  370.  322.  382.  348.  347.  350.  369.  360.  348.  327.
 331.  353.  380.  370.  329.  344.  319.  335.  337.  340.  332.  358.
 339.  311.  347.  329.  301.  315.  324.  349.  313.  358.  333.  335.
 334.  336.  3C7.  327.  309.  334.  304.  292.  327.  320.  310.  301.
 311.  304.  292.  303.
```

```
***** REACTOR SPECTRUM THRU 6.5'' ALUMINUM ALPHA = 1.49MEV  8/24/71 *****
 17165.   17.  155.  415. 1186. 3729.1C642.30460.15747.   50.   39.   89.
   173.  581. 2499.13898.52240.66277.23473.87723.61871.34562.15790.99411.
 87151.75368.64C90.54225.44325.36477.2C283.21178.13772. 7878. 2385.96283.
 91187.86107.82304.78179.74447.70707.67614.63419.61067.58329.56127.53641.
 51030.49287.47387.45165.43736.41696.4C249.38712.37291.36006.34842.33216.
 31782.31072.2S923.29224.28613.27401.27195.25969.25505.25293.24592.24412.
 24073.23402.23451.23292.22841.23247.23022.23152.23051.23205.22963.23492.
 23121.23313.23106.22944.22572.22380.22020.21364.20521.19743.18972.17613.
 16826.15484.14573.13516.12726.11664.1C946.10141. 9642. 9030. 8555. 8101.
  7683. 7350. 7159. 6902. 6521. 6460. 6134. 6101. 5898. 5942. 5667. 5446.
  5419. 5402. 5433. 5190. 5126. 5233. 4985. 5032. 4871. 5023. 4823. 4692.
  4734. 4658. 4810. 4746. 4457. 4577. 4598. 4357. 4394. 4329. 4397. 4298.
  4127. 4088. 4182. 4140. 4166. 4034. 4078. 3832. 3876. 3942. 3803. 3856.
  3652. 3652. 3751. 3612. 3419. 3524. 3421. 3425. 3481. 3371. 3244. 3214.
  3246. 3156. 3112. 3123. 3048. 3030. 3105. 2963. 2964. 2837. 2937. 2765.
  2744. 2655. 2778. 2740. 2743. 2658. 2692. 2758. 2623. 2632. 2567. 2454.
  2528. 2602. 2615. 2548. 2536. 2487. 2517. 2550. 2476. 2423. 2439. 2526.
  2442. 2513. 2552. 2476. 2506. 2515. 2396. 2386. 2439. 2418. 2421. 2435.
  2362. 2435. 2405. 2421. 2459. 2439. 2420. 2390. 2332. 2382. 2403. 2355.
  2333. 2437. 2392. 2343. 2314. 2322. 2309. 2373. 2254. 2252. 2259. 2301.
  2324. 2329. 2365. 2190. 2235. 2301. 2225. 2241. 2284. 2232. 2310. 2321.
  2243. 2170. 2199. 2166. 2235. 2217. 2200. 2200. 2239. 2175. 2177. 2162.
  2135. 2193. 2290. 2170. 2115. 2076. 2188. 2086. 2130. 2088. 2088. 2115.
  2061. 2081. 2C86. 2095. 2041. 2077. 2050. 2108. 2055. 2044. 2016. 2021.
  2036. 2142. 2019. 2033. 2011. 1993. 2028. 2023. 2096. 2040. 2052. 1981.
  1968. 1995. 1951. 1994. 1959. 1900. 1876. 1943. 1975. 1987. 1894. 1948.
```

1913. 1966. 1949. 1920. 1845. 1987. 1922. 1876. 1886. 1857. 1894. 1886.
1779. 1784. 1800. 1771. 1789. 1877. 1773. 1759. 1761. 1747. 1774. 1699.
1630. 1676. 1698. 1710. 1674. 1610. 1669. 1588. 1615. 1640. 1610. 1532.
1667. 1557. 1604. 1600. 1590. 1486. 1512. 1474. 1524. 1469. 1534. 1402.
1406. 1498. 1392. 1539. 1442. 1419. 1427. 1416. 1378. 1397. 1371. 1379.
1384. 1393. 1374. 1333. 1321. 1316. 1367. 1267. 1306. 1309. 1340. 1375.
1351. 1310. 1281. 1316. 1235. 1309. 1226. 1215. 1308. 1247. 1267. 1253.
1227. 1220. 1281. 1202. 1220. 1269. 1229. 1187. 1201. 1238. 1199. 1174.
1216. 1220. 1200. 1207. 1158. 1171. 1192. 1126. 1175. 1162. 1272. 1156.
1108. 1133. 1155. 1127. 1125. 1131. 1194. 1128. 1107. 1156. 1158. 1132.
1127. 1161. 1134. 1149. 1065. 1141. 1145. 1089. 1156. 1112. 1150. 1116.
1105. 1039. 1006. 1055. 1074. 1090. 1073. 1045. 1035. 1016. 1092. 1014.
1038. 1027. 1044. 1018. 1039. 1024. 1041. 1010. 947. 949. 982. 1029.
979. 1013. 953. 961. 1003. 938. 928. 966. 966. 1008. 1004. 928.
960. 904. 856. 946. 906. 962. 965. 858. 904. 931. 868. 919.
874. 857. 900. 896. 862. 835. 887. 856. 921. 854. 862. 811.
858. 810. 804. 806. 841. 872. 837. 801. 826. 834. 850. 865.
827. 805. 800. 822. 766. 864. 785. 807. 731. 688. 757. 742.
753. 752. 767. 749. 757. 709. 782. 738. 740. 764. 744. 739.
720. 724. 746. 692. 744. 720. 719. 706. 720. 682. 740. 699.
699. 680. 715. 701. 714. 701. 695. 700. 680. 671. 693. 665.
702. 620. 674. 705. 727. 665. 656. 699. 676. 676. 660. 674.
651. 626. 640. 679. 668. 643. 673. 665. 630. 681. 662. 650.
665. 640. 598. 620. 665. 606. 631. 624. 652. 624. 631. 694.
639. 607. 662. 633. 592. 583. 618. 627. 579. 590. 617. 652.
620. 615. 598. 623. 557. 613. 648. 588. 600. 601. 559. 554.
561. 551. 601. 581. 573. 586. 580. 588. 601. 544. 538. 574.
570. 588. 562. 561. 602. 569. 519. 556. 574. 577. 548. 563.
527. 527. 579. 527. 596. 566. 571. 536. 573. 504. 539. 539.
537. 530. 522. 508. 532. 479. 562. 501. 521. 514. 553. 525.
513. 496. 486. 517. 489. 501. 522. 533. 451. 499. 482. 512.
483. 510. 467. 492. 465. 492. 477. 502. 494. 506. 466. 474.
490. 523. 496. 427. 478. 463. 499. 508. 496. 458. 475. 450.
489. 469. 489. 497. 468. 435. 471. 506. 450. 436. 444. 442.
431. 451. 494. 420. 434. 424. 454. 450. 462. 433. 471. 443.
435. 426. 460. 461. 431. 436. 438. 479. 420. 420. 437. 421.
460. 454. 426. 447. 420. 400. 460. 452. 396. 405. 387. 394.
395. 387. 411. 408. 393. 406. 407. 391. 408. 403. 420. 395.
376. 359. 400. 398. 372. 384. 341. 401. 402. 337. 433. 393.
390. 396. 410. 409. 394. 333. 350. 383. 359. 397. 368. 369.
372. 365. 376. 372. 376. 364. 358. 356. 362. 352. 362. 343.
368. 353. 374. 335. 338. 373. 348. 334. 375. 357. 359. 374.
355. 386. 310. 389. 355. 310. 331. 308. 310. 322. 352. 324.
290. 314. 333. 316. 323. 338. 336. 314. 320. 365. 321. 299.
341. 288. 327. 301. 334. 294. 306. 309. 325. 316. 287. 322.
302. 277. 309. 315. 300. 316. 324. 304. 302. 332. 298. 296.
266. 289. 305. 296. 282. 305. 308. 285. 289. 305. 317. 281.
277. 274. 279. 282. 282. 301. 263. 240. 294. 254. 276. 261.
290. 275. 270. 275. 282. 255. 292. 275. 268. 293. 278. 273.
292. 251. 272. 257. 265. 313. 252. 259. 259. 272. 264. 248.
256. 254. 270. 266. 266. 236. 227. 236. 275. 254. 233. 253.
249. 262. 240. 232. 246. 275. 243. 258. 242. 232. 251. 231.
239. 247. 234. 281. 259. 215. 240. 235. 231. 227. 230. 228.
199. 241. 222. 223. 210. 235. 203. 206. 207. 208. 202. 207.
211. 222. 221. 229. 225. 219. 225. 186. 217. 194. 227. 223.
195. 219. 217. 226. 183. 241. 187. 206. 204. 226. 209. 186.
251. 232. 216. 212. 210. 191. 203. 204. 220. 167. 239. 193.
191. 206. 198. 184. 186. 200. 174. 193. 215. 202. 177. 175.
175. 199. 185. 182. 197. 187. 220. 193. 181. 189. 175. 170.
179. 171. 157. 190.

***** REACTOR SPECTRUM THRU 6.5'' ALUMINUM ALPHA = MEV 8/24/71 *****

26.	1.	1.	1.	9.	25.	132.	142.	84.	46.	50.	66.
143.	1229.	2823.	792.	88.	96.	243.	544.	807.	1005.	1046.	1027.
1072.	1152.	1266.	1250.	1428.	1519.	1721.	1868.	2045.	2252.	2361.	2724.
2886.	3243.	3554.	3974.	4366.	4720.	5271.	5757.	6267.	6927.	7315.	8044.
8549.	9097.	9721.	9855.	10582.	10869.	11232.	11466.	11501.	11870.	11807.	11706.
11625.	11920.	11720.	11431.	11445.	11074.	10804.	10513.	10262.	10241.	9939.	9514.
9364.	30409.	8658.	8377.	7945.	7998.	7502.	7136.	6947.	6657.	6449.	6082.
5737.	5529.	5166.	5013.	4727.	4787.	4483.	4276.	4235.	3955.	3872.	3674.
3655.	3550.	3472.	3503.	3358.	3223.	3253.	3230.	3126.	3034.	3109.	3113.
2936.	2917.	2946.	3008.	2921.	2977.	2993.	2930.	2956.	2861.	2932.	2806.
2821.	2907.	2972.	2876.	2909.	2906.	2875.	2820.	2854.	2903.	2801.	2792.
2871.	2856.	2759.	2853.	2734.	2754.	2815.	2836.	2786.	2811.	2816.	2717.
2635.	2635.	2815.	2796.	2754.	2745.	2851.	2692.	2679.	2771.	2691.	2664.
2584.	2721.	2641.	2683.	2619.	2626.	2572.	2593.	2535.	2451.	2561.	2558.
2509.	2459.	2572.	2521.	2503.	2432.	2413.	2487.	2326.	2393.	2311.	2354.
2337.	2318.	2356.	2299.	2217.	2292.	2202.	2128.	2144.	2173.	2135.	2073.
2136.	2117.	2045.	2062.	2067.	1975.	2070.	1904.	2026.	1858.	1880.	1903.
1879.	1809.	1765.	1839.	1752.	1756.	1738.	1643.	1735.	1707.	1678.	1579.
1633.	1612.	1567.	1500.	1452.	1578.	1496.	1403.	1467.	1434.	1387.	1361.
1439.	1362.	1350.	1356.	1286.	1302.	1287.	1312.	1288.	1286.	1213.	1228.
1219.	1242.	1198.	1203.	1191.	1131.	1096.	1140.	1155.	1170.	1216.	1166.
1190.	1085.	1164.	1180.	1127.	1105.	1141.	1077.	1167.	1079.	1110.	1069.
1163.	1063.	1055.	1055.	1064.	1110.	1120.	1019.	1061.	1081.	1081.	1054.
1011.	1014.	1029.	1031.	1024.	1071.	1004.	1060.	1087.	1019.	1040.	1035.
969.	1050.	1070.	1054.	1082.	1044.	1040.	985.	1036.	1015.	1035.	1055.
1009.	988.	1027.	1054.	1052.	997.	928.	1044.	1011.	928.	979.	1026.
983.	984.	989.	940.	984.	993.	967.	1003.	967.	978.	999.	941.
965.	949.	974.	1006.	1017.	906.	986.	961.	989.	968.	954.	926.
966.	912.	991.	981.	915.	962.	1002.	923.	937.	879.	913.	868.
878.	972.	886.	925.	935.	869.	912.	927.	868.	897.	897.	890.
908.	876.	925.	890.	877.	860.	824.	869.	901.	838.	887.	905.
811.	861.	863.	783.	789.	872.	785.	830.	889.	806.	805.	804.
813.	812.	802.	841.	809.	792.	850.	744.	829.	760.	769.	792.
792.	752.	777.	759.	770.	755.	755.	728.	746.	733.	745.	746.
739.	747.	737.	729.	688.	698.	691.	677.	728.	647.	649.	676.
683.	625.	679.	690.	602.	607.	654.	589.	615.	553.	592.	578.
597.	611.	569.	621.	567.	529.	559.	569.	574.	517.	545.	562.
558.	546.	571.	522.	475.	548.	531.	510.	504.	539.	524.	463.
549.	497.	505.	535.	521.	508.	494.	473.	495.	484.	489.	551.
501.	473.	483.	474.	490.	468.	492.	506.	483.	455.	472.	491.
506.	488.	491.	487.	496.	489.	462.	458.	481.	463.	437.	476.
503.	462.	458.	482.	462.	482.	468.	480.	531.	468.	450.	439.
456.	447.	418.	496.	450.	507.	463.	437.	490.	454.	465.	453.
437.	489.	408.	421.	425.	426.	451.	435.	454.	430.	455.	389.
429.	462.	437.	471.	444.	381.	431.	434.	436.	427.	436.	430.
449.	438.	415.	470.	421.	402.	409.	413.	411.	432.	451.	440.
417.	421.	449.	445.	430.	409.	382.	403.	441.	422.	422.	420.
420.	413.	405.	404.	399.	361.	415.	369.	422.	393.	402.	400.
420.	413.	404.	410.	389.	428.	401.	394.	371.	415.	378.	327.

384. 387. 396. 400. 389. 431. 403. 387. 405. 377. 388. 374.
394. 407. 371. 427. 402. 367. 347. 330. 400. 369. 359. 392.
388. 335. 347. 340. 379. 385. 356. 368. 368. 379. 341. 381.
361. 341. 349. 383. 330. 361. 370. 345. 345. 355. 330. 346.
333. 343. 380. 356. 331. 336. 355. 340. 355. 376. 355. 357.
336. 345. 341. 329. 341. 355. 326. 351. 329. 331. 351. 316.
311. 321. 306. 325. 342. 354. 329. 325. 343. 331. 360. 331.
317. 341. 339. 357. 308. 343. 331. 330. 304. 326. 360. 314.
305. 298. 308. 311. 326. 298. 308. 348. 323. 316. 293. 283.
340. 313. 306. 303. 294. 299. 303. 339. 286. 311. 315. 307.
284. 333. 300. 326. 295. 318. 307. 295. 279. 298. 292. 288.
293. 308. 304. 284. 290. 323. 291. 288. 314. 291. 315. 291.
321. 297. 267. 285. 280. 306. 306. 279. 300. 266. 273. 276.
283. 327. 305. 289. 274. 290. 281. 289. 287. 274. 280. 305.
257. 288. 261. 256. 271. 305. 266. 276. 264. 262. 277. 281.
268. 261. 277. 252. 284. 234. 317. 282. 286. 256. 252. 257.
286. 231. 251. 288. 274. 315. 249. 274. 245. 222. 258. 266.
234. 261. 278. 256. 276. 216. 262. 282. 264. 229. 251. 258.
257. 241. 247. 238. 230. 240. 265. 254. 268. 238. 248. 205.
244. 200. 219. 228. 229. 239. 224. 250. 241. 235. 230. 207.
224. 222. 232. 212. 209. 230. 212. 189. 213. 222. 194. 234.
194. 217. 213. 218. 223. 224. 221. 229. 206. 180. 206. 216.
204. 188. 195. 189. 199. 200. 172. 186. 184. 174. 195. 188.
198. 174. 197. 192. 180. 163. 183. 177. 183. 158. 169. 161.
160. 173. 165. 163. 173. 178. 172. 156. 157. 146. 148. 167.
171. 165. 171. 158. 175. 164. 147. 152. 147. 141. 157. 162.
172. 157. 162. 155. 159. 150. 171. 154. 169. 164. 152. 156.
151. 177. 137. 153. 161. 142. 139. 168. 151. 126. 136. 133.
128. 141. 149. 142. 140. 109. 116. 140. 160. 139. 122. 117.
162. 153. 128. 142. 130. 137. 124. 133. 125. 141. 152. 164.
125. 133. 140. 143. 131. 143. 135. 130. 120. 109. 109. 124.
124. 126. 137. 136. 123. 132. 128. 114. 125. 137. 142. 129.
134. 127. 133. 132. 133. 118. 120. 111. 138. 119. 122. 108.
147. 120. 132. 110. 120. 120. 130. 127. 121. 120. 139. 105.
141. 128. 120. 100. 117. 134. 128. 118. 112. 113. 123. 119.
129. 135. 129. 114. 124. 110. 113. 105. 126. 105. 107. 117.
125. 123. 123. 120.

***** CALIFORIUM - 252 10 ATM. 4-TH SET 9/1/71 *****
79743. 84. 832. 2265. 5240.18858.45633.82773.18549. 2419. 280. 376.
740. 1682. 4984.16441.38224.72290.17545.28515.86172.54490.33266.12261.
94857.77488.61136.43172.27996.12380.97878.81773.66609.53309.40533.26579.
16693. 4073.94211.83400.73381.65594.56367.48056.40796.33880.26630.20790.
14843. 9818. 4549.99019.94243.90124.86397.81835.77855.75500.73124.68965.
65733.63608.61358.60006.57809.56408.54219.52906.51848.49908.48816.47671.
46441.45467.44897.43483.42669.41975.41616.40972.40101.39452.39075.38205.
37980.37352.36622.36369.35764.35417.35490.34901.34424.33998.33650.33487.
33328.32687.32463.31972.32011.31932.31735.31239.31101.30980.30551.30656.
30212.30149.29873.29419.29291.29381.29178.28760.28652.28636.28401.28141.
27952.28004.27731.27420.27485.27264.27124.26866.26989.26835.26481.26044.
26474.26138.25925.25939.25824.25478.25725.25201.25149.25084.25086.24979.

24527.24616.24201.24287.24384.24005.23726.23897.24004.23685.23728.23496.
23578.23028.23239.22941.22766.23073.22415.22792.22407.22338.22139.22103.
22033.22152.21733.21854.21711.21684.21348.21411.21588.21015.21148.20971.
21107.20586.20487.20626.20460.20410.20405.20221.19841.20196.19958.20002.
19745.19680.19611.19531.19423.19643.19478.19031.19204.19194.18930.18763.
18579.18576.18709.18477.18552.18314.18257.18277.18037.18192.17929.17800.
18107.17819.17992.17624.17377.17354.17756.17394.17375.17319.17220.17163.
16834.16896.17041.16997.16759.16622.16800.16548.16491.16610.16261.16382.
16189.16217.16005.16115.15937.16194.15913.15666.15587.15682.15813.15583.
15332.15365.15390.15308.15182.15090.15212.15386.15094.14838.14771.14867.
15116.14746.14682.14796.14826.14773.14718.14655.14335.14083.14403.14292.
14127.14119.14435.14078.14210.13958.14117.13872.13759.13940.13836.13630.
13542.13654.13760.13388.13380.13350.13166.13213.13333.13271.13364.13171.
13148.12993.12932.13002.12974.12847.12777.12593.12632.12622.12524.12393.
12439.12419.12603.12546.12425.12551.12251.12268.12157.12120.12157.11965.
12330.11946.11930.11934.11792.11818.12010.11729.11634.11490.11654.11671.
11457.11354.11390.11407.11347.11310.11201.11057.11312.11166.11194.11102.
11182.10882.10923.10973.10941.10792.10915.10851.10563.10774.10735.10719.
10710.10538.10563.10500.10358.10619.10407.10235.10277.10441.10186.10140.
10079.10061.10108.10119. 9870. 9991. 9774. 9938. 9810. 9794. 9792. 9782.
 9728. 9474. 9657. 9656. 9462. 9514. 9571. 9425. 9530. 9408. 9339. 9443.
 9254. 9261. 9111. 9057. 9148. 9392. 9170. 9041. 9230. 8997. 8996. 9105.
 9132. 8878. 8924. 8958. 8628. 8829. 8594. 8619. 8746. 8639. 8685. 8740.
 8696. 8506. 8570. 8459. 8459. 8467. 8323. 8383. 8474. 8185. 8350. 8240.
 8240. 8268. 8288. 8196. 8205. 8061. 8014. 8156. 7892. 8141. 7869. 7999.
 7925. 7942. 7858. 7820. 7792. 7853. 7836. 7763. 7652. 7580. 7590. 7541.
 7642. 7552. 7581. 7529. 7540. 7534. 7286. 7385. 7301. 7310. 7171. 7245.
 7403. 7262. 7235. 7142. 7133. 7164. 7066. 7160. 6893. 7104. 7134. 6990.
 7017. 6991. 6931. 6944. 6861. 6799. 6900. 6821. 6895. 6717. 6867. 6707.
 6627. 6563. 6643. 6504. 6466. 6377. 6456. 6587. 6375. 6402. 6533. 6367.
 6392. 6518. 6322. 6201. 6310. 6393. 6092. 6244. 6322. 6257. 6278. 6072.
 6136. 6003. 6151. 6165. 5943. 6071. 5794. 5947. 5998. 5846. 5850. 5770.
 5777. 5761. 5851. 5625. 5752. 5672. 5736. 5688. 5733. 5476. 5535. 5576.
 5457. 5675. 5482. 5460. 5484. 5378. 5500. 5270. 5342. 5351. 5359. 5390.
 5434. 5347. 5261. 5274. 5356. 5245. 5339. 5227. 5135. 5210. 5058. 5208.
 4993. 5015. 5086. 4989. 5111. 4998. 5052. 4937. 4902. 5062. 4791. 4994.
 4857. 4868. 4795. 4789. 4764. 4840. 4787. 4722. 4810. 4694. 4644. 4629.
 4591. 4613. 4494. 4691. 4467. 4507. 4458. 4549. 4590. 4473. 4489. 4443.
 4468. 4479. 4474. 4418. 4393. 4285. 4399. 4244. 4414. 4209. 4281. 4309.
 4275. 4257. 4120. 4216. 4186. 4187. 4239. 4147. 4054. 4062. 4199. 4079.
 4126. 4057. 4135. 4015. 4024. 3983. 3936. 4004. 4024. 3902. 3882. 3879.
 3885. 3833. 3948. 3795. 3821. 3857. 3718. 3701. 3742. 3721. 3722. 3739.
 3786. 3820. 3673. 3695. 3622. 3667. 3665. 3622. 3675. 3613. 3630. 3583.
 3485. 3491. 3563. 3502. 3564. 3460. 3398. 3447. 3354. 3447. 3453. 3413.
 3403. 3395. 3383. 3348. 3373. 3329. 3350. 3271. 3304. 3296. 3337. 3283.
 3243. 3211. 3169. 3247. 3067. 3150. 3114. 3152. 3102. 3145. 3131. 3098.
 3107. 3002. 2999. 3041. 3038. 2964. 3067. 2999. 2935. 3022. 2985. 2956.
 2821. 3007. 2898. 2873. 2835. 3001. 2878. 2816. 2902. 2799. 2828. 2869.
 2775. 2851. 2768. 2766. 2770. 2792. 2758. 2701. 2710. 2687. 2687. 2700.
 2680. 2678. 2634. 2660. 2603. 2518. 2647. 2638. 2638. 2583. 2466. 2526.
 2499. 2531. 2498. 2479. 2613. 2503. 2368. 2411. 2418. 2413. 2457. 2433.
 2372. 2365. 2366. 2374. 2346. 2308. 2432. 2414. 2221. 2345. 2336. 2230.
 2310. 2419. 2275. 2224. 2393. 2258. 2178. 2167. 2198. 2264. 2109. 2166.
 2169. 2223. 2293. 2176. 2131. 2117. 2154. 2131. 2156. 2163. 2138. 2088.
 2111. 2125. 1991. 2060. 2094. 2071. 2003. 2020. 1985. 2007. 2026. 2062.
 2003. 1956. 1961. 1977. 1869. 1965. 1924. 1902. 1938. 1877. 1874. 1900.
 1915. 1793. 1874. 1845. 1860. 1800. 1806. 1803. 1758. 1843. 1801. 1712.
 1775. 1784. 1716. 1751. 1784. 1719. 1757. 1756. 1641. 1749. 1703. 1634.
 1624. 1687. 1721. 1632. 1667. 1622. 1630. 1558. 1653. 1624. 1568. 1570.
 1613. 1590. 1578. 1504. 1502. 1496. 1613. 1560. 1487. 1495. 1546. 1609.

1537. 1533. 1462. 1485. 1467. 1516. 1479. 1535. 1449. 1410. 1464. 1416.
1412. 1432. 1357. 1408. 1398. 1424. 1380. 1300. 1388. 1349. 1422. 1279.
1399. 1284. 1288. 1261. 1347. 1407. 1260. 1271. 1263. 1269. 1257. 1331.
1244. 1221. 1223. 1235. 1293. 1246. 1230. 1211. 1235. 1178. 1191. 1187.
1189. 1171. 1172. 1198. 1208. 1179. 1193. 1101. 1137. 1162. 1163. 1116.
1159. 1113. 1110. 1088. 1084. 1042. 1129. 1137. 1087. 1021. 1084. 1057.
1053. 1045. 1055. 994. 1074. 1022. 976. 985. 1047. 954. 972. 944.
971. 996. 1009. 964. 951. 1004. 939. 956. 968. 976. 933. 919.
919. 922. 911. 936. 903. 931. 859. 907. 905. 875. 885. 858.
870. 861. 878. 832. 882. 905. 824. 847. 814. 817. 805. 787.
819. 824. 806. 778. 833. 766. 767. 823. 830. 826. 816. 795.
769. 774. 796. 748. 734. 742. 746. 710. 768. 728. 716. 695.
785. 764. 745. 718. 720. 731. 682. 728. 706. 670. 656. 698.
698. 663. 724. 634.

***** CALIFORIUM - 252 4 ATM. 4-TH SET 9/1/71 *****
11534. 357. 3144. 8001.19948.91466.29799.81385.55631.84289. 578. 835.
1419. 4191.15269.32016.61022.87309.66106.33058.43622.92189.85632.96225.
24330.56066. 1519.45546.96931.55298.17503.77519.47758.14545.88391.59237.
36606.11678.93347.71281.50933.34722.18140. 928.86809.72717.59707.44870.
33100.20844.10186.97054.85759.73813.65025.52949.43828.32475.23557.11450.
97472.89124.81344.73758.65570.57718.49742.40653.32761.26263.18178. 9160.
2477.94325.88213.81247.74176.69139.63098.56316.51137.45634.40806.35510.
30862.25633.21582.15839.11882. 8365. 4564. 691.96873.94138.90221.86895.
84882.81751.79445.76210.73718.72059.69632.66896.65350.62964.62219.59416.
58780.56389.55379.53424.52315.50708.49896.48419.47610.46544.45534.44425.
43365.42490.42075.40790.40387.39756.39637.38891.38120.37778.37195.36359.
35999.35648.35037.34930.34204.34051.33455.33243.32734.32662.32312.31832.
31618.31562.31282.31068.30513.30019.30291.30166.30195.29538.29478.29347.
28800.28984.28544.28219.28362.28319.27893.28033.27837.27557.27454.27367.
26995.27078.27183.26846.27072.26788.26634.26545.26188.26607.26304.26004.
26019.26214.25860.25743.25455.25420.25720.25478.25545.25348.25184.24971.
24825.24951.24781.24661.24535.24570.24673.24317.24154.24396.24355.24161.
23941.23952.24082.23733.23747.23512.23627.23752.23465.23703.23366.22972.
23312.23160.23154.23095.22868.22651.22857.23086.23234.23045.22542.22529.
22622.22647.22519.22126.22358.22418.22156.22053.21979.22301.22095.21890.
21909.21683.21926.21592.21680.21770.21578.21500.21428.21397.21367.20980.
20970.21351.21235.20874.20963.20904.20849.20915.20887.20606.20310.20578.
20450.20628.20573.20369.20472.20341.20201.20464.20350.20242.20057.20094.
20064.20287.19863.19515.19848.19597.19530.19769.19618.19840.19773.19392.
19307.19477.19470.19074.19285.19139.19193.19306.18943.19036.19052.19204.
19169.18929.18967.18869.18836.18742.18913.18454.18708.18471.18318.18248.
18692.18374.18145.18453.18278.18436.18237.18009.17948.18344.17894.18133.
18222.17991.17968.17977.18065.18036.17806.17480.17781.17501.17539.17640.
17684.17696.17350.17369.17352.17415.17382.17303.17155.17322.17092.17116.
16851.17067.17121.17142.16939.16638.16960.16950.16916.16698.16768.16377.
16800.16515.16551.16719.16444.16328.16454.16341.16471.16372.16308.16314.
16238.16029.16071.16012.15975.16072.15933.15940.15776.15747.16049.16004.
15992.15640.15865.15392.15663.15738.15674.15847.15711.15482.15698.15477.
15446.15604.15650.15386.15367.15457.15210.15265.14794.15107.15042.14928.
15081.14981.15083.14875.15021.14935.14649.14624.14810.14830.14888.14673.

14827.14732.14659.14525.14502.14735.14798.14753.14391.13983.14358.14434.
14220.14273.14285.14071.14248.14065.14261.13915.14375.13975.13890.13981.
14078.14146.13960.13960.13806.13774.13757.13675.13709.13867.13643.13821.
13834.13667.13470.13814.13503.13595.13583.13527.13562.13246.13333.13476.
13188.13100.13237.13266.13342.13067.13169.13049.13005.13168.13107.13331.
13048.13102.12902.12899.12903.12855.12826.12863.12751.12721.12644.12708.
12627.12530.12513.12579.12456.12760.12625.12525.12348.12438.12465.12327.
12426.12330.12438.12326.12006.12155.12200.12254.12073.12203.12222.12009.
11957.12193.11832.11777.11857.11882.11964.11828.11803.11918.11869.11721.
11767.11743.11778.11531.11683.11754.11757.11555.11442.11227.11643.11519.
11444.11528.11599.11212.11261.11256.11403.11537.11221.11190.11407.11375.
11469.11164.11247.11311.10967.11025.11129.11049.11156.10859.10926.11047.
10951.10817.10961.10797.10755.10553.10796.10713.10801.10887.10741.10767.
10837.10863.10741.10785.10626.10534.10431.10524.10396.10354.10533.10398.
10281.10420.10487.10155.10308.10276.10318.10219.10231.10230.10216.10165.
10143.10023.10077. 9984. 9961.10141.10150. 9879.10040.10154. 9853. 9882.
 9920. 9843. 9933. 9915. 9864. 9864. 9971. 9593. 9648. 9671. 9704. 9573.
 9729. 9684. 9568. 9681. 9563. 9790. 9619. 9471. 9474. 9466. 9520. 9380.
 9553. 9615. 9455. 9438. 9314. 9268. 9318. 9305. 9518. 9214. 9266. 9366.
 9206. 9285. 9343. 9243. 8987. 9221. 9173. 8912. 9019. 9090. 8973. 9025.
 9105. 9001. 8995. 8990. 8909. 8759. 8876. 8954. 8739. 8754. 8727. 8807.
 8752. 8813. 8920. 8690. 8733. 8842. 8631. 8706. 8801. 8645. 8705. 8632.
 8594. 8568. 8577. 8484. 8450. 8434. 8446. 8416. 8338. 8368. 8361. 8488.
 8308. 8383. 8431. 8165. 8158. 8247. 8216. 8190. 8403. 8008. 8165. 8269.
 8218. 8028. 8225. 7944. 7965. 7986. 7802. 7983. 8072. 8007. 7957. 7899.
 7944. 8011. 7969. 8005. 7582. 7828. 7971. 7909. 7935. 7745. 7920. 7834.
 7849. 7909. 7657. 7830. 7620. 7645. 7687. 7737. 7728. 7439. 7654. 7596.
 7456. 7650. 7392. 7503. 7533. 7428. 7568. 7502. 7324. 7399. 7400. 7460.
 7548. 7234. 7444. 7580. 7361. 7334. 7276. 7207. 7238. 7300. 7300. 7018.
 7361. 7085. 7183. 7236. 7083. 7244. 7156. 7182. 7104. 6976. 7111. 6909.
 7044. 7193. 6849. 6954. 6998. 6899. 7001. 6973. 6910. 6850. 6921. 6846.
 6970. 7005. 6840. 6861. 6728. 6869. 6655. 6734. 6796. 6747. 6726. 6688.
 675C. 6655. 6747. 6745. 6880. 6725. 6792. 6605. 6777. 6698. 6629. 6483.
 6557. 6566. 6500. 6608. 6577. 6520. 6610. 6340. 6480. 6465. 6400. 6492.
 6333. 6533. 6400. 6430. 6479. 6271. 6328. 6330. 6329. 6342. 6375. 6384.
 6291. 6279. 6253. 6333. 6315. 6122. 6110. 6247. 6184. 6130. 6229. 6239.
 5998. 6096. 6113. 6144. 6098. 6082. 5975. 5961. 6044. 6061. 5899. 6016.
 6005. 6115. 6010. 6055. 6030. 5883. 5964. 5977. 5888. 5997. 5840. 5872.
 5817. 5733. 5804. 5839. 5787. 5758. 5933. 5688. 5724. 5662. 5775. 5711.
 5791. 5687. 5715. 5726. 5740. 5599. 5813. 5578. 5644. 5634. 5770. 5642.
 5603. 5612. 5583. 5601. 5504. 5360. 5474. 5583. 5573. 5429. 5375. 5579.
 5406. 5233. 5474. 5365. 5297. 5309. 5438. 5385. 5382. 5276. 5360. 5314.
 5159. 5297. 53C0. 5261. 5377. 5191. 5181. 5263. 5286. 5241. 5161. 5141.
 5317. 5133. 5216. 5152. 5183. 5094. 5169. 5079. 5041. 5092. 5169. 5026.
 5056. 4993. 5C93. 5144. 5051. 5150. 5083. 5017. 4811. 4916. 4946. 5032.
 5036. 4931. 5C14. 4983. 5132. 4991. 4884. 4878. 4925. 4852. 4990. 4935.
 4866. 4999. 4778. 4802. 4874. 4814. 4888. 4731. 4769. 4780. 4680. 4719.
 4707. 4687. 4698. 4747. 4703. 4766. 4803. 4697. 4679. 4662. 4615. 4744.
 4659. 4607. 4599. 4627. 4734. 4585. 4669. 4606. 4553. 4560. 4467. 4650.
 4521. 4711. 4556. 4658. 4600. 4528. 4518. 4387. 4521. 4389. 4481. 4452.
 4445. 4475. 4393. 4504.

***** CALIFORIUM - 252 1 ATM. 4-TH SET 9/1/71 *****

6.	0.	0.	1.	10.	10.	66.	105.	68.	75.	98.	134.
228.	1791.	6765.	14001.	9364.	3377.	1316.	791.	567.	409.	273.	301.
234.	7.	2.	2.	4.	4.	6.	8.	16.	24.	33.	50.
64.	114.	100.	108.	151.	145.	133.	123.	133.	119.	124.	125.
162.	159.	166.	179.	217.	206.	258.	249.	273.	317.	338.	382.
504.	562.	724.	902.	1122.	1547.	1814.	2405.	2893.	3634.	4290.	4901.
5575.	6429.	6972.	7430.	7959.	8418.	8692.	8950.	8993.	9181.	9189.	9515.
9664.	9573.	9586.	9783.	9690.	9874.	9739.	9813.	9807.	10078.	9693.	9905.
9822.	9861.	9931.	9860.	9798.	9917.	9961.	9939.	9840.	9896.	9840.	10044.
10028.	9896.	9867.	9683.	9796.	9863.	9456.	9601.	9547.	9621.	9657.	9453.
9666.	9475.	9715.	9578.	9393.	9441.	9419.	9468.	9412.	9454.	9426.	9281.
9389.	9275.	9404.	9300.	9171.	9134.	9205.	9255.	9138.	9205.	9121.	9026.
9100.	9118.	8995.	9002.	9005.	9003.	8853.	8874.	8832.	8914.	8921.	8868.
8893.	8928.	8683.	8725.	8679.	8778.	8695.	8600.	8646.	8491.	8772.	8736.
8559.	8468.	8554.	8454.	8545.	8462.	8413.	8285.	8412.	8247.	8356.	8285.
8389.	8415.	8445.	8014.	8221.	8336.	8320.	8175.	8282.	8093.	8270.	7896.
8038.	8321.	8156.	8135.	8268.	7940.	7896.	8017.	8078.	8032.	8054.	7956.
7892.	7950.	7895.	7685.	7952.	7758.	7807.	7732.	7660.	7867.	7811.	7677.
7715.	7698.	7842.	7695.	7570.	7592.	7625.	7670.	7717.	7509.	7519.	7511.
7548.	7458.	7547.	7408.	7541.	7404.	7471.	7401.	7420.	7310.	7299.	7256.
7410.	7400.	7273.	7223.	7323.	7305.	7126.	7322.	7324.	6996.	7091.	7002.
7069.	7219.	7169.	7054.	6923.	6924.	6950.	7058.	7018.	6761.	6927.	6920.
6854.	6923.	6801.	6808.	6933.	6756.	6929.	6802.	6788.	6815.	6724.	6581.
6665.	6647.	6629.	6538.	6506.	6571.	6677.	6580.	6723.	6568.	6424.	6440.
6506.	6440.	6439.	6395.	6375.	6523.	6478.	6365.	6246.	6440.	6253.	6325.
6279.	6260.	6137.	6256.	6361.	6307.	6114.	6155.	6046.	6054.	6272.	6035.
6086.	6144.	5903.	6102.	5920.	6114.	6043.	5933.	5884.	6122.	5976.	6006.
5783.	5872.	5873.	5855.	5873.	5906.	5812.	5876.	5749.	5838.	5745.	5732.
5653.	5712.	5739.	5637.	5614.	5594.	5660.	5698.	5613.	5526.	5708.	5653.
5586.	5534.	5604.	5656.	5579.	5412.	5541.	5397.	5348.	5492.	5418.	5459.
5372.	5521.	5224.	5383.	5336.	5292.	5285.	5283.	5270.	5251.	5295.	5145.
5245.	5238.	5254.	5114.	5142.	5268.	5036.	5216.	5261.	5180.	5135.	4994.
5127.	5111.	5165.	4965.	5064.	5038.	5098.	5015.	4978.	4950.	4995.	4933.
4816.	4951.	4994.	5027.	4989.	4794.	5019.	4832.	4811.	4818.	4780.	4736.
4814.	4600.	4696.	4747.	4672.	4641.	4810.	4750.	4651.	4791.	4673.	4574.
4639.	4757.	4527.	4671.	4540.	4684.	4641.	4581.	4649.	4714.	4568.	4668.
4463.	4552.	4627.	4369.	4527.	4392.	4474.	4549.	4446.	4385.	4446.	4438.
4354.	4299.	4425.	4455.	4494.	4214.	4346.	4386.	4327.	4318.	4411.	4261.
4413.	4217.	4236.	4354.	4355.	4282.	4261.	4193.	4160.	4147.	4061.	4144.
4066.	4301.	4097.	4047.	4055.	4094.	4065.	4052.	4099.	3985.	4059.	3916.
4108.	4031.	4077.	4078.	4048.	3862.	4083.	3846.	3996.	4012.	3960.	4061.
3916.	3904.	3832.	3875.	3833.	3842.	3930.	3956.	3782.	3901.	3789.	3816.
3804.	3906.	3752.	3747.	3864.	3786.	3717.	3760.	3784.	3766.	3745.	3607.
3700.	3793.	3613.	3713.	3658.	3585.	3568.	3618.	3666.	3571.	3608.	3618.
3574.	3532.	3675.	3471.	3507.	3555.	3521.	3513.	3561.	3568.	3512.	3417.
3491.	3395.	3512.	3428.	3543.	3489.	3529.	3434.	3438.	3400.	3484.	3396.
3358.	3397.	3458.	3461.	3475.	3388.	3404.	3457.	3226.	3336.	3315.	3332.
3280.	3253.	3243.	3319.	3262.	3341.	3259.	3234.	3293.	3210.	3216.	3271.
3160.	3176.	3145.	3104.	3243.	3177.	3121.	3215.	3268.	3148.	3214.	3119.
3110.	3086.	3176.	3097.	3148.	3084.	3024.	2991.	3217.	2960.	3139.	3061.
3071.	3083.	3062.	2953.	3019.	3074.	3011.	3012.	2966.	3067.	3008.	2874.
2911.	2946.	2947.	2941.	2919.	3028.	3007.	3035.	2894.	2888.	2889.	2912.
2847.	2873.	2943.	2898.	2922.	2948.	2861.	2781.	2882.	2836.	2840.	2737.
2835.	2820.	2755.	2819.	2799.	2839.	2766.	2719.	2948.	2751.	2745.	2731.
2753.	2732.	2700.	2759.	2691.	2786.	2730.	2747.	2772.	2747.	2696.	2642.
2691.	2739.	2731.	2608.	2706.	2663.	2650.	2653.	2661.	2563.	2621.	2672.
2682.	2586.	2577.	2681.	2523.	2554.	2614.	2527.	2614.	2506.	2626.	2513.
2631.	2612.	2586.	2508.	2509.	2581.	2567.	2425.	2492.	2513.	2419.	2496.

2434. 2536. 2563. 2378. 2429. 2471. 2499. 2426. 2395. 2380. 2441. 2384.
2358. 2483. 2421. 2391. 2400. 2459. 2421. 2331. 2424. 2289. 2402. 2421.
2353. 2448. 2354. 2419. 2374. 2361. 2369. 2406. 2360. 2287. 2287. 2260.
2288. 2335. 2302. 2261. 2293. 2243. 2306. 2282. 2245. 2211. 2193. 2255.
2239. 2239. 2134. 2210. 2216. 2234. 2298. 2234. 2217. 2197. 2153. 2200.
2185. 2138. 2172. 2197. 2181. 2196. 2155. 2159. 2180. 2109. 2170. 2103.
2164. 2154. 2139. 2177. 2189. 2199. 2109. 2186. 2138. 2069. 2042. 2116.
2074. 2116. 2105. 1988. 2024. 2134. 1901. 2044. 1992. 1968. 2069. 2046.
1911. 2015. 2022. 2035. 1943. 2044. 1917. 2078. 2011. 1921. 1988. 2028.
1959. 2006. 1967. 2004. 1882. 1919. 1985. 1938. 1852. 1977. 1905. 1884.
1872. 1932. 2007. 1890. 1946. 1911. 1896. 1903. 1937. 1923. 1909. 1817.
1735. 1830. 1878. 1875. 1867. 1836. 1925. 1840. 1900. 1846. 1805. 1831.
1753. 1782. 1789. 1789. 1774. 1774. 1746. 1814. 1737. 1794. 1808. 1827.
1768. 1783. 1719. 1723. 1741. 1818. 1810. 1711. 1715. 1703. 1699. 1760.
1765. 1756. 1657. 1737. 1698. 1695. 1734. 1675. 1807. 1699. 1666. 1635.
1688. 1686. 1724. 1650. 1663. 1655. 1618. 1631. 1696. 1684. 1669. 1588.
1637. 1718. 1580. 1690. 1645. 1554. 1627. 1667. 1581. 1585. 1650. 1619.
1583. 1613. 1610. 1602. 1634. 1538. 1591. 1648. 1541. 1470. 1587. 1554.
1541. 1639. 1540. 1549. 1478. 1516. 1517. 1448. 1535. 1546. 1558. 1520.
1547. 1510. 1534. 1546. 1475. 1519. 1531. 1559. 1516. 1494. 1504. 1498.
1437. 1463. 1466. 1447. 1420. 1442. 1400. 1444. 1482. 1493. 1415. 1474.
1386. 1471. 1448. 1454. 1373. 1413. 1467. 1402. 1405. 1339. 1459. 1464.
1437. 1401. 1388. 1392. 1394. 1352. 1353. 1363. 1327. 1352. 1427. 1448.
1406. 1377. 1350. 1327. 1413. 1308. 1422. 1449. 1375. 1309. 1418. 1344.
1364. 1389. 1352. 1259. 1347. 1354. 1370. 1311. 1349. 1295. 1313. 1316.
1326. 1287. 1288. 1369. 1306. 1290. 1298. 1380. 1283. 1302. 1340. 1241.
1261. 1358. 1392. 1341. 1290. 1316. 1333. 1314. 1358. 1286. 1224. 1276.
1293. 1255. 1259. 1331.

INITIAL DEVELOPMENT OF A BENJAMIN-TYPE NEUTRON SPECTROMETER SYSTEM

by

C. MICHAEL ESTES

B.S., KANSAS STATE UNIVERSITY, 1970

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirement for the degree

MASTER OF SCIENCE

Department of Nuclear Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

ABSTRACT

A Benjamin-Type Neutron Spectrometer System was put into operation using detectors filled to pressures of 10.4, and 1 atmospheres. Biasing of the spherical gas-filled proportional counters was accomplished with a negative high voltage power supply. A special charge-sensitive preamplifier was built and used for the initial amplification of the signal and a linear pulse shaping system was designed. Studies were performed to obtain the optimum resolution for the system.

Several gamma-ray discrimination systems were designed, built, and tested, with the final design using a fast and slow component of the signal to accomplish discrimination. The fast component was adjusted to cancel the gamma-ray induced pulses in the slow component of the signal.

Neutron penetration data were obtained through iron and aluminum specimens using the KSU TRIGA MARK II nuclear reactor as a neutron source. These data served as a means for obtaining an energy calibration for the spectrometer system. Finally, a Californium-252 neutron spectrum was obtained. All unfolded neutron spectrums were obtained with the code SPEC 4; this code was verified through the use of artificially generated proton-recoil distributions.