DEVELOPMENT OF AN NE-213 FAST-NEUTRON TAC SPECTROMETER SYSTEM UTILIZING OFF-LINE GAMMA-RAY DISCRIMINATION

by

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1.0 INTRODUCTION

A number of organic scintillators yield light pulses whose shape varies with the rate of energy loss of an exciting particle. This property makes them useful for fast-neutron spectroscopy work using a fission reactor because the difference in pulse shape between a neutron induced light pulse and a gamma-ray induced light pulse provides a means of separating neutron pulses from gamma pulses. In light of this fact, many electronic pulse shape discrimination (PSD) systems have been developed which perform on-line pulse shape discrimination in fast-neutron spectrometer systems. On-line pulse shape discrimination systems generally work well for neutron energies above 1.5 MeV; however, below that energy, little pulse shape difference exists between neutron induced and gamma induced light pulses, and gamma discrimination becomes less and less exact. Uncertainty in gamma discrimination effectively puts a lower limit on the useful energy range of fast neutron spectrometers using organic scintillators which is well above their neutron threshold level of around 0.7 MeV.

In this study, an attempt is made to optimize the gamma discrimination process by off-line computer analysis of the data from a TAC spectrometer system somewhat similar to that reported by Haas.[1] In the system developed in this work, the linear signal from an NE-213 detector is integrated and double differentiated to produce a bipolar pulse whose cross over point is a function of the original pulse shape. A time to amplitude converter (TAC) converts the zero cross-over time of the bipolar pulse to a pulse height. The TAC signal and the NE-213 linear signal are fed to a 4096 channel multiparameter analyzer operated in a two parameter mode. The analyzer produces a 64 X 64 array of data in which neutrons and gammas lie in two "ridges". The 64 X 64 array of data is analyzed by a specifically constructed computer

code and the neutron and gamma information are separated. In the low energy region, an attempt is made to optimize the gamma discrimination by an iterative weighted least squares gaussian fitting routine.

2.0 NE-213 FAST NEUTRON TAC SPECTROMETER SYSTEM

2.1 Basic Characteristics of The NE-213 Scintillator

NE-213 is an organic scintillator which responds to incident radiation indirectly through recoil protons, recoil electrons, and carbon nuclei interactions which result in recoil alpha particles. Neutrons incident on the solution interact to produce recoil protons and carbon scattering events while the only evident gamma ray interaction in the solution is by Compton scattering.[2] Owen[12] has shown that the pulse shape of the light pulse from a scintillation producing event is a function of the rate of energy loss of the exciting particle and that the light pulse can be expressed as the sum of two exponentials with different decay constants. It is obvious then that neutrons and gamma rays will produce light pulses of different pulse shape since they react through mechanisms which are known to have different specific ionizations. In fact, it has been shown that the slow exponential decay component of a neutron induced light pulse has a greater relative magnitude than that of a gamma induced light pulse.

Roush[11] has shown that if a pulse is integrated, then double differentiated a bipolar pulse is produced whose zero cross-over point is, ideally, invariant with amplitude and a function only of pulse shape. Ideally then, neutron and gamma pulses from the detector treated in this manner should yield bipolar pulses with definite and different zero cross-over points. With nonideal electronic components however, it is not possible to produce a bipolar pulse with a zero cross-over point which is entirely invariant with pulse height. This problem has plagued TAC spectrometer systems similar to that reported by Haas[1] which use this principle, especially in the energy range below about 2 MeV. The non-ideality of the zero cross-over

method posed no problem in this study however, since subsequent computer analysis of the raw data required only that the zero cross-over points for neutrons and gamma pulses be different at any given pulse height. It is not necessary that the zero cross-over points also be invariant for all pulse heights as is necessary for the operation of spectrometers using the TAC procedure for on-line gamma discrimination.

2.2 Assembly of the NE-213 Detector, Photomultiplier Tube, and Static Shield

The NE-213 detector, photomultiplier tube, and static shield are of the same configuration as that reported by Simons.[2] The NE-213 Scintillation solution, a purified solution of Xylene and napthalene activators with POPOP added to shift the emission spectrum to match the photomultiplier tube response, was encapsulated at the factory in a glass cell 2.00 inches high and 2.03 inches in diameter with a scintillator volume of approximately 103 cc. The glass cell was optically coupled to an RCA 6810-A photomultiplier tube using Dow Corning 10^6 centistokes compound. The glass cell was carefully wrapped with light weight aluminum foil to act as a light reflector, and finally the entire glass cell and photomultiplier tube assembly was wrapped with black plastic electrician's tape to ensure a mechanically sound, light tight unit. Two concentric 6-3/4 inch long static shields separated by 3/16 inch of polyethylene were placed around the photomultiplier tube to shield it from stray magnetic fields which would alter its operating characteristics since it was the electrostatically focused type.

2.3 Photomultiplier Tube Base Assembly

The photomultiplier tube base, shown in figure 1, contains the electronic network necessary to properly bias the tube. In addition to the

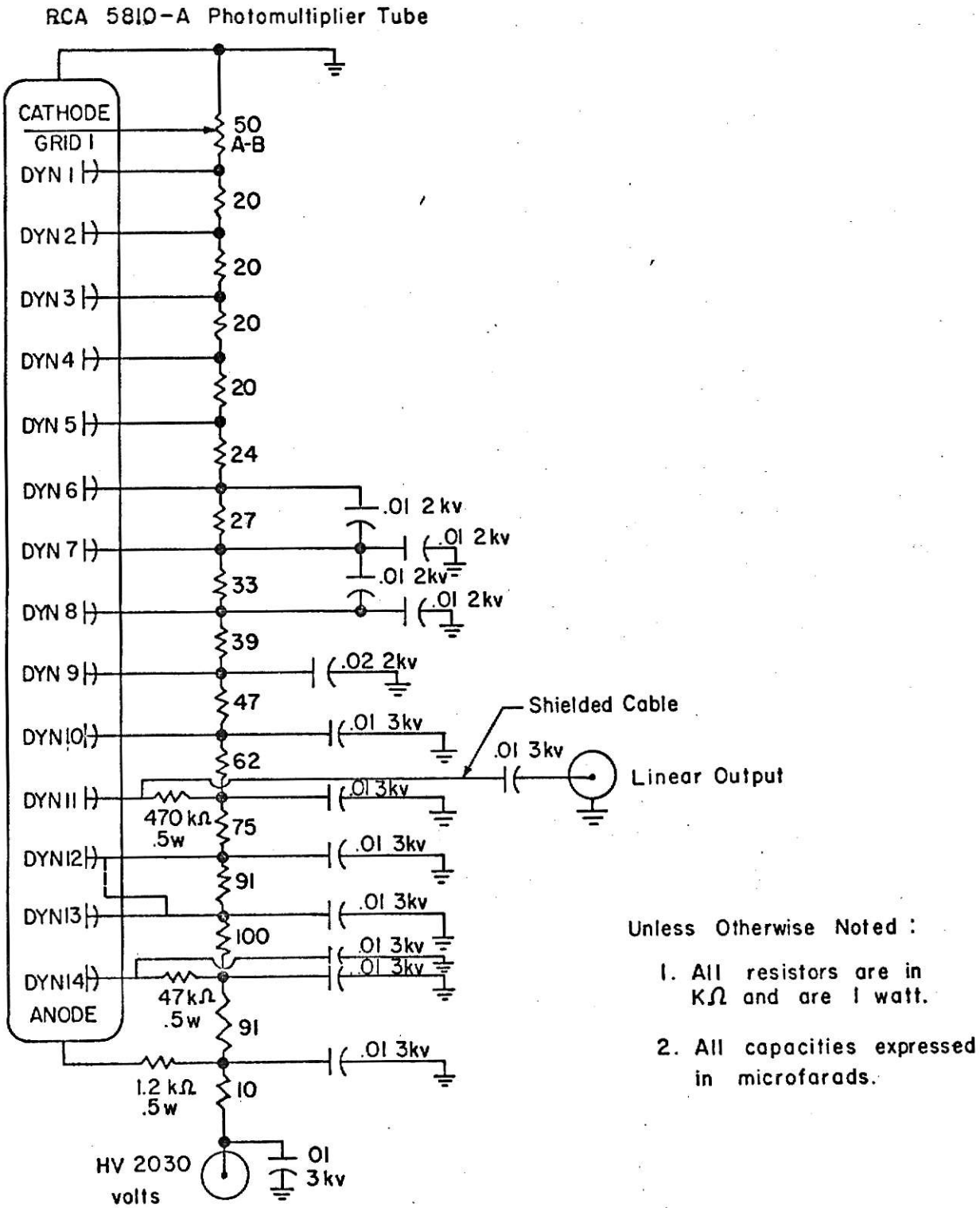


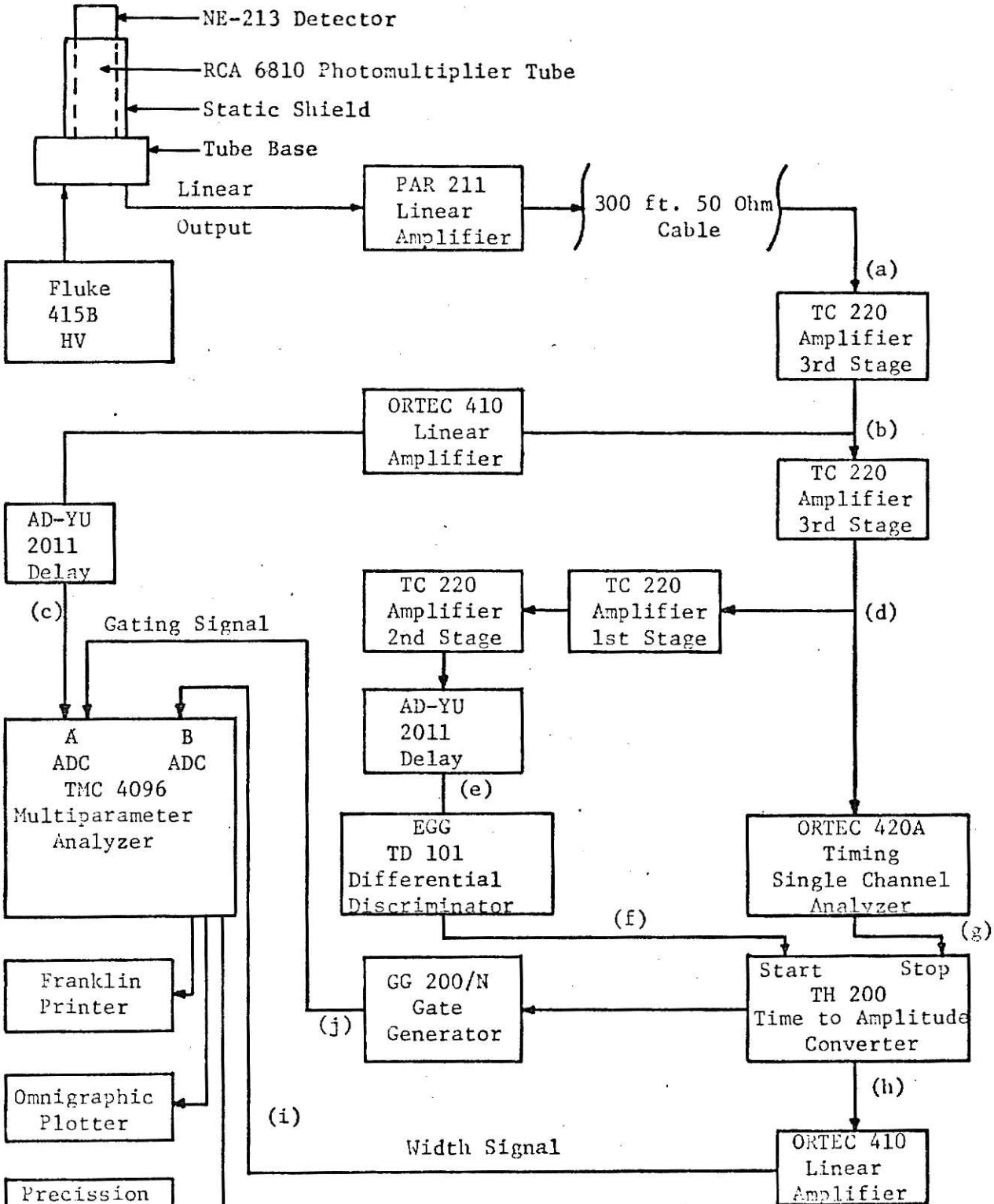
Figure 1. Schematic Diagram of NE-213 Photomultiplier Tube Base Assembly

biasing circuitry in the tube base, the linear signal is taken from the eleventh dynode and passed through a capacitor to remove its dc component before being transmitted to the rest of the circuitry.

2.4 Operating Principles of the TAC Spectrometer

A block diagram of the NE-211 fast-neutron TAC spectrometer system and sketches of the signals at various points in the system showing their relative shapes and timing are presented in figures 2 and 3 respectively. The electronic circuitry of the spectrometer system consists primarily of solid state AEC standard, NIM, modules selected for maximum stability, flexibility, minimum linear signal distortion, precise pulse shaping, and low level timing.

The linear signal from the eleventh dynode of the photomultiplier tube is passed through an eight foot cable to a Princeton Applied Research PAR-211 amplifier. This low noise, high gain amplifier was found suitable for transmitting the linear signal with minimal distortion from the Reactor Bay (location of the KSU TRIGA Mark II Reactor where all measurements were made) through 300 feet of 50 ohm cable to room 117 Ward Hall where the remainder of the TAC spectrometer system was located. After transmission from the Reactor Bay the signal passes through the third stage of a Tennelec TC-220 amplifier where it is integrated and differentiated to shorten and smooth the signal. After leaving the TC-220 amplifier, figure 2 position b, the signal is split. Part of the signal is led to an ORTEC model 410 amplifier where it is shaped to match the input requirements of a Technical Measurements Corporation, TMC, model 217 A analog to digital converter[3] (ADC) (Achieving proper input pulse hape for the TMC ADC units is crucial if pulse height distortion is to be avoided.). The linear signal is led from the ORTEC 410 amplifier to an AD-YU 2011 continuously variable delay to put the linear



AD-YU: Ad-Yu Electronics, Passaic, N. J.
Fluke: John Fluke Mfg., Seattle, Washington
TC: Tennelec, Oak Ridge, Tennessee
Omnigraphic: Houston Omnigraphic Corp., Bellaire, Tx.
TMC: Technical Measurements, Corp., North Haven, Ct.
EGG: EG & G Inc., Salem, Massachusetts
ORTEC: ORTEC Incorporated, Oak Ridge, Tennessee
PI: Precission Instruments Co., Palo Alto, Calif.

Figure 2. Block Diagram of NE-213 Fast-Neutron TAC Spectrometer

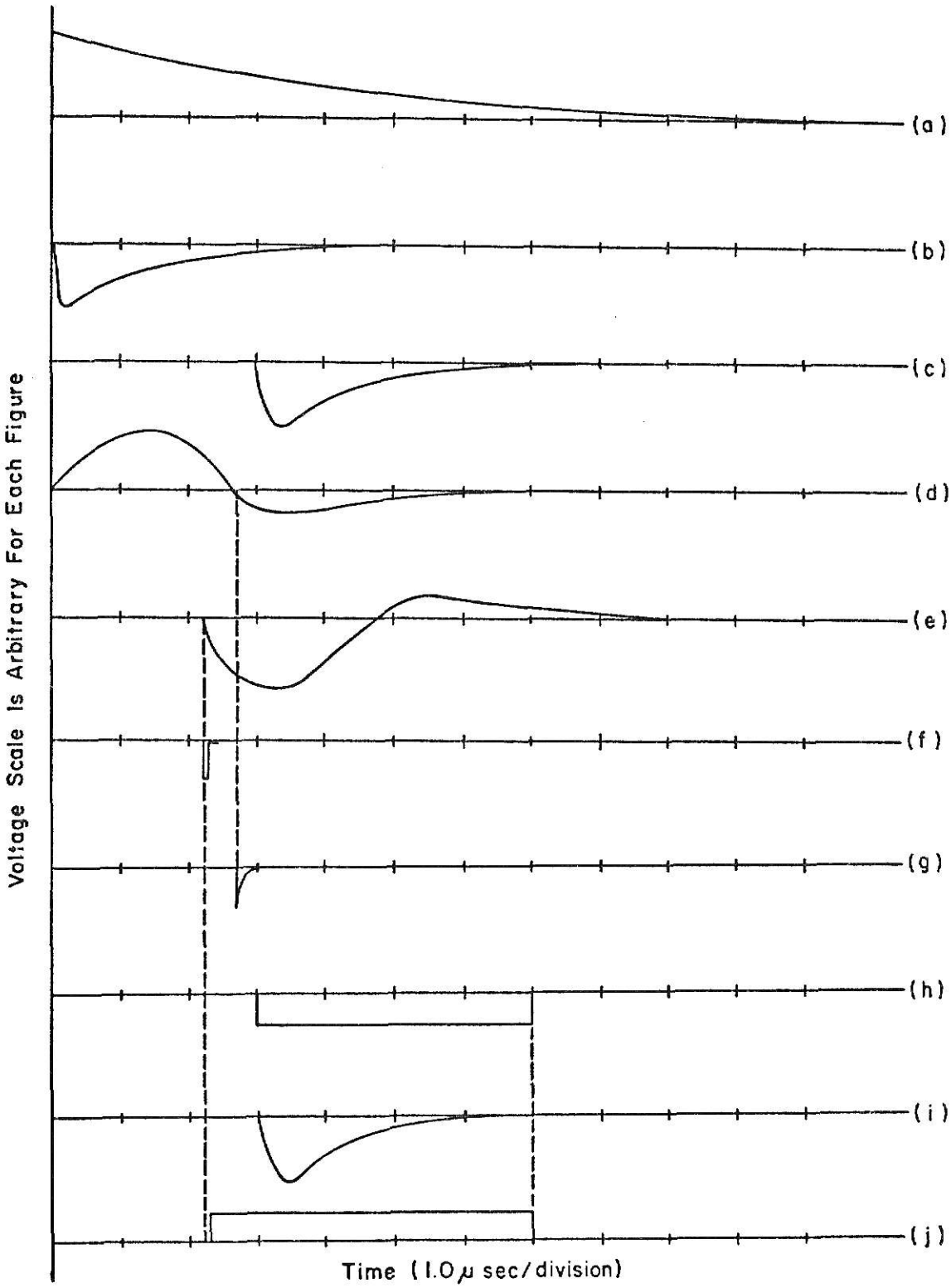


Figure 3. Relative Timing of Signals at the Labeled Locations in Figure 2.

signal in the proper time sequence with the output of the TAC unit, figure 3c and 3h, which will be described later, and then to the 217 A ADC unit at the A input of a TMC 4096 multiparameter analyzer.

The other branch of the linear signal, figure 2 position b, is passed to the third stage of a TC-220 amplifier. At this point, the signal is integrated and differentiated to produce a bipolar pulse as shown in figures 4 and 5. The cross over point of this bipolar pulse is a function of its pulse shape as described in section 2.1 and is different for a neutron pulse and a gamma-ray pulse of the same pulse height as illustrated in figure 5. In addition to this, it should be noted from figure 5 that the time to the zero cross-over point of the bipolar signal (This signal will be referred to as the "pulse shape signal") for a very low level pulse is shorter than for a high level pulse but does not go to zero. Choice of the best pulse shape signal form to be used was made by varying the parameters of the pulse shape signal and choosing that pulse shape which gave the best separation between neutron and gamma information (See section 4.1.) without raising the low energy cutoff of the system. It should be mentioned that in the course of this study it was found that proper choice of the parameters of the pulse shape signal was crucial to obtain maximum separation of neutron and gamma information.

The pulse shape signal is used to initiate the START and STOP commands for a time to amplitude converter (TAC). To initiate the START command, the pulse shape signal (figure 2 position d) is passed through the first and second stages of TC-220 amplifier where it is inverted and greatly amplified to eliminate any low energy cut-off problems in subsequent triggering circuitry. The pulse shape signal is then delayed a length of time about 0.2μ sec less than the time to cross-over of a pulse shape signal corresponding

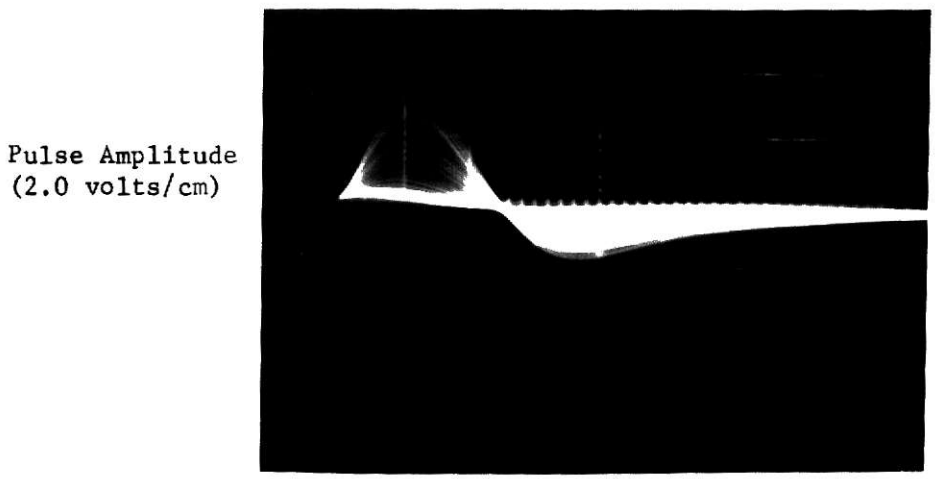


Figure 4. Photograph of PuBe Gamma-Ray and Neutron Induced "Pulse Shape Signals"

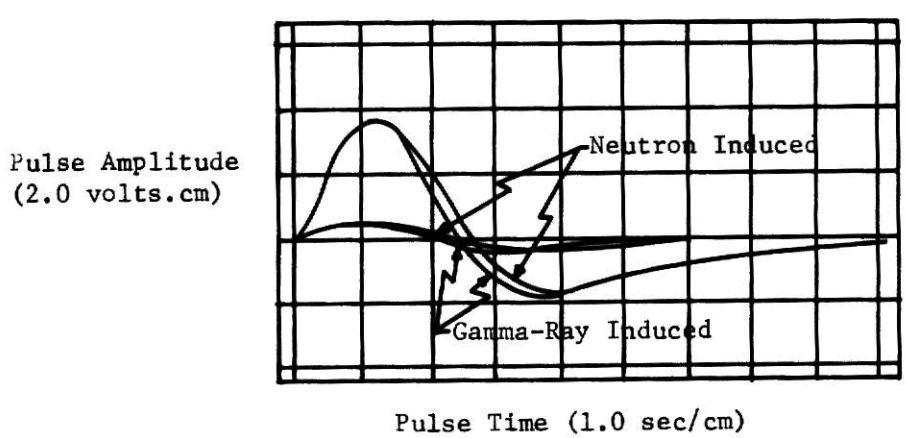


Figure 5. Skematic Diagram of PuBe Gamma-Ray and Neutron Induced "Pulse Shape Signals"

to the smallest linear signal to which the multiparameter analyzer will respond. The 0.2μ sec time cushion was used to ensure that the low energy end of the spectrum was being treated. The pulse shape signal from the AD-YU 2011 delay, figure 2 position e, is led to an EGG TD 101 differential discriminator operated in the integral mode. When the input signal rises above the threshold level of the discriminator, a fast timing output signal (figure 3F) is produced and led to the START input of an EGG TH 200 TAC module.

The STOP command for the TAC unit is generated by taking the pulse shape signal directly from the TC-220 third stage (figure 2 position d) and leading it to an ORTEC model 420 timing single channel analyzer operated in a cross-over pick-off mode. This unit provides a fast timing signal at the zero cross-over point of the pulse shape signal (figure 3g). The timing signal from the cross-over pick-off is led to the STOP input of the TAC unit.

The TAC unit provides a rectangular output signal of variable width (figure 3h) with a voltage proportional to the time between the START and STOP commands to the unit. The TAC output ("pulse width signal") is led to an ORTEC 410 amplifier where it is shaped to match the input signal requirements of a TMC 210 ADC unit (figure 3i). The pulse width signal is then led to a TMC 210 ADC unit at the B input of the multiparameter analyzer.

The VALID STOP output of the TAC unit is led to an EGG GG 200/N gate generator. The output of the gate generator (figure 3j) is led to the coincidence input of the TMC 217 ADC unit which accepts the linear detector signal. The gate signal effectively "slaves" the multiparameter analyzer to the TAC spectrometer by allowing the analyzer to accept only those detector signals which the TAC system treats.

A detailed block diagram of the TAC spectrometer system is presented in Appendix E.

2.5 Operational Mode of the TMC 4096 Multiparameter Analyzer

In this study, the TMC 4096 Multiparameter Analyzer is operated in a two parameter mode. In this mode, the memory of the analyzer is electronically arranged in a rectangular xy array with 4096 locations. Although several rectangular xy arrays can be obtained by appropriately wiring the patchboard of the format selector on the analyzer, a 64x64 array was used for this study because it provided the best combination of energy resolution and pulse shape separation.

When operating in this mode, the analyzer examines the input signals to the two ADC units simultaneously, determines the appropriate x and y address in the array, and adds one count to that array location. Each detector output signal which the TAC system analyzes is thus stored in the array at a location corresponding to the relative pulse height of the signal and the zero cross-over point of the corresponding pulse shape signal.

3.0 FAST NEUTRON PULSE HEIGHT MEASUREMENTS USING THE NE-213 TAC SPECTROMETER SYSTEM

3.1 Neutron Spectra Measured

The NE-213 TAC spectrometer was used to measure pulse height spectra of a packaged PuBe source, spectra of neutrons resulting from the $T(d,n)^4He$ reaction, and the spectra of KSU TRIGA Mark II reactor fast beam part neutron both before and after penetration through a thick sample of liquid oxygen. Included in this chapter are descriptions of the neutron sources, associated mechanical equipment, and procedure required for each experiment.

3.2 Calibration of the NE-213 TAC Spectrometer System

Prior to each measurement an energy calibration of the NE-213 TAC spectrometer was made using a "standard ^{60}Co pulse-height spectra." The multiparameter analyzer is operated in a single parameter 1024 chanel mode during the calibration to facilitate the process. Calibration was accomplished by setting the gain of the linear signal to locate the extrapolated tail of the standard ^{60}Co pulse height spectra in channel 200 of the 1024 channel range (figure 6). After calibration, the patchboard of the format selector on the multiparameter analyzer was rewired to alter the operation of the analyzer from the single parameter mode to the two parameter mode.

Since only 64 channels of pulse height information are available when the analyzer is operated in the two parameter mode to produce a 64x64 array of data, it was necessary to take both a high gain and a low gain set of data for each spectral measurement. The energy calibration is used to calibrate only the low gain data. Once the low gain energy calibration had been established, the high gain energy calibration was known since the high gain was always set 2.5 times greater than the low gain. This was done by

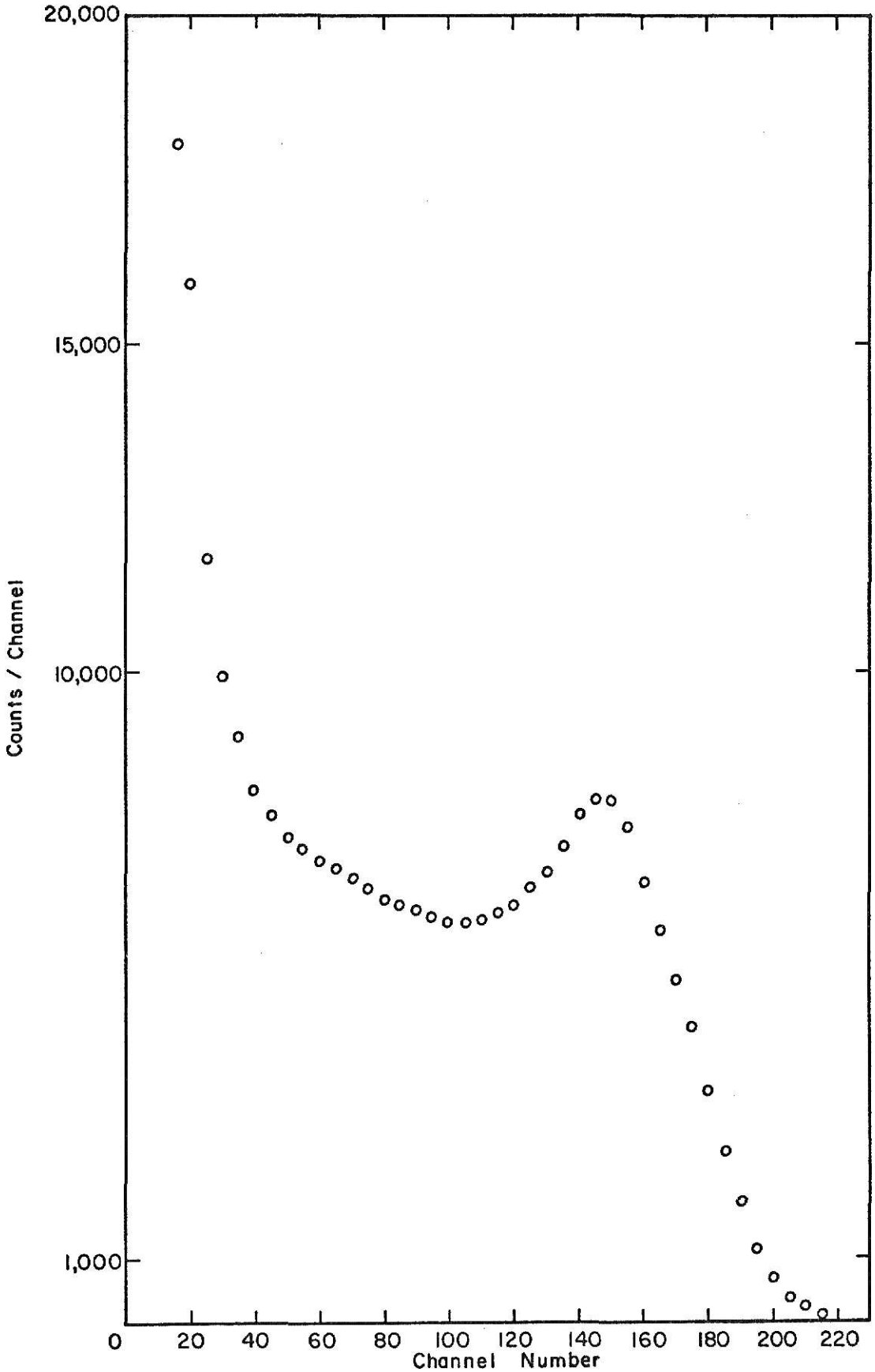


Figure 6. Standard ^{60}Co Pulse Height Spectrum

moving the input attenuator switch on the ORTEC 410 amplifier between two of its five positions, and it is used because it provides a quick, accurate, and easy means of determining the energy calibration of the high gain data.

Calibration of the TAC output signal at the "B" input of the multiparameter analyzer is not done because it is only necessary that the gain be such that all neutron and gamma information lie in the 64x64 array.

3.3 Packaged PuBe Source Pulse Height Measurement

A 60 minute measurement was made of the spectrum from a PuBe source encapsulated in a cylindrical stainless steel container more than 3/16 in. thick. The center of the PuBe source was positioned 16 in. from the center of the detector and on the same horizontal plane as the detector. A background spectrum was taken by placing a plexyglass shield 12 in. long by 2 in. square between the detector and the PuBe source. The use of the shadow shield was necessary to correct foreground spectra for neutrons which reach the detector after scattering off the floor and walls of the Reactor Bay.

3.4 $T(d,n)^4He$ Reaction Spectrum

A Texas Nuclear Cockroft-Walton accelerator was used to produce 14 MeV neutrons from the $T(d,n)^4He$ reaction. The detector was placed in line with the beam and about 26 inches away from the tritium target. Because of the high efficiency of the detector and the difficulty of operating the accelerator at extremely low beam currents a plexyglass collimator approximately twenty-four inches long and four inches square in cross section with a 0.1 $in.^2$ aperture was placed between the detector and the accelerator target. The collimator was constructed so the aperture could be filled with water and thus provide an effective shadow shield to use during background measurements.

It should be noted that in order to measure neutrons of this energy it was necessary to reduce the gain of the linear signal so that ^{60}Co calibration tail fell in channel 140 instead of channel 200. This increased the energy range of the spectrometer from about 0-11 MeV to about 0-16 MeV. Normalization of foreground, background, high gain, and low gain measurements was done by aluminum foil activation.[8]

3.5 Fast-neutron Pulse Height Measurement at the KSU TRIGA Mark II Reactor Fast Beam Port

The KSU TRIGA Mark II fast radial beam port is aligned with a cylindrical void in the graphite core reflector and allows a fast neutron beam from the reactor core to pass through it. Direct beam measurements were made with the NE-213 detector positioned about 140 inches from the reactor wall along the center line of the fast beam port with the reactor operating at a nominal power of 30 watts.

The NE-213 detector is sensitive to gamma rays. If neutron spectra are measured in a strong gamma field using the TAC spectrometer system, difficulty may be encountered in effectively separating the neutron peak from the gamma peak in the composite neutron-gamma-ray grid of data. In direct beam measurements a strong gamma field was present. The problem was minimized by making the direct beam measurement after the reactor had been shut down for four days to allow residual gamma activity in the core to decay to some extent and by placing a 2 inch long bismuth metal plug in the collimator of the beam port to attenuate the gamma intensity.

The transmitted spectra through a 36 inch thick liquid oxygen sample was measured in the same manner as that reported by Miller.[4]

Normalization of foreground, background, high gain, and low gain measurements was completed using nickle foil activation in the reactor core.[7]

4.0 ANALYSIS OF DATA

4.1 Gamma-Ray Discrimination in the Raw Data

Figures 7 and 8 illustrate the form of the raw data obtained using the TAC system. In figure 7 the apparent height above the grid plane of each grid location is proportional to the number of counts in that grid location. Thus, it can easily be seen that neutron information and gamma-ray information tend to lie in two "ridges" in the data grid. Also, since neutrons have a greater pulse width to pulse height ratio than gamma-ray pulses, the upper "ridge can be identified as the "neutron ridge."

Investigation of the distribution of information in the two "ridges" at various pulse height channels in the high gain data sets (figure 9) indicates that, above channel 10, the two "ridges" are nearly gaussian in cross section. Below channel 10 in the high gain pulse height spectrum the cross section of the two "ridges" becomes skewed, but are still somewhat gaussian in shape. In view of these facts a computer code, DISCRIM, was developed to effect an "optimal" separation of the neutron and gamma-ray information in the 64x64 channel data grid. The "optimal" separation is accomplished by fitting the neutron and gamma peaks at a given pulse height channel with a gaussian curve in a weighted least squares manner. The number of neutrons and gammas at that pulse height channel are then taken as the area under the gaussian fitted curve (See Appendix A and B-1).

4.2 Analysis of Neutron Pulse Height Spectra

The high and low gain neutron pulse height spectra calculated by the DISCRIM code were analyzed by a code, DATABIN, written during the course of this study (APPENDIX B-2). This code combines the low gain and high gain neutron pulse height spectra into a single set of data with one gain and

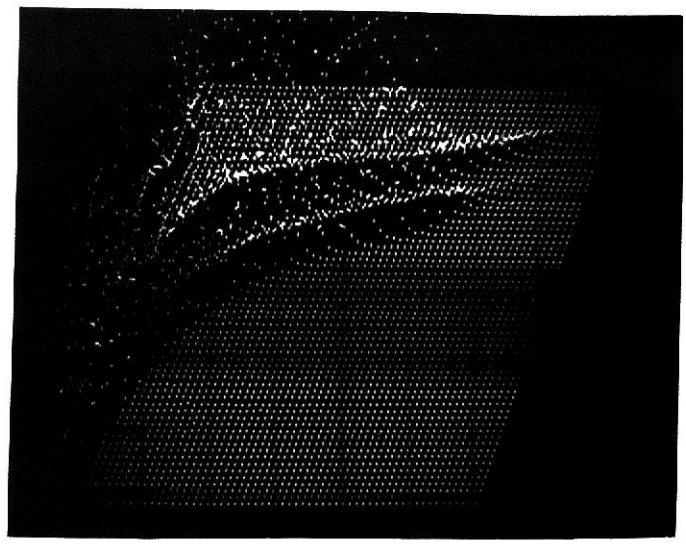


Figure 7. Photograph of Raw Data Grid from TAC Spectrometer System

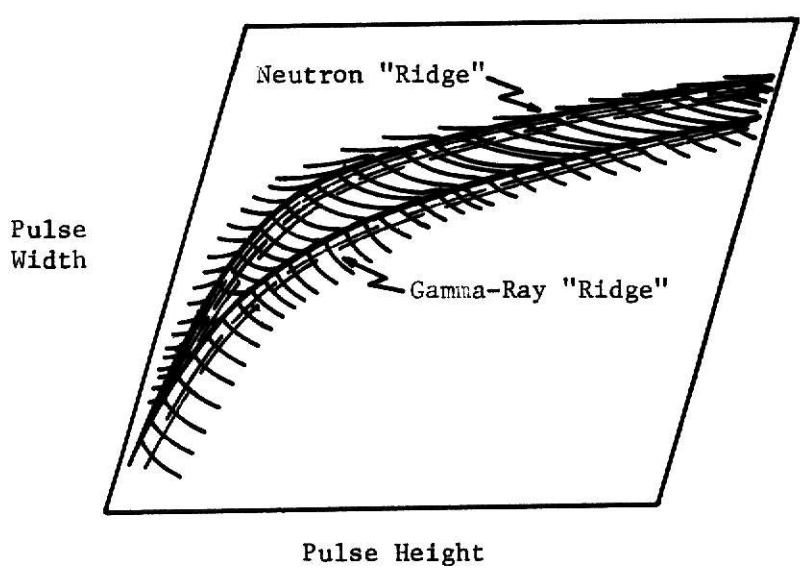


Figure 8. Diagram of Raw Data Grid from TAC Spectrometer System

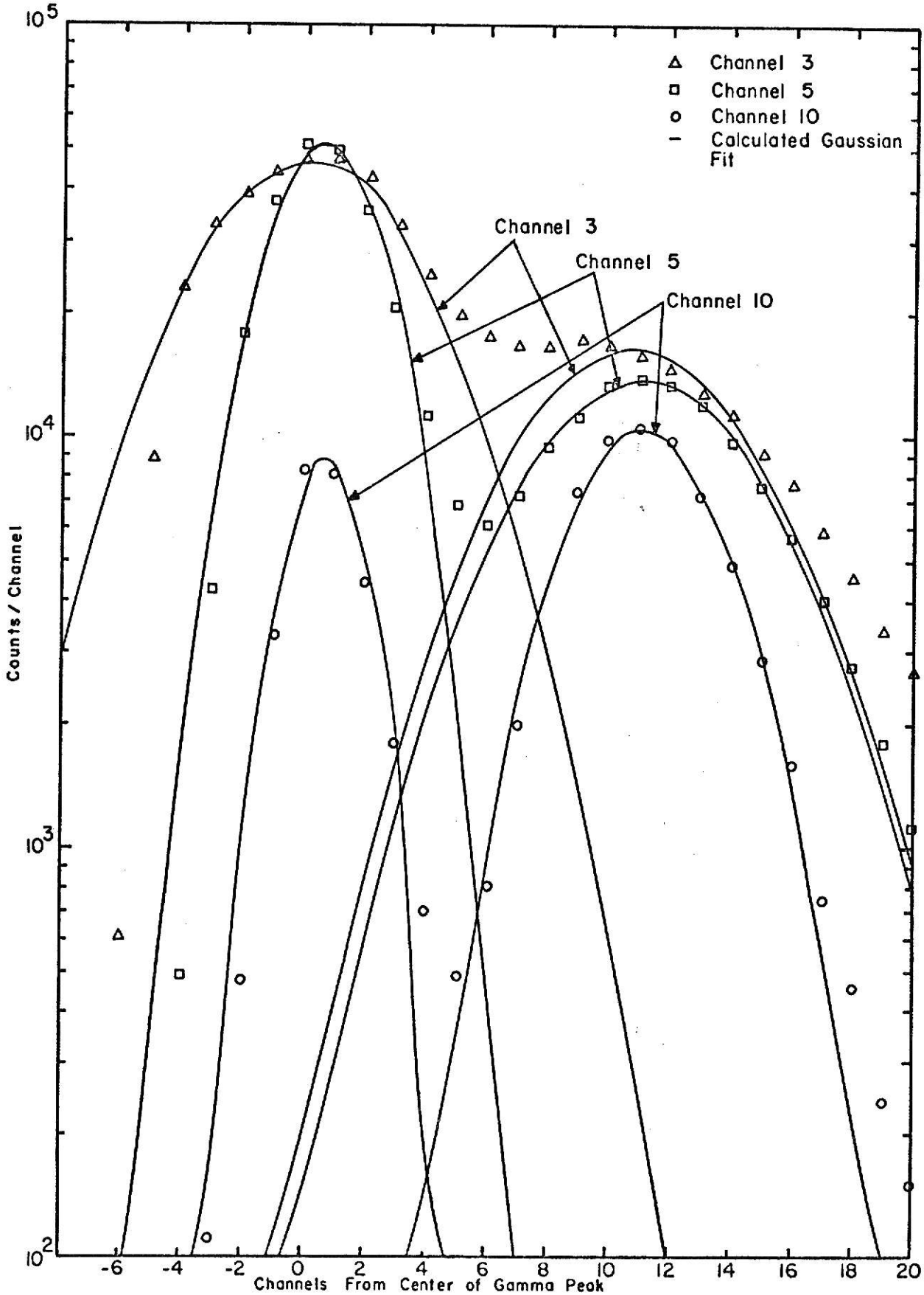


Figure 9. Distribution of Raw Data in Pulse Height-Pulse Width Data Grid at Various Pulse Height Channels

then arranges the data in a format of the form obtained using the KSU NE-213 neutron spectrometer system described by Meyer et al., and thus the data can be subsequently analyzed using existing computer codes.[3,5,13]

With the neutron pulse height spectra in the proper format, it is then shifted to a "standard gain" using the standard ^{60}Co pulse height spectrum calibration data and the computer code, NUDASBIN I.[13] The NUDASBIN I results are then unfolded using the unfolding codes FERDOR developed at ORNL by Burrus[5] and DUFOLD developed at KSU by Coolbaugh.[10]

5.0 RESULTS AND CONCLUSIONS

5.1 14 MeV $T(d,n)^4He$ Neutron Energy Spectrum

The FERDOR unfolded neutron energy spectra of the $T(d,n)^4He$ reaction is presented in figure 10. The values of the flux in the peak region were fitted to a gaussian curve, and from this curve it was determined that the peak had a true center at 13.87 MeV and a full width at half-max, FWHM, of 1.384 $\pm$ .016 MeV. The calculated center of the peak, 13.87 MeV, is 0.23 Mev below the true 14.1 MeV energy of the product neutrons from the reaction. Although it is possible that this discrepancy is due to an error in the energy calibration of the system, this author feels that the shift is more likely caused by the FERDOR unfolding code. This is examined further in section 5.4.

The FWHM of the peak, a measure of the resolution of the spectrometer system, is nearly 25 per cent less than that reported by Verbinski using an NE-213 spectrometer system at ORNL. Thus, the KSU TAC spectrometer has better resolution at this energy than the ORNL NE-213 spectrometer.

Also evident in figure 10 is a 2.45 MeV peak due to the $D(d,n)^3He$ reaction which occurs when deuterons become embedded in the tritium target of the accelerator. The FWHM of the peak is approximately 0.7 MeV. This is also nearly 25 per cent better than the resolution reported by Verbinski at this energy and is in good agreement with other measurements made using the TAC system (Section 5.3).

5.2 TRIGA Mark II Fast Beam Port Neutron Spectra

Figure 11 shows the neutron energy spectrum of the fast beam port measured with both the TAC system and the 2 inch KSU NE-213 spectrometer.[3] The measurements made with the two spectrometer systems are in good

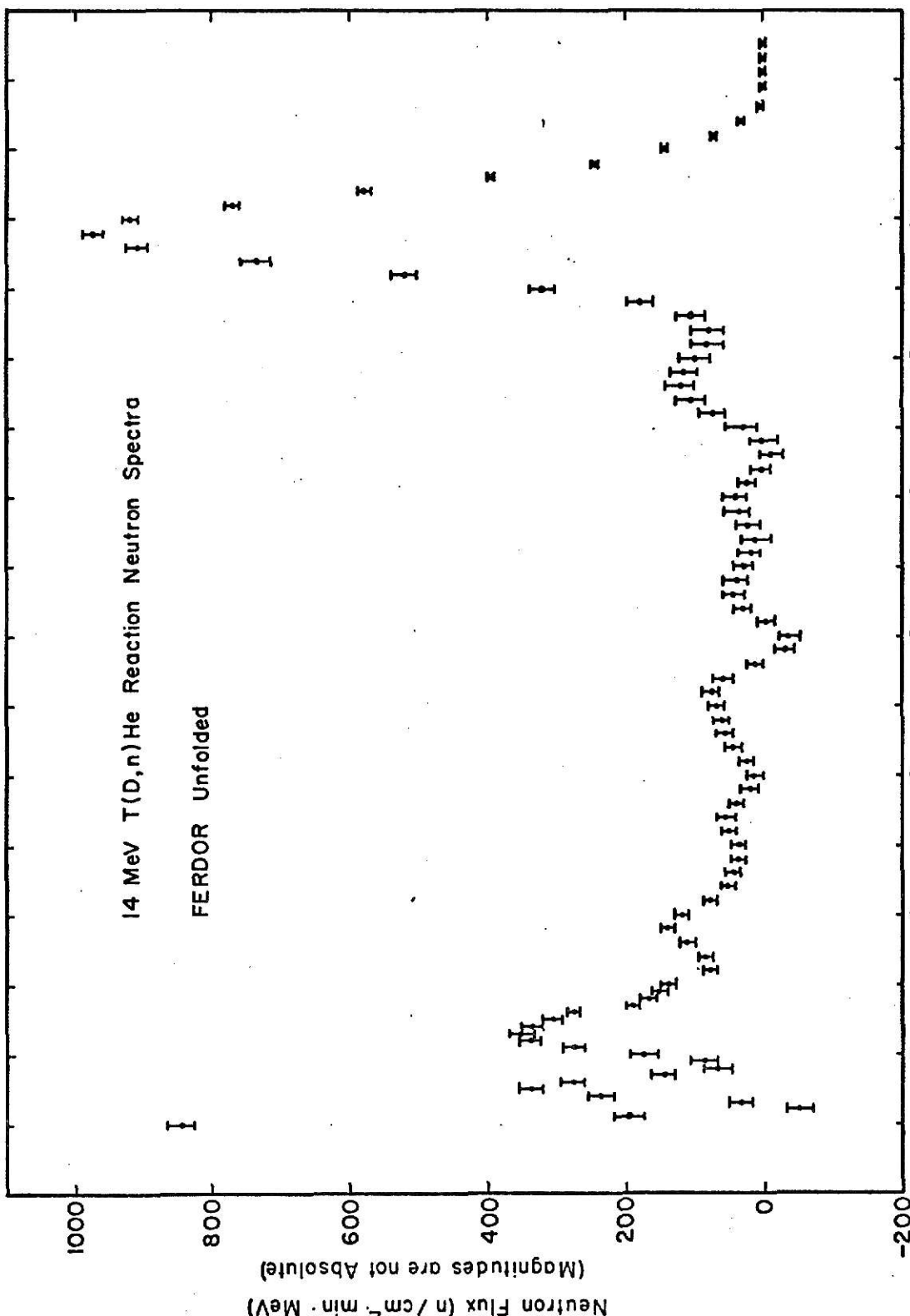


Figure 10. FERDOR Unfolded $T(d,n)^4He$ Reaction Neutron Spectra

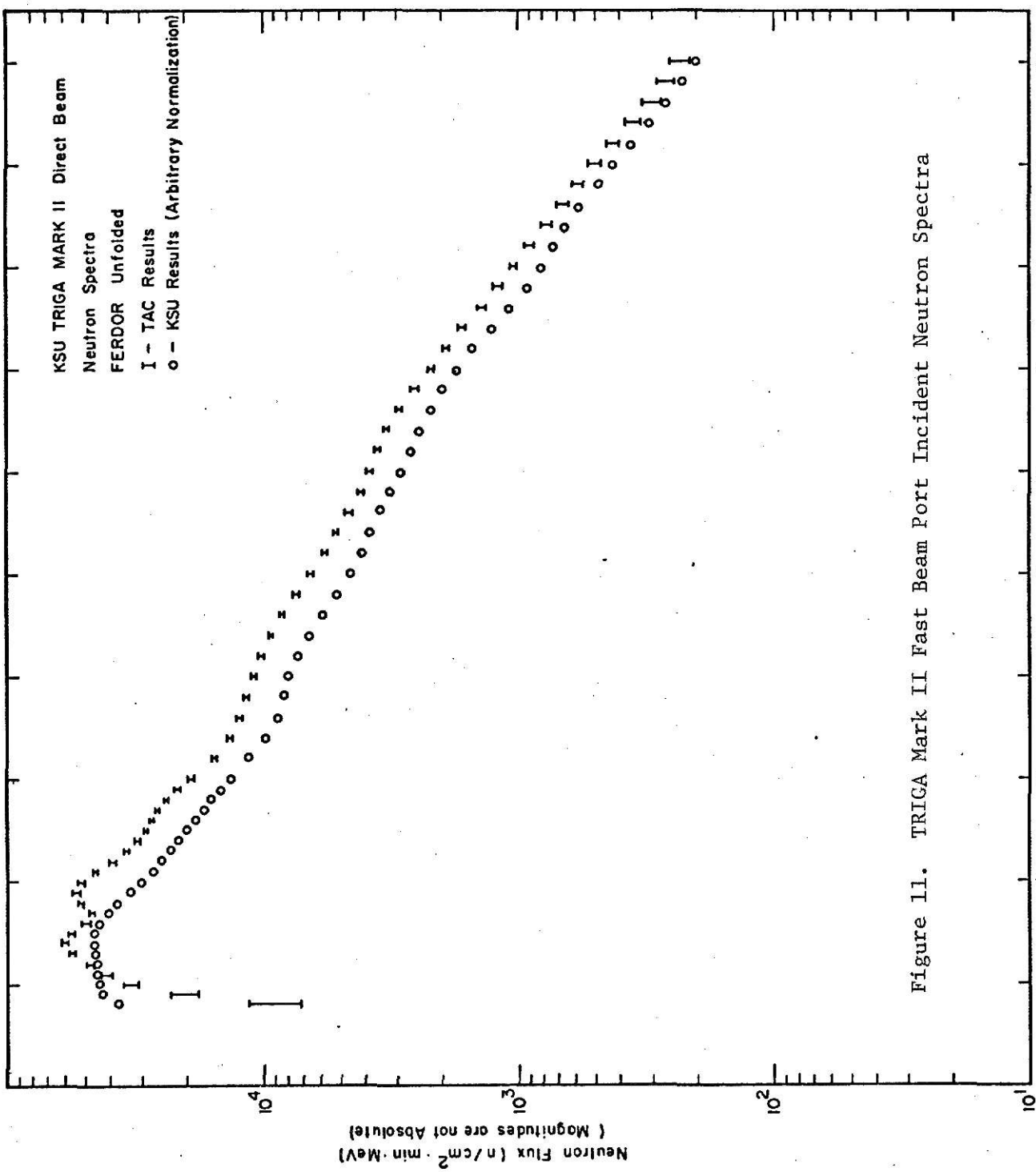


Figure 11. TRIGA Mark II Fast Beam Port Incident Neutron Spectra

agreement above about 1.7 MeV. Below 1.7 MeV the TAC measurement indicates a slight dip in the neutron flux which the measurement with the 2 inch KSU NE-213 spectrometer does not indicate. The dip in the flux indicated by the TAC measurement is probably in error because there is no physical reason to suspect such a depression at that energy. This phenomenon probably indicates that below about 1.7 Mev difficulty is encountered in separating neutrons from gammas in the raw data when a very strong gamma field is present while making the measurement as was the case in this instance.

5.3 TRIGA Mark II Fast Beam Port Neutron Spectra after Transmission Through a Thick Oxygen Absorber

The neutron energy spectra after transmission through a thick oxygen absorber is shown in figure 12. The spectrum measured with the TAC spectrometer system is in good agreement with measurements made by Miller[4] using the 2 inch KSU NE-213 spectrometer system. A gaussian fit of the peak indicates that the peak is centered at 2.34 $\pm$ 0.16 MeV with a FWHM of 0.599 $\pm$ 0.20 MeV. The center of the peak agrees well with the 2.35 MeV minimum in the oxygen cross section which causes the peak in the transmitted neutron spectrum.[15] The FWHM of this peak is also about 25% less than that reported by Verbinski[6] at ORNL for the same energy.

5.4 PuBe Neutron Energy Spectrum

Figure 13 shows the FERDOR unfolded PuBe neutron spectrum measured with the TAC system compared with that measured with the KSU spectrometer. Both spectra show minima at 1.7, 3.6, and 5.8 MeV, maxima at 1.3, 2.9, 4.2-4.4, and 6.4-7.0 MeV, and a shoulder at 9.4-9.6 MeV. The TAC results show a shoulder at 1.9-2.0 MeV, and the KSU results show a small peak at 1.8 MeV.

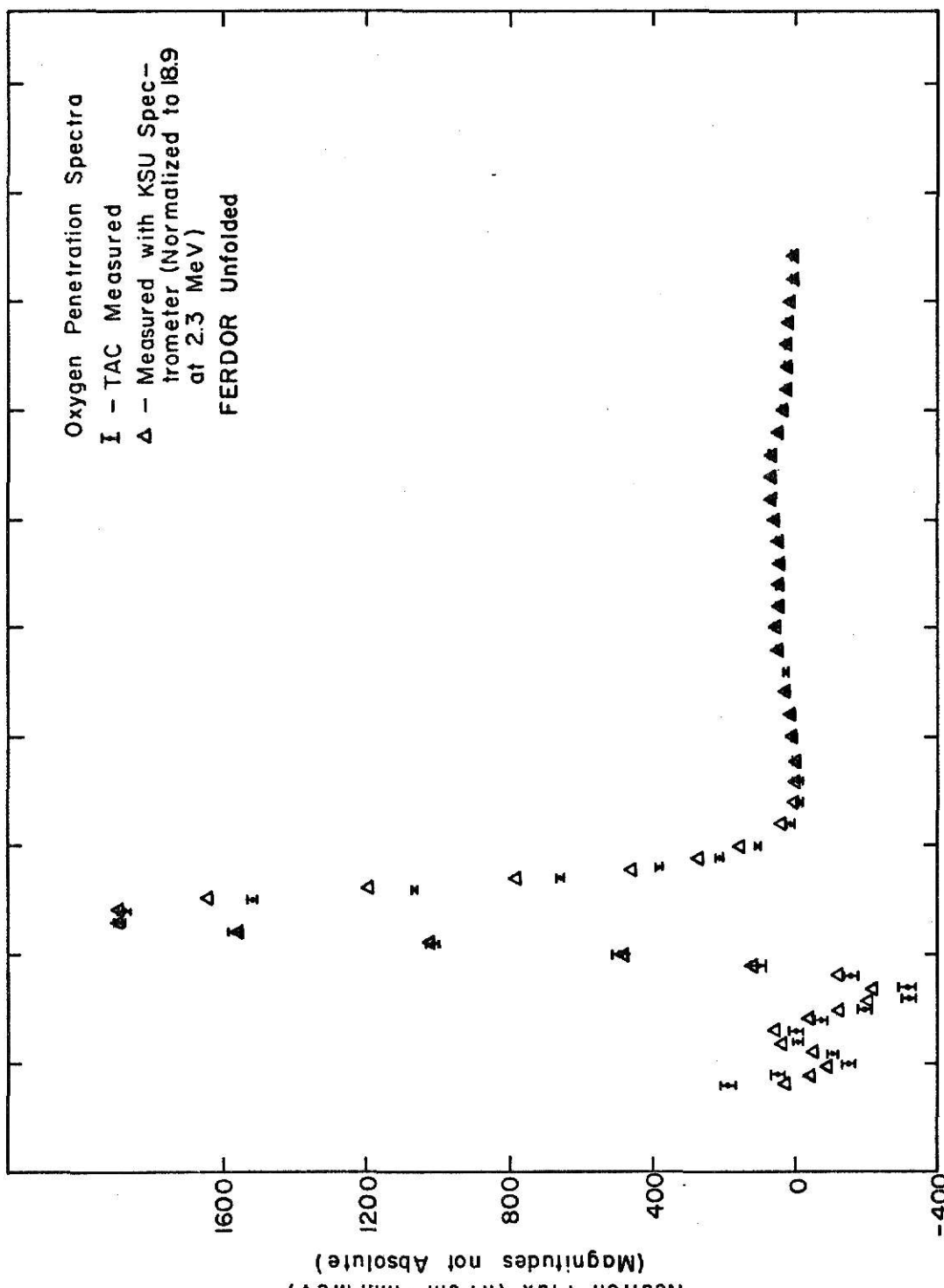


Figure 12. Oxygen Penetration Spectrum

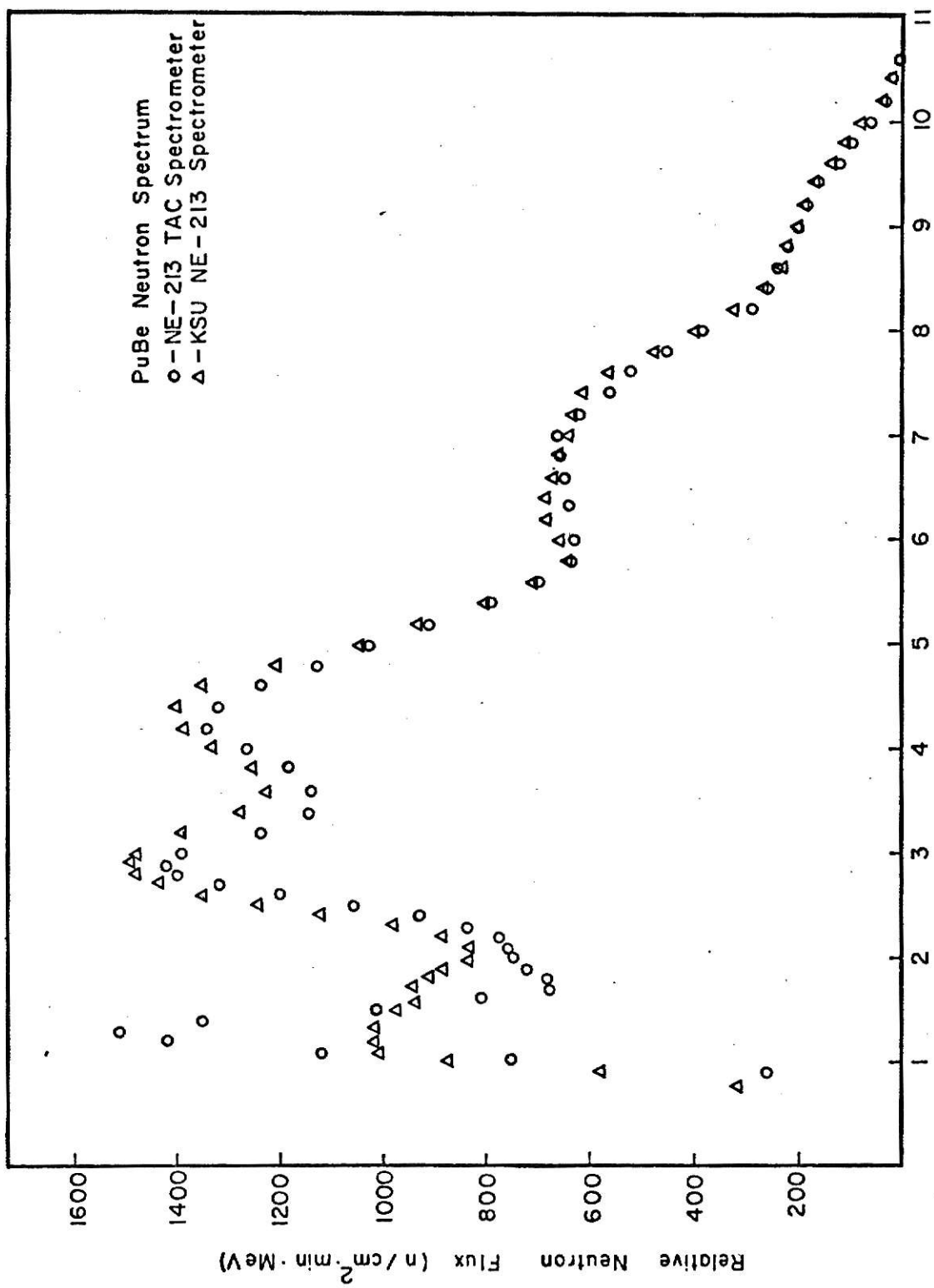


Figure 13. FERDOR Unfolded PuBe Neutron Spectrum

The TAC results are, in general, lower in magnitude than the KSU results. This is due to the fact that the TAC system has less overall efficiency than the KSU spectrometer (the TAC spectrometer is "dead" during the internal conversion time of the time to amplitude converter). Unfolding of the neutron pulse height spectra was completed using the known efficiency of the KSU spectrometer system because an absolute efficiency measurement of the TAC system has not been made. The unfolded TAC results thus lie below the unfolded KSU results because the TAC system is slightly less efficient than the 2 inch KSU spectrometer system.

Figure 14 shows the Ferdor unfolded PuBe spectrum compared with a normalized plot of the nuclear emulsion PuBe data of Lehman.[9] The nuclear emulsion data are useful in describing the important features of the PuBe spectrum i.e., the minima at 1.6, 2.6, 3.8, 6.4, 7.1, and 9.0 MeV and maxima at 2.1, 3.5, 4.5, 6.6, 7.8, and 9.9 MeV.

In comparing the nuclear emulsion data and the FERDOR unfolded TAC results, it appears that a shift of about 0.2-0.3 MeV has occured in the entire spectrum measured with the TAC system. It is difficult to say if this shift is a result of differences in the sources used or differences in measurement and unfolding techniques. This shift is in agreement however with the shift noticed in the measurement of the 14 MeV T(d,n)^{4}He neutrons (section 5.1). This agreement tends to indicate that the shift may be caused by some anomaly in the unfolding technique used. Aside from the shift in the spectrum, the FERDOR unfolded TAC results agree well with the emulsion data although the TAC results exhibit poorer resolution as indicated by the shoulders at 2.0 and 9.4 MeV and the single broad peak from 6.0-7.5 MeV. In addition, the peak at 1.2 MeV in the TAC results is much larger than the rise in the spectrum shown in the emulsion data around 1.0 MeV.

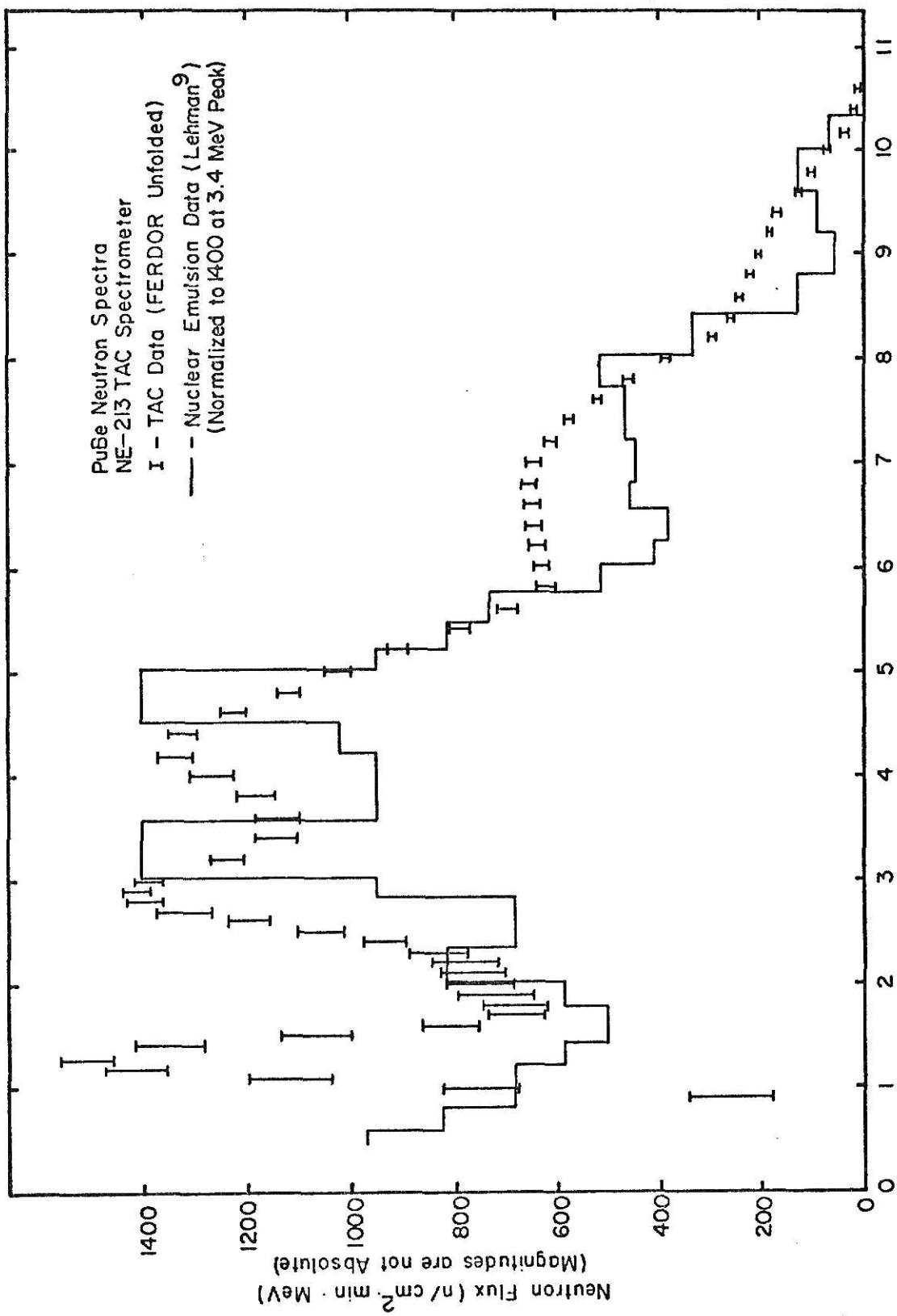


Figure 14. PuBe Neutron Spectrum

Though the results shown in figure 14 indicate that the TAC system has insufficient resolution to resolve the separate peaks in the emulsion data at 2.1, 6.6, 7.8, and 9.9 MeV, the results shown in figure 15 which were obtained by unfolding the same set of TAC data with the DUFOLD unfolding code[10] show peaks at 2.0, 6.5, 7.5, and 9.9 MeV. The DUFOLD unfolded results indicate that the upper limit of the resolution of the PuBe spectrum shown in figure 14 is probably set by the FERDOR unfolding procedure and not by the raw data obtained with the TAC spectrometer.

5.5 Conclusions

In general, the results obtained by using the TAC spectrometer developed in this study agreed well at energies above 1.5 MeV with similar measurements using the KSU 2 inch spectrometer.[3,4] Below 1.5 MeV considerable discrepancy was noted in the unfolded reactor fast beam port spectrum and the PuBe spectrum measured with the two systems. The unfolded PuBe spectra measured with the TAC spectrometer was also in disagreement with the nuclear emulsion data below about 1.5 MeV. The consistent disagreement of the TAC results with other measurements at energies below 1.5 MeV suggests that the TAC results are in error in this energy region. The error in this region is probably caused by the skewed gaussian distribution of the neutron and gamma-ray information in the raw data at low pulse heights as discussed in section 4.1. Attempting to fit a gaussian curve to a skewed distribution will obviously result in a large error, and that error in the low pulse height channels is probably the cause of the anomalous TAC results at energies below 1.5 MeV.

The oxygen penetration data and the $T(d,n)^4He$ data indicate that the resolution of the TAC spectrometer system is an improvement over the resolution reported by Verbinski[6] for an NE-213 spectrometer at ORNL. In both

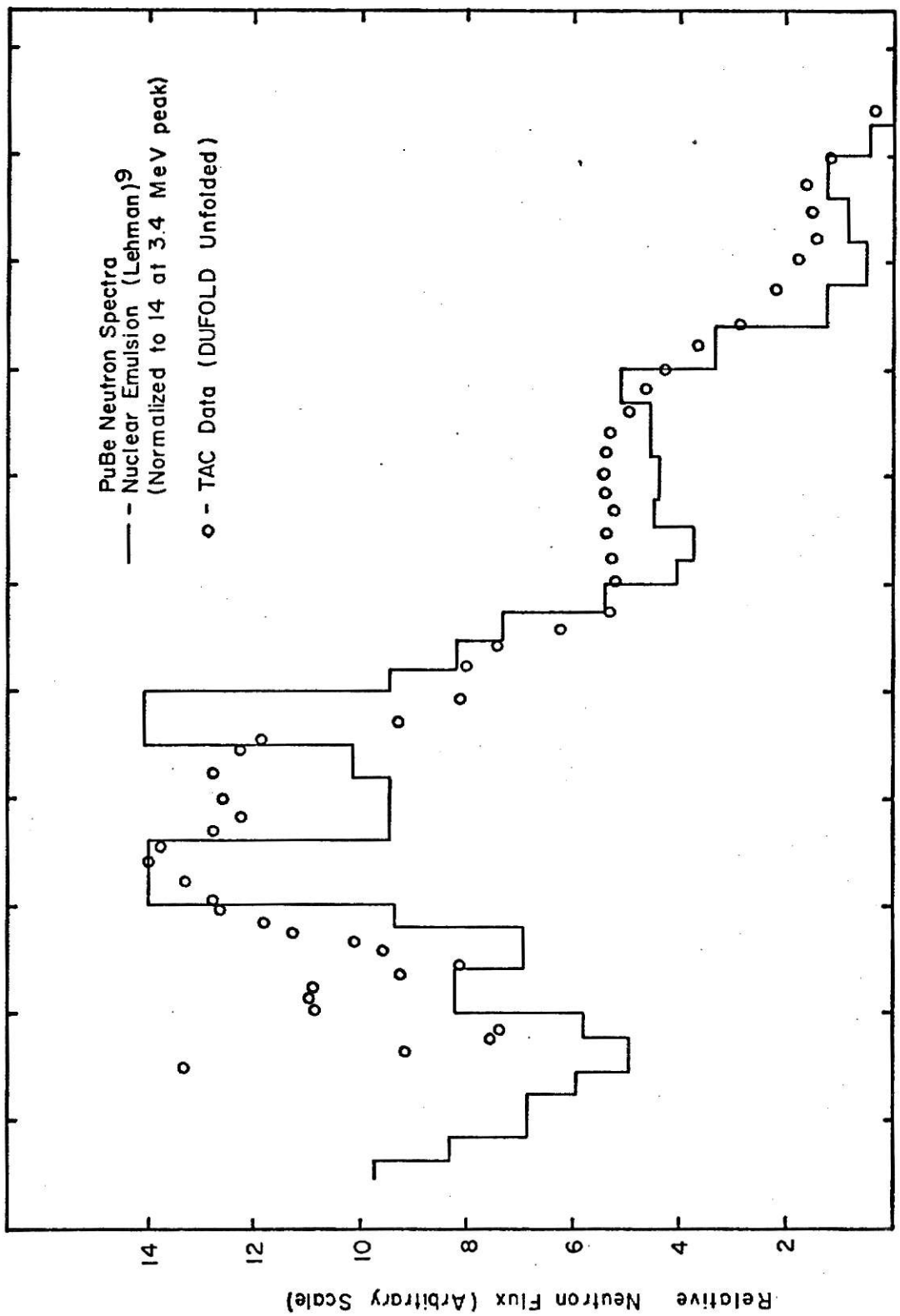


Figure 15. PuBe Neutron Spectrum

cases, the FWHM of the respective 2.34 and 13.87 MeV peaks was nearly 25% less than that reported by Verbinski at similar energies. These results indicate that the TAC spectrometer system is capable of providing results which are as good as those obtained using other NE-213 spectrometers even though the TAC spectrometer yields a total of just 128 channels of pulse height data.

This study has also demonstrated that optimal gamma-ray discrimination can be achieved by off-line computer analysis of the TAC data. This is certainly an advantage of this TAC system since the quality of the data obtained from a given measurement is not dependent upon some critical adjustment to determine the proper gamma-ray discrimination.

The TAC spectrometer system does have two disadvantages in comparison to other NE-213 spectrometers. First, since the data from the TAC system are collected in two large arrays, it is necessary to accumulate data for longer periods of time in order to obtain statistically meaningful data throughout the arrays. This necessitates tying up expensive auxiliary equipment such as a multiparameter analyzer, a reactor, or an accelerator for longer periods of time to make a specific measurement than is necessary with other NE-213 spectrometers. Secondly, an additional cost is incurred when doing the gamma-ray discrimination off-line by computer (The DISCRIM code costs about $1.25 - $1.50 per data set to run on an IBM 360/50 computer). This cost is not large however when compared with the cost of completing the remainder of the data analysis and unfolding procedure ($65.00 - $70.00 using the FERDOR unfolding routine).

In summary, the initial results presented in this study indicate that a TAC spectrometer system of the type described will produce results comparable to the results obtained by using other NE-213 spectrometer systems with little additional cost or effort.

6.0 SUGGESTIONS FOR FURTHER STUDY

Several aspects of the TAC spectrometer system developed in this study warrant further investigation. As noted in section 5.5, the erroneous TAC results below 1.5 MeV are probably caused by the attempt to fit a gaussian curve to the skewed distribution of neutron and gamma-ray information in the low pulse height channels during the off-line gamma-ray discrimination process in the DISCRIM code. This error can be corrected two ways. One way would be to investigate the present distribution of the neutron and gamma-ray information in the data grids and attempt to devise a procedure for fitting some type of skewed gaussian curve to the data where necessary. A second and probably more promising way to correct the error would be to search for a way of producing a "pulse shape signal" which has more nearly ideal characteristics. A more nearly ideal pulse shape signal would yield neutron and gamma-ray distributions in the data grids which are more nearly gaussian. The gaussian fitting procedure of the DISCRIM code would then better match the actual data and give correspondingly better results in the low energy region of the neutron spectra. Roush, Wilson, and Hornyak[11] have indicated that the use of delay-line pulse shaping to produce the bipolar "pulse shape signal" should provide better performance, particularly in the low energy region, than can be obtained by using the active amplifier in the present system.

Secondly, the efficiency of the TAC spectrometer system must be determined if the TAC spectrometer is to be used to make absolute flux measurements.

An investigation needs to be made of the optimum ratio of high gain to low gain for the two data sets that are taken for each spectrum measured.

The ratio of 2.5 used in this study is arbitrary and was chosen primarily for reasons of convenience. The high gain setting of the spectrometer system should be such that the resolution of the spectrometer in the low energy region, where the high gain data is applicable, is determined by the detector and photomultiplier tube rather than by the binning of the data in the multiparameter analyzer.

Fourth, additional monoenergetic responses need to be measured at energies other than those measured in this study. This information would provide enlarged knowledge of the variation in resolution with energy. It would also provide a much more meaningful comparison of the resolution of the TAC spectrometer developed in this study with the resolution of other spectrometers.

Fifth, a study should be made to determine if it is possible to propogate errors through the gamma-ray discrimination process in the DISCRIM code. This would provide a new and useful means of assessing the degree of confidence that can be placed in a particular set of data based on the degree of optimization that can be achieved in the gamma-ray discrimination procedure.

Finally, if at some future time additional equipment becomes available that is capable of producing a data grid larger than 64x64, many of the problems presently encountered with the TAC system can be eliminated. If the grid size could be increased by a factor of 2.5 to 64 X 160, a single set of data would contain all the information presently available in the two sets of data (high gain and low gain) taken for each measurement. A grid size larger than 64 X 160 would allow even greater energy resolution, particularly in the low energy region where the present TAC system gives anomalous results, or better neutron and gamma-ray separation in the data

grid, or both. Increasing the size of the data grid must be done with caution however because increasing the size of the data grid increases the length of time necessary to get statistically good results. This author feels that with the TAC system in its present configuration the "best" practical grid size would be 64 x 256. If improvement can be made in the neutron-gamma-ray distribution at low energies by the use of delay-line clipping to produce the pulse shape signal, then increasing the number of divisions in the pulse width parameter of the data grid may result in better neutron and gamma-ray separation. At present however, the problem of separating neutron and gamma-ray information in the low pulse height channels appears to be due primarily to the non-gaussion distribution of the data in those channels and not by the separation of the data in the data grid. Thus, unless the distribution of the data in the low pulse height channels can be made more gaussian very little improvement can probably be made in the gamma-ray discrimination process at low pulse height channels.

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9.0 APPENDICES

APPENDIX A

Derivation of Weighted Least Squares Gaussian Curve Fitting Equations

The equations used in the DISCRIM code to effect the weighted least squares gaussian curve fitting to the neutron and gamma-ray "ridges" in the raw data from the TAC spectrometer are derived below.

The general equation for a gaussian curve can be written as

$$y = y_0 \cdot EXP(-(x - x_0)^2/b_0) \tag{1}$$

where y = value of gaussian at point x

y_0 = magnitude of gaussian at center

x_0 = center of gaussian

b_0 = decay constant.

Equation 1 can be discretized for any finite set of points by evaluating it at the desired set of points; i.e.,

$$y_i = y_0 \cdot EXP(-(x_i - x_0)^2/b_0) \quad . \tag{2}$$

This equation can be linearized by taking the natural logarithm of both sides. This yields,

$$\ln(y_i) = \ln(y_0) - (x_i - x_0)^2/b_0 \tag{3}$$

After expanding the squared term and collecting like powers of x, equation 3 can be written as

$$Z_i = x_i^2 S_1 + x_i S_2 + S_3 \tag{4}$$

where $Z_i = \ln(y_i)$

$S_1 = -1/b_0$

$S_2 = 2x_0/b_0$

$S_3 = \ln(y_0) - x_0^2/b_0$

Equation 4 can be written in matrix form for n points as

$$\begin{bmatrix} x_1^2 & x_1 & 1 \\ x_2^2 & x_2 & 1 \\ \vdots & \vdots & \vdots \\ x_n^2 & x_n & 1 \end{bmatrix} \cdot \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_n \end{bmatrix} \tag{5}$$

This equation is of the form

$$X \cdot S = Z \tag{7}$$

If n is greater than 3, the weighted least squares solution of equation 7 for S is found by solving

$$X^T W X S = X^T W Z$$

The solution is

$$S = (X^T W X)^{-1} X^T W Z \tag{9}$$

W is a variance-covariance weighting matrix which weights each of the equations by the inverse variance and covariance of Z.[14] In this work each of the Z_i is independent of the other Z_i. Thus, the covariance in the weighting matrix are zero.

The variance of Z_i is

$$^2Z_i = (\partial Z_i / \partial y_i)^2 \sigma^2 y_i = (1/y_i)^2 \sigma^2 y_i \tag{10}$$

The weighting matrix can thus be written as

$$W = \begin{bmatrix} \frac{y_i^2}{\sigma^2 y_1} & 0 & 0 & \cdots & 0 \\ 0 & \frac{y_2^2}{\sigma^2 y_2} & 0 & \cdots & 0 \\ \vdots & & \ddots & & \\ 0 & \cdots & & & \frac{y_n^2}{\sigma^2 y_n} \end{bmatrix} \tag{11}$$

After S has been solved for, the parameters of the gaussian fit are easily found from the relations

$$b_0 = -1/S_1 \tag{12}$$

$$x_0 = b_0 S_2/2 \tag{13}$$

$$y_0 = \mathrm{EXP}(S_3 + x_0^2/b_0) \tag{14}$$

The full width at half-max (FWHM) of the gaussian is determined from

$$y_0/2 = y_0 \cdot \mathrm{EXP}(-(\mathrm{FWHM}/2)^2/b_0) \quad . \tag{15}$$

Solving for FWHM yields

$$\mathrm{FWHM} = 2(b_0 \cdot \ln(2))^{\frac{1}{2}} \quad . \tag{16}$$

The area under the gaussian in the data grid is

$$\mathrm{AREA} = \int_0^{64} y_0 \cdot \mathrm{EXP}(-(x_0 - x_0)^2/b_0)\, dx \quad . \tag{17}$$

or

$$\mathrm{AREA} \simeq y_0 \int_{\infty}^{\infty} \mathrm{EXP}(-(x - x)^2/b)\, dx \quad . \tag{18}$$

The exact closed form solution to 18 is

$$\text{AREA} = y_0\sqrt{b_0\pi} \quad . \tag{19}$$

APPENDIX B

B-1.0 Gamma-Ray Discrimination Code, DISCRIM

This computer code separates the neutron and gamma-ray information in the data grids from the TAC spectrometer, prints both the neutron and gamma-ray pulse height spectra, plots a semilog plot of the neutron pulse height spectra, and, if desired, punches the neutron pulse height spectra for further analysis. In addition, background data can be subtracted from the foreground, if desired. This must be done with extreme caution however, because the subtraction is done point by point in the data grid. Thus, the pulse height and pulse width gain must be identical in both the foreground and background data grids if the background option is used. A provision is also made in the code to correct for overflows in the foreground data. No provision is made to correct for overflows in the background data.

The code divides the data grid into four pulse height regions. In the first region, the first two or three pulse height channels, there is little or no data because of the characteristics of the multiparameter analyzer. The code ignores this region and sets the number of neutron and gamma-ray counts in this region equal to zero.

In the next three regions, the program proceeds through the data one pulse height channel at a time. At each pulse height channel it looks at the corresponding 64 pulse width channels and separated the neutron induced and gamma-ray induced information.

In the second region the program fits a gaussian to the largest peak, subtracts the least squares fit from the data, then fits the peak that is left with a gaussian. The gaussian fit to the smaller peak is then subtracted from the original data to give a new estimate of the larger peak. This process

repeats itself until the change in the calculated area of the largest peak converges to a value smaller that a limit that is read in as input (The convergence limit was set at one per cent in this work.) or until a specified number of iterations is exceeded.

In the third region the two peaks in the data are only fit once with a gaussian curve. In this region the peaks are separated well enough that only a single iteration is necessary.

In the fourth and last region the data do not have sufficient statistics to enable an accurate gaussian fit of the peaks. The neutron and gamma-ray data in the grid are well separated however, and they are separated by simply summing the data on each side of the minima between the two peaks.

A print option is available in the computer code, but it should be used only if difficulty is encountered in analyzing a set of data. The print option, when used, will give a detailed listing of the raw data, every gaussian fit, and the raw data after each gaussian fit has been subtracted during the iteration process. This option in useful for locating errors in the data (usually unknown overflows) which cause erroneous results.

B-1.1 DISCRIM Input Data Format

Card	Format	Variable and Description
1	215	1. JO1MIN = Number of channels from center of largest peak toward smaller peak to be included infirst gaussian fit of iterative routine
		2. JO1MAX = Number of channels from center of largest peak away from smaller peak to be included in first gaussian fit of iterative routine
2	15	1. NCHK = Maximum number of iterations allowed in iterative routine
3	2F5.0	1. CONV = Convergence limit for iterative routine. Iteration is terminated when the relative change in area of the largest peak in n^{th} iteration becomes less than CONV
		2. YFRACT = Fraction of the peak to be excluded from gaussian fit. All data which are greater than YFRACT times the maximum value of the peak are included in the least squares fit.
4	15,45H	1. CHANE1 = First channel that discrimination is to be attempted
		2. LABEL = An arbitrary alphanumeric label to identify the data
5	515	1. IMAX1 = Last channel iterative routine is to be done
		2. IMAX2 = Last channel gaussian fit is to be done. Simple sum of peaks is done beyond IMAX2
		3. PNCH = 0 if punched output is not desired
		= 1 if punched output is desired
		4. PRNT = 0 if detailed printing is not desired
		= 1 if detailed printing is desired

5. BKG = 0 if no background data is to be subtracted

= 1 if background data is to be subtracted

6(Deck)	6X,12F6.0	4096 Channel foreground data deck
7(Deck)	215	Specify all (I,J) locations of overflows in data grid. Use as many cards as necessary with just one (I,J) location per card.
8	----	Blank card
9(Deck)	----	Background deck if any. (If "BKG" on card 5 is 1). Deck consists of cards 4, 6, and 8.
10(Decks)	----	Other sets of data (cards 4-9). Any number of data sets may be run at one time.
11	----	Blank card. Put an extra blank card behind all the data to terminate the program.

Notes: 1. The values specified on cards 1-3 are read only once and used for all data sets.

2. If background is subtracted, the foreground and background data must both have identical pulse width and pulse height gains since the background subtraction is done point for point in the data grid.

B-1.2 DISCRIM Code Listing

```
C      PUT DATA IN THIS FORM.
C
C      CODE SPECIFICATIONS....
C         0) SPECIFY THE TWO "J" CRITERIA FOR THE GAUSSIAN FITS.
C         1) MAX NO OF ITERATIONS ALLOWED IN STRIPPING ROUTINE (I5)
C         2) CONVERGENCE CRITERIA AND PEAK FRACTION VALUE FOR STRIPPING
C            ROUTINE. (2F5.0)
C
C      DATA PACK FORMAT....
C         1) CHANNEL WHERE YOU WANT TO START DISCRIMINATING (I5).  SPECIFY
C            'CHANNEL' FOR EACH DATA SET.  LABELS MAY BE PUNCHED IN CH 10-45.
C         1A) SPECIFY IMAX1, IMAX2, PNCH, PRNT, AND BACKGROUND (5I5)
C              (MAKE "BACKGROUND" NONZERO IF BKG GRID IS TO BE SUBTRACTED)
C         2) 64 X 64 GRID OF DATA
C         3) GIVE (I,J) LOCATIONS OF ALL OVERFLOWS IN THE DATA GRID. (2I5)
C            ONLY ONE OVERFLOW LOCATION PER CARD.  USE AS MANY CARDS AS NECESSARY
C         3A) 64 X 64 GRID OF BKG DATA IF ANY.
C         4) PUT A BLANK CARD BEHIND EACH DATA SET.
C         5) PUT ANOTHER BLANK CARD BEHIND ALL THE DATA.  IE.. THERE SHOULD BE
C            TWO BLANK CARDS AT THE VERY END OF THE DATA.  THERE SHOULD BE ONE
C            BLANK CARD BETWEEN EACH SET OF DATA ( A 64 X 64 GRID).
C
C            "PRNT" IS A CODE TO CAUSE A DETAILED PRINTING OF THE PEAK FITS.
C                  MAKE "PRNT" NONZERO TO CAUSE PRINTING
C      "NCHK" IS THE MAX NO OF ITERATIONS ALLOWED IN THE STRIPPING ROUTINE.
C      "CONV" IS THE CONVERGENCE CRITERIA FOR THE STRIPPING ROUTINE.
C      "CHANEL" IS THE LOWEST ENERGY CHANNEL THAT CAN BE SEPARATED.
C      "PNCH" IS A CODE FOR PUNCHING NEUTRON SPECTRA.  MAKE NONZERO TO GET
C      PUNCHED CARDS.
C      IMAX1= THE LAST CHANNEL THAT THE STRIPPING IS TO BE DONE.
C      IMAX2= THE LAST CHANNEL THAT A GAUSSIAN FIT IS TO BE DONE. ( DONE FROM
C      IMAX1 TO IMAX2)
C      BEYOND IMAX2 JUST A SIMPLE SUM IS TAKEN TO CHANNELS EITHER SIDE OF THE
C      MINIMUM BETWEEN THE PEAKS.
C
       INTEGER CHANEL,CHECK,PNCH,PRNT
       DIMENSION Z(4096),XNEUT(64),GAMA(64),X(64),Y(64),V(64),BKG(4096)
       DIMENSION D1(64),D2(64),PL(64),PS(64)
C      THE VARIABLES IN THIS READ STATEMENT ARE UPPER AND LOWER LIMIT CRITERIA
C      FOR THE GAUSSIAN FITTING SECTION.
       READ 64,J01MIN,J01MAX
       READ 64,NCHK
       READ 65,CONV,YFRACT
  100  READ 57,CHANEL
       IF(CHANEL.EQ.0) GO TO 101
       READ 51,IMAX1,IMAX2,PNCH,PRNT,NBKG
       READ 50,Z
       PRINT 56
       PRINT 57,CHANEL
       PRINT 58
       PRINT 515
       PRINT 516
       PRINT 517
C      THIS SECTION CORRECTS FOR OVERFLOWS AT THE SPECIFIED (I,J) LOCATIONS
C      IN THE MAIN DATA.
    1  READ 51,I,J
       IF(I.EQ.0) GO TO 603
       K=(J-1)*64 + I
       Z(K)=Z(K) + 1.0E5
```

```
      GO TO 1
  603 IF(NBKG.EQ.0) GO TO 2
      READ 65,DUMMY
      READ 50,BKG
      READ 65,DUMMY
C        "DUMMY" IS A DUMMY VARIABLE TO MAKE THE BKG DATA PACKS THE SAME AS
C        THE OTHER DATA PACKS. IT IS NOT USED.
      DO 602 I=1,4096
  602 Z(I)=Z(I) - BKG(I)
    2 EO=0.
      KMIN=0
      KG=0
      KN=0
      JLO=5
      N=CHANEL-1
      DO 98 I=1,N
      GAMA(I)=0.
      XNEUT(I)=0.
   98 PRINT 519,I,XNEUT(I),KN,GAMA(I),KG
      KGCHK=1
      KNCHK=1
C     THIS SECTION DOES THE DISCRIMINATION.
      DO 1000 I=CHANEL,64
      DO 3 J=1,64
      M=I + (J-1)*64
      V(J)=Z(M)
      Y(J)=Z(M)
    3 X(J)=Z(M)
      XN=0.
      XG=0.
      GAMA(I)=0.
      XNEUT(I) = 0.
      IF(KG.LT.KGCHK) KG=KGCHK
      IF(KN.LT.KNCHK) KN=KNCHK
      KNCHK=KN
      KGCHK=KG
      KMINCK=KMIN
      LA=0
      JLO=KG-6
      KDIFF=KN-KG
      KN=JLO
      KG=JLO
      IF(JLO.LT.5) JLO=5
C    **THIS SECTION STRIPS OUT THE PEAKS ONE AT A TIME
      IF(I.GT.IMAX1) GO TO 70
      IF(PRNT.EQ.0) GO TO 103
      PRINT 512
      PRINT 513,I
      PRINT 505
      PRINT 504,V
  103 CHECK=0
      X1CHK=1.0
      X1=0.
      M=0
C     THIS LOOP FINDS THE CENTER CHANNEL OF THE HIGHEST PEAK
      DO 71 J=JLO,64
      IF(X(J).LT.X1) GO TO 71
      X1=X(J)
      K1=J
   71 CONTINUE
```

```
      XK1=.5*V(K1)
      JL=K1-6
      JU=K1+6
      CALL SSCHK(JL,JU)
      RATIO=X(JU)/X(JL)
      CALL DERIV(X,K1,RATIO,DMIN)
      IF(1.-RATIO) 72,72,73
   72 KUP1=K1 + J01MIN
      KLO1=K1 - J01MAX
      GO TO 74
   73 KUP1= K1 + J01MAX
      KLO1= K1 - J01MIN
   74 CALL SSCHK(KLO1,KUP1)
      IF(X(K1-1).LT.XK1) X(K1-1)=XK1
      IF(X(K1+1).LT.XK1) X(K1+1)=XK1
      NDP=KUP1 - KLO1 + 1
      CALL PEAK(KLO1,NDP,Y,X)
      CALL GAUSS(NDP,KLO1,Y,X1,E1,B1,Y1)
C     THIS LOOP SUBTRACTS OFF THE FIRST PEAK
      X2=0.
      CALL CALPK(PL,Y1,E1,B1)
      DO 76 J=5,64
      X(J)= V(J) - PL(J)
      IF(X(J).LT.1.) X(J)=1.
      IF(X(J).LT.X2) GO TO 76
      E=J
      IF(ABS(E-E1).LT.DMIN) GO TO 76
      X2=X(J)
      K2=J
   76 CONTINUE
      XK2=.5*X(K2)
      IF(X(K2-1).LT.XK2) X(K2-1)=XK2
      IF(X(K2+1).LT.XK2) X(K2+1)=XK2
      CALL DAMP(X,D2,CHECK)
      IF(PRNT.EQ.0) GO TO 81
      PRINT 506,CHECK
      PRINT 504,PL
      PRINT 508
      PRINT 504,X
   81 Y2X=YFRACT*X2
      KLO2=1
      KUP2 = 1
      DO 600 J=2,5
      JL=K2-J
      JU=K2+J
      CALL SSCHK(JL,JU)
      IF(X(JL).GT.X(JL+1)) KLO2=JL+1
      IF(X(JU).GT.X(JU-1)) KUP2=JU-1
      IF(X(JL).LT.Y2X.AND.KLO2.EQ.1) KLO2=JL
      IF(X(JU).LT.Y2X.AND.KUP2.EQ.1) KUP2=JU
  600 CONTINUE
      IF(KLO2.LT.JL) KLO2=JL
      IF(KUP2.EQ.1) KUP2=JU
      NDP=KUP2 - KLO2 + 1
      CALL PEAK(KLO2,NDP,Y,X)
      CALL GAUSS(NDP,KLO2,Y,X2,E2,B2,Y2)
      K2=E2
      CONVP=(X1-X1CHK)/X1CHK
C**   THIS SECTION (TO 91) SUBTRACTS OFF THE SMALLER PEAK FROM THE ORIGINAL
C     COMPLEX PEAK STRUCTURE THEN RETURNS TO STATEMENT 74 TO FIT A GAUSSIAN
```

```
C      TO THE LARGEST PEAK WHICH HAS BEEN CORRECTED BY AN ESTIMATE OF THE
C      CONTRIBUTION OF THE SECOND PEAK.  THIS PROCESS WILL BE REPEATED UNTIL
C      THE NUMBER OF ITERATIONS SET IN THE FOLLOWING 'IF' STATEMENT HAS BEEN
C      MET OR THE ITERATION RESULTS IN LESS FRACTIONAL IMPROVEMENT THAN
C      SPECIFIED IN STATEMENT 900.
       IF(CHECK.EQ.NCHK) GO TO 93
  900  IF(ABS(CONVP).LT.CONV) GO TO 93
       CHECK=CHECK+1
       X1CHK=X1
       CALL CALPK(PS,Y2,E2,B2)
C      THIS LOOP SUBTRACTS OFF THE SECOND PEAK
       DO 91 J=5,64
       X(J) = V(J) - PS(J)
       IF(X(J).LT.1.) X(J)=1.
   91  CONTINUE
       L=CHECK-1
       CALL DAMP(X,D1,L)
       IF(PRNT.EQ.0) GO TO 82
       PRINT 507,CHECK
       PRINT 504,PS
       PRINT 508
       PRINT 504,X
       PRINT 514,X1,X2
   82  Y1X=YFRACT*V(K1)
       KLO1=1
       KUP1=1
       DO 92 J=2,5
       JL=K1-J
       JU=K1+J
       CALL SSCHK(JL,JU)
       IF(X(JL).GT.X(JL+1)) KLO1=JL+1
       IF(X(JU).GT.X(JU-1)) KUP1=JU-1
       IF(X(JL).LT.Y1X.AND.KLO1.EQ.1) KLO1=JL
       IF(X(JU).LT.Y1X.AND.KUP1.EQ.1) KUP1=JU
   92  CONTINUE
       IF(KLO1.EQ.1) KLO1=JL
       IF(KUP1.EQ.1) KUP1=JU
       GO TO 74
C      THIS STATEMENT DETERMINES WHICH PEAK IS THE NEUTRON PEAK
   93  IF(E2-E1) 78,78,79
   78  KN=K1
       E0=E1
       Y0=Y1
       B0=B1
       B0G=B2
       E0G=E2
       XNEUT(I)=X1
       KG=K2
       GAMA(I)=X2
       KLO=KLO1
       GO TO 80
   79  KN=K2
       E0=E2
       Y0=Y2
       B0=B2
       B0G=B1
       E0G=E1
       XNEUT(I)=X2
       GAMA(I)=X1
       KG=K1
```

```
      KLO=KLO2
   80 KUP=KLO+10
      IF(PRNT.GT.0) PRINT 512
      IF(PRNT.EQ.0) GO TO 110
      PRINT 515
      PRINT 516
      PRINT 517
  110 IF(CHECK.EQ.NCHK) PRINT 66,NCHK
      IF(CHECK.EQ.NCHK) PRINT 67,CONVP
      FWHMN=2.*SQRT(BO*ALOG(2.))
      FWHMG=2.*SQRT(BOG*ALOG(2.))
      PRINT 518,I,XNEUT(I),EO,FWHMN,GAMA(I),EOG,FWHMG,CHECK
      IF(PRNT.GT.0) PRINT 512
      IF(I.LT.10) GO TO 1000
      XP=V(KG)
      CALL SSCHK(KG,KN)
      DO 605 J=KG,KN
      IF(V(J).LT.XP) XP=V(J)
  605 CONTINUE
      XPC=.5*YFRACT
      IF(XP/V(KN).LT.XPC) IMAX=I
      GO TO 1000
C     THIS SECTION SEARCHES FOR THE TWO PEAKS.
   70 DO 4 J=JLO,64
      IF(X(J) - XN) 5,6,7
    5 IF(X(J) - XG) 4,8,8
    6 K=J-KN
      IF(K.LT.2) GO TO 15
      XG=XN
      KG=KN
      XN = X(J)
   15 KN=J
      GO TO 4
    7 K=J-KN
      IF(K.LT.2) GO TO 16
      XG=XN
      KG=KN
   16 KN=J
      XN = X(J)
      GO TO 4
    8 IF(X(J).LE.X(J-1)) GO TO 4
      XG= XN
      KG=KN
      XN= X(J)
      KN=J
    4 CONTINUE
C     THIS LOOP FINDS THE MIN. BETWEEN THE TWO PEAKS.
   40 XMIN=1.E50
      DO 12 J=KG,KN
      IF(X(J) - XMIN) 10,12,12
   10 XMIN=X(J)
      KMIN=J
   12 CONTINUE
      IF(XN.LT.3..AND.XG.LT.3.) GO TO 108
      IF(I.GT.IMAX2) GO TO 19
      IF(KNCHK-KN.GT.5.OR.KG-KGCHK.GT.5) GO TO 102
      IF(XN.LT.5..OR.XG.LT.5.) GO TO 102
      IF(X(KMIN)/XN.GT..8) GO TO 103
      KLO=KMIN+1
      KUP=KN+1
```

```
      XN=YFRACT*XN
   25 IF(X(KUP).LT.XN) GO TO 26
      KUP=KUP+1
      IF(KUP.GT.64) GO TO 19
      GO TO 25
   26 NDP=KUP - KLO + 1
      M=0
      CALL PEAK(KLO,NDP,Y,X)
      CALL GAUSS(NDP,KLO,Y,XNEUT(I),EO,BO,YO)
      EON=EO
      BON=BO
      IF(M.LT.1) GO TO 41
      PRINT 60,M
      PRINT 69
   41 IF(PRNT.EQ.0) GO TO 111
      PRINT 505
      PRINT 504,V
      PRINT 509
      CALL CALPK(PS,YO,EO,BO)
      PRINT 504,PL
C     THIS SECTION FITS A GAUSSIAN TO THE GAMMA PEAK.
  111 KLO=KG-3
      KUP=KMIN
      CALL SSCHK(KLO,KUP)
      NDP=KUP - KLO +  1
      CALL PEAK(KLO,NDP,Y,X)
      CALL GAUSS(NDP,KLO,Y,GAMA(I),EO,BO,YO)
      BOG=BO
      EOG=EO
      KG=EO
  606 FWHMN=2.*SQRT(BON*ALOG(2.))
      FWHMG=2.*SQRT(BOG*ALOG(2.))
      IF(PRNT.EQ.0) GO TO 601
      PRINT 510
      CALL CALPK(PS,YO,EO,BO)
      PRINT 504,PS
      PRINT 515
      PRINT 516
      PRINT 517
  601 PRINT 518,I,XNEUT(I),EON,FWHMN,GAMA(I),EOG,FWHMG
      IF(PRNT.GT.0) PRINT 512
      GO TO 1000
C     THESE TWO LOOPS SUM THE NEUTRONS AND GAMMAS IN THE CHANNEL.
   19 KL=KMIN
      KU=KL+10
      IF(KU.GT.64) KL=64
      DO 13 J=KL,KU
   13 XNEUT(I) = XNEUT(I) +X(J)
      EO=0.0
   20 KSTOP = KMIN - 1
      KL=KG - 10
      IF(KL.LT.1) KL=1
      DO 14 J=KL,KSTOP
   14 GAMA(I) = GAMA(I) + X(J)
    9 PRINT 519,I,XNEUT(I),KN,GAMA(I),KG
      GO TO 1000
C*****   THIS SECTION (TO 108) HANDLES THE DATA IF ONLY ONE SIGNIFICANT PEAK
C        IS FOUND.  A GAUSSIAN FIT IS MADE OF THE LARGER PEAK, THE LARGER PEAK
C        IS FOUND.  A GAUSSIAN FIT IS MADE OF THE LARGER PEAK, THE CALCULATED
C        PEAK IS THEN SUBTRACTED FROM THE ORIGINAL DATA.
```

```
C         THE DATA REMAINING AFTER THE SUBTRACTION OF THE GAUSSIAN FIT IS THEN
C         SUMMED OVER THE CHANNELS WHERE THE OTHER PEAK SHOULD LIE.  THE AREA
C         UNDER THE GAUSSIAN FIT AND THE SUM TAKEN OVER THE REMAINING DATA ARE
C         THEN TAKEN AS THE TOTAL COUNTS IN THE TWO PEAKS.
  102 PRINT 503,I
      PRINT 61,X
      XN=0.
      DO 105 J=JLO,64
      IF(XN.GT.X(J)) GO TO 105
      XN=X(J)
      KN=J
  105 CONTINUE
      LA=1
      IF(IABS(KNCHK-KN).LT.IABS(KGCHK - KN)) LA=-LA
      KLO= KN - LA*5
      KUP= KN + LA*2
      CALL SSCHK(KLO,KUP)
      NDP= KUP - KLO + 1
      CALL PEAK(KLO,NDP,Y,X)
      CALL GAUSS(NDP,KLO,Y,XNEUT(I),EON,BON,YO)
      KUP=KN + LA*15
      KLO=KN
      CALL SSCHK(KLO,KUP)
      KG=KN - KDIFF
      KMIN=KN-(KDIFF/2)
      DO 106 J=KLO,KUP
      EXPNT= -((EON-E)**2)/BON
      IF(EXPNT.GT.100.) EXPNT=100.
      IF(EXPNT.LT.-75.) EXPNT=-75.
      X(J) = X(J) - YO*EXP(EXPNT)
      IF(X(J).LT.0.) X(J)=0.0
      GAMA(I)=GAMA(I) + X(J)
  106 X(J)=V(J)
      IF(LA.LT.0) GO TO 606
      KG=KN
      KN=KG + KDIFF
      KMIN=(KG + KN)/2
      EOG=EON
      BOG=BON
      EON=0.0
      BON=0.0
      G=GAMA(I)
      GAMA(I)= XNEUT(I)
      XNEUT(I)=G
      GO TO 601
C*****    THIS STATEMENT PRINTS AN ERROR MESSAGE IF NO SIGNIFICANT PEAK IS FOUND.
  108 PRINT 62,I
 1000 CONTINUE
C         THIS LOOP ESTABLISHES THE PARAMETERS FOR THE PLOTTING SUBROUTINE.
      DO 84 J=1,64
      PL(J)=J
      X(J)=XNEUT(J)
      IF(J.LT.CHANEL) X(J)=XNEUT(64)
      IF(X(J).LT.0.0) X(J)=X(64)
      IF(X(J).LT.1.) X(J)=1.
   84 Y(J)=ALOG(X(J))
      PRINT 511
      PRINT 57,CHANEL
      N=64
      CALL PLAT2(PL,Y,N)
```

```
      IF(PNCH.EQ.0) GO TO 100
      PUNCH 58
      PUNCH 61,(XNEUT(I), I=1,64)
      GO TO 100
  101 PRINT 501
      STOP
   50 FORMAT(6X,12F6.0,2X)
   51 FORMAT(10I5)
   56 FORMAT(1H1)
   57 FORMAT(1X,I4,45H                                                )
   58 FORMAT(1H )
   60 FORMAT(1X,'**** WARNING.. DATA ERROR IN CHANNEL',I4,'.  A DATA VAL
     1UE .LE. 0 WAS ENCOUNTERED WHEN TRYING TO FIT A GAUSSIAN TO THE DAT
     2A.')
   61 FORMAT(1X,10F7.0)
   62 FORMAT(1X,I2,'     NO SIGNIFICANT PEAK FOUND.')
   64 FORMAT(10I5)
   65 FORMAT(10F5.0)
   66 FORMAT(1X,'****WARNING..  NO CONVERGENCE IN STRIPPING ROUTINE AFTE
     1R ',I5,' ITERATIONS')
   67 FORMAT(16X,'LAST ITERATION MADE FRACTIONAL CHANGE OF',F10.6,'  IN
     1LARGEST PEAK')
   69 FORMAT(16X,'STANDARD LINEAR FIXUP TAKEN')
  501 FORMAT(1X,'      *******NORMAL END OF PROGRAM*******')
  503 FORMAT(1X,' ONLY ONE DOMINANT PEAK FOUND IN CHANNEL'I3,'.  ONE PEA
     1K FIT ATTEMPTED')
  504 FORMAT(1X,16F7.0)
  505 FORMAT(/,1X,'64 CHANNELS OF RAW DATA')
  506 FORMAT(/,1X,'CALCULATED VALUES IN LARGEST PEAK FOR ITERATION'I5)
  507 FORMAT(/,1X,'CALCULATED VALUES IN SMALLEST PEAK FOR ITERATION',I5)
  508 FORMAT(/,1X,'PEAK REMAINING AFTER SUBTRACTION OF LAST CALCULATED P
     1EAK')
  509 FORMAT(/,1X,'CALCULATED NEUTRON PEAK')
  510 FORMAT(/,1X,'CALCULATED GAMMA PEAK')
  511 FORMAT(1H1,1X,'SEMILOG PLOT OF CALCULATED NEUTRON PULSE HEIGHT SPE
     1CTRA',//)
  512 FORMAT(1X,'**********************************************************
     1**************************************************')
  513 FORMAT(40X,'******CHANNEL',I4,' STATISTICS******')
  514 FORMAT(10X,'******ITERATION STATISTICS ARE ---- (LARGEST PEAK AREA
     1='F10.0,8X,'SMALLEST PEAK AREA=',F10.0,')******')
  515 FORMAT(' CHANNEL',10X,'NEUTRONS    CENTER      FWHM',10X,'GAMMAS
     1 CENTER      FWHM           ITERATIONS')
  516 FORMAT(29X,'CHANNEL',28X,'CHANNEL')
  517 FORMAT(29X,'OF PEAK',28X,'OF PEAK')
  518 FORMAT(I4,F20.C,F11.2,F9.2,F16.0,F11.2,F9.2,I16)
  519 FORMAT(I4,F20.C,I9,F27.0,I9)
      END
      SUBROUTINE GAUSS(NDP,KLO,Y,AREA,E0,B0,Y0)
C
C     THIS PROGRAM FITS A GAUSSIAN CURVE TO A SET OF POINTS IN A LEAST
C     SQUARES MANNER.
C
C     Y= Y0*EXP(-(E-E0)**2/B0)   IS THE FORM OF THE FIT.
C     Y = THE COUNTS IN CHANNEL E.
C     E0= THE CENTER CHANNEL OF THE PEAK. (MAY BE A FRACTIONAL CHANNEL)
C     Y0= THE COUNTS IN THE CENTER CHANNEL.
C     NDP= THE NUMBER OF DATA PTS TO BE FIT.
C     KLO= THE SUBSCRIPT CORRESPONDING TO THE FIRST Y
C
```

```
C
      DIMENSION Y(NDP),EN(25),A(3,3),B(3),VAR(25),BDUM(3,1)
      DO101 I=1,3
      B(I)=0.
      DO 101 J=1,3
  101 A(I,J)=0.
      DO 102 I=1,NDP
      EN(I) = I
C****    THE NEXT STATEMENT CORRECTS FOR NEGATIVE VALUES WHICH MAY OCCUR
C        DURING THE ITTERATION PROCESS.
      IF(Y(I).LE.0.) Y(I)=1.
      RATIO=Y(I)
      A(3,3)=A(3,3)+RATIO
      A(2,3)=A(2,3)+RATIO*EN(I)
      A(2,2)=A(2,2)+RATIO*EN(I)*EN(I)
      A(2,1)=A(2,1)+RATIO*(EN(I)**3)
      A(1,1)=A(1,1)+RATIO*(EN(I)**4)
      B(1) = B(1)+RATIO*ALOG(Y(I))*EN(I)*EN(I)
      B(2) = B(2)+RATIO*ALOG(Y(I))*EN(I)
  102 B(3) = B(3)+RATIO*ALOG(Y(I))
      A(3,2)=A(2,3)
      A(3,1)=A(2,2)
      A(1,3)=A(2,2)
      A(1,2)=A(2,1)
      DO 176 I=1,3
  176 BDUM(I,1)=B(I)
      N1 = 1
      N3 = 3
      CALL MATINV(A,N3,BDUM,N1,DETERM,N3)
      DO 177 I=1,3
  177 B(I)=BDUM(I,1)
      B0=-1./B(1)
      E0=B0*B(2)/2.
      Y0 =  EXP(B(3)+E0*E0/B0)
      PI=3.1415927
      E0= E0 + KLO - 1
      IF(B0.LT.0.0) GO TO 201
      AREA = Y0*SQRT(B0*PI)
      RETURN
  201 AREA = -999999.0
      RETURN
      END
      SUBROUTINE MATINV (A,N,B,M,DETERM,NMAX)
C
C     MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C        A  INPUT-COEFFICIENT MATRIX
C           RETURN-INVERSE MATRIX
C        N  NUMBER OF EQUATIONS
C        B  INPUT-RIGHT HAND SIDE VECTOR(S)
C           RETURN-SOLUTION VECTOR(S)
C        M  NUMBER OF RIGHT HAND SIDE VECTOR(S)
C        DETERM  RETURN-DETERMINATE OF A
C        NMAX  MAXIMUM NUMBER OF EQUATIONS AS DIMENSIONED IN MAIN PROGRAM
C
      REAL*4 PIVOT
      DIMENSION A(NMAX,NMAX),B(NMAX,1)
      COMMON /F402/ PIVOT(100), INDEX(100)
C
C     INITIALIZE DETERMINANT AND PIVOT ELEMENT ARRAY
      DETERM=1.0
```

```
      DO 20 I=1,N
      PIVOT(I)=0.0
   20 CONTINUE
C
C     PERFORM SUCCESSIVE PIVOT OPERATIONS (GRAND LOOP)
C
      DO 550 I=1,N
C
C     SEARCH FOR PIVOT ELEMENT AND EXTEND DETERMINANT PARTIAL PRODUCT
C
      AMAX=0.0
      DO 105 J=1,N
      IF (PIVOT(J).NE.0.0) GO TO 105
      DO 100 K=1,N
      IF (PIVOT(K).NE.0.0) GO TO 100
      TEMP= ABS(A(J,K))
      IF (TEMP.LT.AMAX) GO TO 100
      IROW=J
      ICOLUM=K
      AMAX=TEMP
  100 CONTINUE
  105 CONTINUE
      INDEX(I)=4096*IROW+ICOLUM
      J=IROW
      AMAX=A(J,ICOLUM)
      DETERM=AMAX*DETERM
C
C     RETURN IF MATRIX IS SINGULAR (ZERO PIVOT) AFTER COLUMN INTERCHANGE
C
      IF (DETERM.EQ.0.0) GO TO 600
C
      PIVOT(ICOLUM)=AMAX
C
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
      IF (IROW.EQ.ICOLUM) GO TO 260
      DETERM=-DETERM
      DO 200 K=1,N
      SWAP=A(J,K)
      A(J,K)=A(ICOLUM,K)
      A(ICOLUM,K)=SWAP
  200 CONTINUE
      IF (M.LE.0) GO TO 260
      DO 250 K=1,M
      SWAP=B(J,K)
      B(J,K)=B(ICOLUM,K)
      B(ICOLUM,K)=SWAP
  250 CONTINUE
C
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
  260 K=ICOLUM
      A(ICOLUM,K)=1.0
      DO 350 K=1,N
      A(ICOLUM,K)=A(ICOLUM,K)/AMAX
  350 CONTINUE
      IF (M.LE.0) GO TO 380
      DO 370 K=1,M
      B(ICOLUM,K)=B(ICOLUM,K)/AMAX
  370 CONTINUE
```

```
C
C     REDUCE NON-PIVCT ROWS
C
  380 DO 550 J=1,N
      IF (J.EQ.ICOLUM) GO TO 550
      T=A( J,ICOLUM)
      A( J,ICOLUM)=0.0
      DO 450 K=1,N
      A( J,K)=A( J,K)-A(ICOLUM,K)*T
  450 CONTINUE
      IF (M.LE.0) GO TO 550
      DO 500 K=1,M
      B( J,K)=B( J,K)-B(ICCLUM,K)*T
  500 CONTINUE
  550 CONTINUE
C
C     INTERCHANGE COLUMNS AFTER ALL PIVOT OPERATIONS HAVE BEEN PERFORMED
C
  600 DO 710 I=1,N
      I1=N+1-I
      K=INDEX(I1)/4096
      ICOLUM=INDEX(I1)-4096*K
      IF (K.EQ.ICOLUM) GO TO 710
      DO 705 J=1,N
      SWAP=A(J,K)
      A(J,K)=A(J,ICOLUM)
      A(J,ICOLUM)=SWAP
  705 CONTINUE
  710 CONTINUE
C
      RETURN
      END
      SUBROUTINE PEAK(KLO,NDP,Y,X)
C**      THIS SUBROUTINE SHIFTS THE PEAK TO CHANNEL 1 FOR THE GAUSSIAN FIT.
      DIMENSION X(64),Y(NDP)
      KUP=KLO + NDP - 1
      DO 10 J=KLO,KUP
      K=J-KLO + 1
   10 Y(K)=X(J)
      RETURN
      END
      SUBROUTINE SSCHK(KLO,KUP)
C**      THIS SUBROUTINE CHECKS THE SUBSCRIPTS TO SEE THAT THEY ARE INSIDE
C        THE GRID.   (THE UPPER AND LOWER LIMITS ARE SET AT 2 AND 63 BECAUSE
C        SOME STATEMENTS IN THE MAIN PROGRAM REFER TO X(I +.OR- 1) SO "I"
C        MUST LIE BETWEEN 2 AND 63)
      IF(KUP.GT.KLO) GO TO 1
      K=KUP
      KUP=KLO
      KLO=K
    1 IF(KLO.LT.2) KLO=2
      IF(KUP.GT.63) KUP=63
      RETURN
      END
      SUBROUTINE DAMP(X,D,N)
C**** THIS SUBROUTINE AVERAGES EACH NEW ESTIMATION OF THE PEAKS DURING THE
C     ITERATION PROCESS WITH THE LAST ESTIMATION OF THE PEAK. THIS IS DONE TO
C     DAMP OUT OSCILLATIONS WHICH SOMETIMES OCCUR DURING THE ITERATION
C     PROCESS.
      DIMENSION X(64),D(64)
```

```
      IF(N.GT.0) GO TO 2
      DO 1 I=1,64
    1 D(I)=X(I)
      RETURN
    2 DO 3 I=1,64
      X(I) = (X(I) + D(I))/2.
    3 D(I)= X(I)
      RETURN
      END
      SUBROUTINE CALPK(X,Y,E0,B0)
C**** THIS SUBROUTINE CALCULATES HOW MANY COUNTS ARE IN A PARTICULAR CHANNEL
C     BASED ON THE PARAMETERS DETERMINED IN THE LEAST SQUARES GAUSSIAN FIT.
C     IT IS USED TO CALCULATE THE FITTED PEAKS FOR THE PRINT OPTION, AND TO
C     CALCULATE THE PEAKS DURING THE ITERATION PROCESS SO THE CALCUALTED PEAK
C     CAN BE SUBTRACTED FROM THE ACTUAL PEAK.
      DIMENSION X(64)
      DO 1 J=1,64
      E=J
      EXPNT=-((E-E0)**2)/B0
      IF(EXPNT.GT.120.) EXPNT=120.
      IF(EXPNT.LT.-50.) EXPNT=-50.
    1 X(J)=Y*EXP(EXPNT)
      RETURN
      END
      SUBROUTINE DERIV(X,K1,R,DMIN)
C**** THIS SUBROUTINE LOOKS FOR A MINIMA IN THE DERIVATIVE OF THE DATA BETWEEN
C     THE NEUTRON AND GAMMA PEAKS.  THIS IS DONE SO THAT THE MAIN PROGRAM KNOWS
C     WHERE TO SEARCH FOR THE SECOND PEAK DURING THE ITERATION PROCESS.
C     THIS SUBROUTINE WAS ADDED BECAUSE THE RESIDUAL LEFT AFTER SUBTRACTING
C     THE FIRST FIT TO THE GAMMA PEAK FROM THE ORIGINAL GAMMA PEAK WAS SOMETIMES
C     LARGER THAN THE ACTUAL NEUTRON PEAK.(THIS IS A PROBLEM AT LOW PULSE HEIGHT
C     CHANNELS WHERE THE GAMMA PEAK IS SKEWED)
      DIMENSION X(64),D(15)
      DO 3 I=1,10
    3 D(I)=0.0
      I=1
      IF(R.LT.1.) I=-I
      N=10
      IF(K1.GT.53) N=63-K1
      IF(K1.LT.12) N=K1-2
      DO 1 J=1,N
      L=K1+I*J
    1 D(J)=X(L-1)-X(L)
      DMIN=0.0
      DO 2 J=2,9
      IF(DMIN.GT.0.) GO TO 2
      IF(ABS(D(J)).GT.ABS(D(J-1))) GO TO 2
      IF(ABS(D(J)).LT.ABS(D(J+1))) DMIN=J
    2 CONTINUE
      IF(DMIN.LT.3.) DMIN=3.
      RETURN
      END
      SUBROUTINE PLAT2(Z,Y,N)
C**** THIS SUBROUTINE PLOTS THE CALCULATED PULSE HEIGHT SPECTRA.  (THE DATA
C     IN THE FIRST FEW CHANNELS THAT IS SET TO ZERO IN THE MAIN PROGRAM IS SET
C     EQUAL TO THE DATA IN THE LAST CHANNEL DURING THE PLOT ROUTINE SO THAT THE
C     PLOT WILL HAVE THE GREATEST DEFINITION POSSIBLE)
C
C      PLOTTING SUBROUTINE PLAT2
C
```

```
C      Z=X AXIS DATA
C      Y=YAXIS DATA
C      N= NUMBER OF DATA POINTS.
C
       INTEGER XX
       DIMENSION XX(120),Z(N),Y(N),NN(2)
       DATA NN/1H ,1H*/
       YMAX = -1.E50
       YMIN = 1.E50
       DO 3 I=1,N
       IF(Y(I) - YMAX) 5,5,4
    4  YMAX=Y(I)
    5  IF(YMIN - Y(I)) 3,3,6
    6  YMIN = Y(I)
    3  CONTINUE
       RANGE = YMAX - YMIN
       DIV = RANGE/100.
       PRINT 30, DIV
   30  FORMAT(1H ,25X,' THE SCALE OF THIS GRAPH IS 1 DIVISION =',E12.5,'U
      1NITS'//,29X,'12345678901234567890123456789012345678901234567890123
      2456789012345678901234567890123456789012345678901234567890')
       DO 1 J=1,120
    1  XX(J) = NN(1)
       IX=1
       DO 2 I=1,N
       XX(IX)=NN(1)
       X = 1.0 + (99./RANGE)*(Y(I)-YMIN)
       IX = IFIX(X)
       IF(IX.LT.1.OR. IX.GT.101) GO TO 2
       XX(IX) = NN(2)
       PRINT 20, Z(I),Y(I),(XX(J),J=1,101)
   20  FORMAT(1H ,2E12.4,'----',101A1)
    2  CONTINUE
       RETURN
       END
```

B-1.3 Sample Data Set and Results

DISCRIM Input Data Set

```
    3    4
   20
.01    .10
    3    HG PUBE FGD 4-13-71 (500/200)
   20   30    0    0    0
        0.  507.  961.  473.  422.  352.  242.  156.  125.  112.   98.   92.
       81.   87.   75.   73.   64.   61.   54.   56.   47.   49.   51.   43.
       43.   43.   39.   24.   26.   26.   30.   29.   32.   18.   27.   18.
       28.   17.   16.   15.   18.   11.   13.   20.   14.   26.   20.   15.
       11.    9.   10.    9.   20.   11.   12.   14.    5.   11.   10.    8.
        9.   16.   11.   13.    0.  514. 1020.  505.  398.  355.  227.  159.
      123.  108.  112.   88.   84.   72.   79.   72.   56.   47.   49.   65.
       49.   47.   47.   43.   46.   34.   38.   42.   45.   22.   22.   27.
       29.   18.   27.   23.   27.   17.   21.   29.   16.   26.   16.   17.
       19.   19.   19.   16.   11.   15.   15.   12.    7.   16.   14.    5.
       11.   10.    5.    5.   11.   13.    5.   12.    0.  461.  757.  636.
      367.  242.  201.  145.  110.   82.   78.   81.   59.   72.   57.   52.
       59.   54.   52.   47.   36.   53.   50.   30.   34.   21.   29.   31.
       34.   30.   27.   21.   18.   17.   14.   19.   20.   13.   18.   15.
       17.   12.    8.   10.   20.   10.   18.   11.   11.   12.   14.   10.
        7.   17.    8.    6.    8.   10.    7.   11.   12.    8.    5.    6.
        0.  491.  629.  641.  395.  283.  161.  121.  112.   82.   96.   58.
       59.   60.   46.   51.   52.   58.   47.   40.   51.   44.   42.   37.
       41.   28.   32.   25.   25.   19.   25.   20.   29.   25.   18.   18.
       22.   21.   16.   16.   10.   22.   15.   17.    8.   10.   17.   12.
       12.   10.   10.   16.   11.   11.    6.    9.   13.   11.    5.   10.
        4.    6.    7.    4.    0. 2039.  647.  474.  567.  309.  170.  119.
       90.   88.   68.   73.   69.   53.   58.   48.   42.   30.   44.   44.
       49.   35.   35.   26.   29.   30.   24.   23.   25.   28.   19.   15.
       22.   22.   14.   22.   17.   10.   16.    6.   17.   12.   10.    7.
       26.    9.   11.   12.    6.   14.   13.   19.    8.    7.   13.    8.
       12.    4.    5.    5.    2.    4.    6.    6.    4.99213.12510.  467.
      534.  495.  204.  132.  104.   83.   76.   61.   68.   57.   66.   49.
       57.   51.   50.   30.   53.   40.   33.   42.   38.   37.   25.   36.
       25.   17.   30.   23.   19.   17.   17.   18.   20.   12.   16.   14.
       21.   17.   15.    9.   13.   17.   17.    9.   19.   15.   13.    9.
        9.   10.   10.   11.    9.    8.    8.    5.    6.   10.    3.    5.
        6.58462.33970.  432.  325.  357.  352.  153.  106.   69.   76.   58.
       64.   43.   42.   52.   38.   44.   48.   41.   34.   35.   42.   29.
       24.   29.   28.   32.   28.   15.   27.   20.   18.   19.   22.   20.
       14.   12.   13.   11.   16.   18.   12.   16.   12.   10.   15.   11.
       10.    9.    6.   11.    9.    6.    6.    7.    9.   12.    5.    6.
       11.    6.    7.    7.    4.37978.48742.  391.  302.  232.  200.  222.
      153.  106.   50.   61.   55.   44.   37.   39.   48.   28.   41.   33.
       36.   34.   26.   30.   30.   23.   27.   16.   19.   20.   19.   17.
       16.   14.   21.   20.   17.   10.   11.   17.   14.    6.    8.   12.
       12.   10.   11.    7.    8.   10.    6.   10.    6.   10.    9.    9.
        4.    7.    7.    5.    4.    6.    3.    7.    3.25864.57732.  402.
      289.  214.  153.  110.  108.  130.  115.  101.   67.   42.   38.   43.
       36.   37.   33.   26.   26.   42.   31.   24.   30.   19.   12.   16.
       23.   16.   15.   17.   14.   14.   15.   17.   19.    8.    8.   15.
       10.   12.    8.   11.    8.   11.    7.    6.   11.    7.   11.    8.
       12.    4.   10.    6.    4.    4.    9.    4.    2.    3.    3.    8.
        0.19011.62244.  352.  281.  199.  166.   88.   81.   77.   59.   68.
       86.   88.   76.   62.   53.   43.   38.   34.   21.   30.   30.   21.
       16.   30.   22.   21.   16.   11.   25.   13.   13.   13.    9.   16.
        9.   16.   13.    9.   16.    7.   10.   10.   17.   12.    5.   12.
```

```
    7.     6.    10.     9.     4.     3.     8.     6.     9.     2.     3.     7.
    6.     2.     5.     5.     2.14941.65301.   465.   235.   229.   167.   121.
  111.    74.    43.    58.    42.    46.    44.    44.    53.    46.    50.    68.
   56.    49.    34.    29.    16.    31.    25.    21.    13.    18.    15.    12.
   16.    17.    11.    11.    14.    16.    11.     9.    17.    13.    12.     9.
    7.     4.     9.     8.     5.     7.     9.     7.     4.     3.    10.     3.
   11.     6.     8.     5.     3.     5.     2.     6.     0.11910.66564. 2375.
  236.   205.   160.   124.   112.   109.    94.    51.    58.    49.    48.    39.
   31.    41.    31.    39.    44.    45.    57.    51.    56.    42.    37.    30.
   22.    26.    14.    26.    19.    14.    17.    16.    11.    13.     9.    12.
   11.    12.    10.    10.    15.    13.     9.     8.     8.     9.     7.     7.
    7.     3.     6.     3.     9.     3.     6.     8.     8.     4.     7.    12.
    1. 9663.58869.13644.   278.   170.   136.   124.   100.   101.    94.    77.
   85.    76.    58.    55.    71.    34.    41.    30.    25.    25.    33.    27.
   30.    30.    25.    34.    27.    21.    26.    37.    23.    26.    26.    24.
   19.    20.    21.    11.    15.    14.    11.     7.     9.     8.     8.     8.
    5.     4.     8.     5.     9.     6.     7.     2.     6.     6.     4.    10.
    7.     4.     4.     7.     2. 7836.44049.30985.   245.   186.   135.    97.
   81.    77.    58.    76.    80.    90.    69.    63.    61.    49.    62.    50.
   64.    45.    34.    29.    30.    24.    27.    18.    29.    14.    20.    14.
   22.    12.    18.    10.    24.    23.    24.    18.    20.    19.    16.    15.
   21.    18.    19.    12.    17.    19.    21.     6.    19.    13.    14.    15.
    6.    13.     7.     8.     3.     5.     6.     7.     3. 6750.32063.46999.
  291.   189.   127.   101.    74.    60.    61.    44.    43.    51.    51.    59.
   60.    45.    53.    54.    71.    53.    60.    48.    54.    40.    58.    32.
   32.    35.    26.    12.    20.    14.    10.     6.    17.     6.    13.     6.
    9.     7.     7.     4.    10.     6.    11.     9.    10.    22.    12.    10.
   12.    11.     5.     9.    19.    11.    13.    10.    16.     7.    15.    16.
    0. 5493.24971.58275.   554.   197.   128.    90.    69.    59.    41.    50.
   50.    35.    37.    31.    40.    46.    27.    27.    34.    25.    37.    33.
   28.    42.    34.    38.    28.    33.    32.    30.    25.    32.    33.    21.
   28.    18.    15.    27.    22.    18.    15.    18.    11.    17.    10.     8.
   14.     9.     9.     8.     9.     9.    11.     5.     6.     4.     9.     2.
    7.     6.     5.     4.     0. 4354.20971.61597. 5268.   143.    75.    56.
   48.    41.    39.    35.    25.    30.    16.    26.    20.    22.    16.    12.
   11.    16.    25.    15.    19.    12.    21.    13.    13.    21.    16.    13.
   15.    13.     7.    14.    14.    11.    12.    13.    13.    16.    13.    12.
   11.    13.    12.    11.    15.    17.    13.    10.    10.    10.    16.    10.
   12.     5.     9.    12.     8.    10.     5.     9.     0. 3429.19805.51687.
22512.    97.    60.    36.    32.    20.    26.    17.    13.    22.    14.    16.
   16.    11.    13.    14.    16.    13.    12.     6.     6.     7.     5.     6.
    5.     5.     8.     4.    10.     5.     5.     2.     3.     3.     2.     5.
    4.     6.     1.     3.     5.     3.     5.     1.     5.     4.     5.     3.
    4.     2.     4.     4.     3.     2.     2.     3.     1.     3.     3.     8.
    0. 2749.19065.35047.46385.   188.    32.    30.     9.    12.     9.     5.
   10.     8.     5.     7.     9.     8.     4.    10.     3.     8.     1.     5.
    5.     4.     2.     5.     4.     5.     1.     4.     2.     2.     0.     4.
    4.     1.     2.     6.     1.     1.     0.     2.     1.     5.     0.     2.
    0.     2.     0.     1.     2.     2.     1.     1.     0.     3.     1.     3.
    3.     3.     0.     1.     1. 2142.19224.21662.64189. 2960.    52.    17.
   11.     9.     5.    15.     5.    11.     3.     5.     3.     9.    10.     8.
    4.     9.     6.     4.     4.     2.     8.     7.     2.     2.     1.     3.
    5.     2.     1.     3.     2.     3.     3.     3.     0.     3.     1.     3.
    0.     3.     2.     0.     2.     1.     0.     1.     0.     0.     1.     0.
    2.     1.     1.     0.     2.     1.     1.     2.     1. 1746.18673.14622.
62731.19584.    55.    30.    18.     9.    10.    12.     6.     9.     8.     7.
    6.     3.     4.     8.     3.     4.     7.     5.     4.     4.     5.     3.
    1.     2.     5.     2.     4.     2.     2.     4.     2.     4.     3.     4.
    3.     1.     2.     3.     4.     3.     0.     2.     0.     1.     1.     1.
    1.     0.     1.     1.     1.     1.     0.     0.     2.     1.     0.     2.
```

```
    0. 1382.17840.11897.44315.46487.  614.   29.   20.   13.   15.    9.
    5.   13.    7.    3.    7.    9.    9.    7.    7.    8.    4.    4.
    9.    2.    0.    5.    5.    5.    2.    3.    4.    1.    1.    4.
    1.    3.    1.    4.    2.    1.    1.    2.    2.    3.    2.    2.
    1.    0.    5.    2.    1.    2.    0.    2.    2.    1.    0.    1.
    2.    3.    1.    2.    2. 1134.16696.12149.25903.61597. 8541.   50.
   15.    9.   10.   10.   10.    7.    4.    9.    3.    5.    3.    2.
    3.    6.    7.    4.    5.    0.    2.    2.    4.    7.    2.    4.
    2.    4.    2.    5.    0.    5.    2.    1.    3.    0.    2.    2.
    1.    2.    2.    1.    1.    1.    0.    2.    0.    1.    0.    2.
    3.    0.    1.    0.    1.    0.    1.    2.    0.  891.14358.13748.
13689.50918.28926.  515.   23.   15.   18.   10.    7.   15.    6.    8.
    6.    4.    3.    5.    9.    3.    4.    5.    4.    7.    4.    4.
    2.    7.    6.    1.    7.    1.    1.    3.    3.    2.    2.    3.
    1.    1.    2.    5.    6.    1.    1.    1.    1.    2.    0.    2.
    2.    2.    2.    2.    2.    2.    0.    2.    0.    3.    2.    0.
    1.  730.12482.15669. 8249.30640.43034. 6858.   54.   21.   20.   15.
   13.    7.    5.    6.    3.    9.    5.    7.    4.    3.    4.    5.
    5.    5.    5.    6.    3.    3.    4.    1.    2.    1.    0.    2.
    2.    3.    3.    1.    0.    2.    3.    3.    1.    0.    3.    1.
    2.    2.    1.    0.    0.    0.    1.    1.    2.    2.    0.    1.
    1.    0.    0.    0.    1.  609.10194.16873. 6997.15343.36349.22232.
 1500.   27.   18.    9.    7.    5.    7.    7.    4.    7.    4.    8.
    4.    6.    4.    5.    3.    5.    3.    4.    2.    2.    2.    3.
    2.    3.    7.    1.    1.    1.    3.    1.    2.    2.    4.    4.
    1.    1.    1.    1.    1.    2.    4.    1.    2.    3.    2.    0.
    2.    0.    1.    1.    2.    1.    0.    2.    0.  489. 8542.17302.
 8228. 7473.20756.28795.10667.  503.   31.   16.    9.    8.    4.    5.
    4.    9.    3.   11.    5.    4.    3.    4.    4.    6.    4.    3.
    4.    1.    2.    2.    1.    3.    2.    3.    1.    1.    0.    0.
    2.    1.    1.    1.    1.    3.    1.    2.    1.    0.    2.    3.
    1.    1.    1.    0.    0.    2.    2.    2.    0.    1.    1.    0.
    1.  389. 6569.16778.10517. 4817. 9618.20618.21235. 5892.  238.   19.
   16.    7.    8.    4.    8.    3.    4.    7.    2.    4.    7.    5.
    7.    1.    3.    1.    5.    1.    1.    5.    3.    0.    1.    4.
    3.    1.    1.    1.    2.    2.    1.    1.    0.    2.    2.    6.
    2.    2.    0.    1.    1.    0.    0.    0.    1.    1.    2.    0.
    1.    0.    2.    0.    0.  342. 5136.15059.12854. 4687. 4367.10164.
18020.15478. 4344.  241.   19.   13.    4.    7.    5.    3.    8.    1.
    2.    2.    3.    6.    2.    6.    3.    4.    3.    4.    2.    3.
    1.    5.    2.    3.    0.    0.    2.    3.    0.    2.    1.    0.
    2.    2.    2.    0.    2.    1.    0.    1.    0.    1.    0.    1.
    2.    1.    0.    0.    1.    0.    0.    0.    2.  262. 3904.13153.
14951. 6540. 2769. 4351. 9503.15274.13502. 4519.  389.   24.   15.    7.
    5.    4.    4.    5.    6.    1.    5.   11.    3.    1.    5.    0.
    2.    2.    2.    4.    2.    1.    3.    2.    1.    0.    0.    7.
    1.    3.    0.    1.    2.    1.    2.    0.    1.    0.    0.    1.
    1.    1.    0.    0.    1.    0.    0.    2.    1.    0.    2.    0.
    0.  251. 3022.10321.15244. 9221. 3052. 2031. 3838. 8182.13592.12771.
 5523.  802.   34.    8.    6.    8.    6.    2.    3.    5.    7.    2.
    3.    4.    1.    3.    4.    2.    1.    1.    1.    1.    1.    4.
    4.    1.    1.    1.    1.    1.    0.    0.    0.    1.    3.    2.
    1.    0.    1.    0.    1.    1.    0.    0.    1.    2.    2.    1.
    0.    1.    0.    1.    0.  204. 2284. 8462.14682.11957. 4756. 1684.
 1617. 3240. 6915.11756.12797. 7182. 1604.   78.   12.    8.    6.    5.
    8.    5.    6.    3.    6.    4.    1.    1.    3.    2.    4.    1.
    2.    2.    5.    1.    3.    1.    1.    0.    3.    2.    5.    1.
    0.    2.    1.    2.    1.    0.    0.    2.    2.    0.    2.    2.
    0.    0.    1.    1.    0.    0.    0.    0.    3.  170. 1611. 6351.
13151.13642. 7468. 2471. 1032. 1265. 2571. 5353. 9709.12399. 9192. 2858.
```

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  385.   34.    6.    8.    8.    5.    3.    6.    4.    2.    3.    1.
    4.    3.    6.    4.    4.    3.    2.    0.    5.    1.    0.    1.
    1.    0.    1.    4.    1.    1.    2.    0.    1.    0.    1.    1.
    0.    2.    2.    2.    1.    1.    2.    0.    1.    0.    0.    0.
    0.  162.  1242.  4639.10767.14106.10582.  4664.  1450.  763.  1019.  1920.
 3955.  7541.10897.10395.  5347.  1100.   84.   16.    6.    3.    5.    2.
    1.    7.    2.    2.    1.    3.    2.    2.    2.    0.    1.    0.
    1.    4.    4.    1.    2.    3.    1.    2.    1.    3.    1.    2.
    0.    3.    2.    0.    1.    1.    2.    2.    0.    0.    1.    2.
    0.    1.    0.    3.    0.  139.  1004.  3343.  8326.12947.12612.  7462.
 3074.   997.   567.   759.  1362.  2742.  5370.  9397.10714.  7870.  2998.   512.
   56.    18.    7.    6.    2.    3.    2.    4.    2.    3.    1.    1.
    4.    3.    2.    2.    0.    1.    2.    1.    0.    1.    1.    0.
    2.    2.    4.    3.    0.    0.    1.    2.    2.    2.    1.    0.
    1.    1.    1.    0.    1.    2.    3.    1.    0.  129.  735.  2431.
 6229.10976.13010.10408.  5645.  2248.   789.   486.   550.   916.  1847.  3613.
 6442.  9753.  9688.  6302.  2490.   460.    57.    21.    7.    8.    5.    6.
    4.    4.    1.    5.    5.    2.    4.    4.    1.    2.    2.    3.
    1.    1.    1.    1.    1.    1.    3.    3.    0.    1.    1.    2.
    0.    1.    0.    1.    0.    1.    1.    4.    2.    0.    0.    0.
    2.  101.   556.  1693.  4412.  8671.12129.12226.  8945.  4796.  1932.   726.
  404.  376.   635.  1069.  2165.  4191.  7362.  9788.  9771.  6370.  2398.   466.
   70.   16.     9.     6.     8.     7.     4.     1.     4.     4.     2.     2.
    2.    2.    1.    1.    2.    1.    1.    4.    5.    0.    0.    3.
    1.    0.    0.    2.    0.    1.    1.    0.    2.    1.    0.    2.
    2.    2.    0.    2.    1.   88.   465.  1161.  3009.  6358.  9978.12005.
11478.  8065.  4437.  1983.   778.   325.   294.   419.   688.  1273.  2282.  4566.
 7253.  9589.  9737.  6526.  2790.   809.   142.    23.    14.    3.    2.    3.
    0.    4.    1.    3.    1.    1.    3.    1.    2.    3.    0.    1.
    2.    0.    1.    1.    0.    1.    0.    1.    1.    3.    1.    0.
    1.    0.    1.    1.    4.    2.    0.    0.    0.   93.   364.   792.
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    1.    1.    3.    3.    0.    0.    3.    2.    1.    1.    1.    0.
    0.    1.    0.    2.    2.    2.    5.    1.    1.    0.    1.    1.
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    6.    3.    0.    1.    3.    2.    4.    2.    0.    2.    3.    3.
    2.    3.    1.    3.    1.    2.    1.    4.    2.    1.    2.    0.
    1.    1.    0.    1.    1.   72.   265.   417.   857.  1755.  3442.  5826.
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    5.    3.    3.    1.    0.    0.    2.    2.    2.    0.    1.    4.
    1.    0.    2.    2.    1.    1.    0.    1.    1.   78.   207.   280.
  608.  1161.  2058.  3691.  5728.  7847.  9889.10800.10891.  9384.  6920.  4641.
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    3.    5.    2.    0.    2.    1.    1.    1.    0.    0.    2.    2.
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    3.    2.    0.    0.    1.   73.   173.   194.   261.   455.   760.  1238.
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```

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11.	11.	8.	20.	9.	11.	12.	16.	11.	7.	6.	15.
10.	15.	14.	17.	14.	17.	18.	20.	19.	33.	45.	41.
56.	56.	45.	76.	73.	90.	86.	117.	159.	170.	187.	234.
246.	287.	328.	359.	458.	485.	541.	566.	0.	18.	41.	24.
19.	15.	12.	16.	16.	11.	11.	12.	8.	5.	10.	8.
3.	10.	8.	8.	6.	6.	6.	7.	8.	6.	9.	8.
6.	3.	8.	5.	9.	7.	8.	4.	11.	9.	9.	5.
5.	7.	8.	7.	8.	9.	9.	12.	6.	13.	17.	18.
23.	28.	23.	36.	52.	47.	50.	57.	63.	76.	98.	92.
0.	17.	28.	16.	21.	11.	8.	10.	6.	10.	6.	12.
9.	8.	5.	7.	7.	5.	6.	3.	8.	5.	4.	7.
9.	7.	4.	4.	6.	6.	4.	3.	5.	2.	4.	4.
3.	2.	3.	3.	6.	3.	4.	2.	5.	8.	4.	5.
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8.	10.	12.	11.	0.	9.	24.	17.	13.	14.	15.	10.
6.	7.	7.	6.	5.	7.	7.	10.	5.	9.	5.	3.
5.	6.	3.	6.	4.	8.	7.	5.	7.	5.	4.	6.
5.	4.	3.	3.	5.	2.	9.	2.	2.	6.	6.	4.
5.	3.	1.	3.	5.	2.	8.	5.	3.	3.	1.	3.
2.	2.	5.	4.	3.	3.	5.	2.	0.	13.	17.	26.
14.	18.	15.	11.	9.	8.	8.	5.	9.	7.	5.	5.
7.	5.	2.	3.	5.	6.	10.	5.	8.	9.	4.	5.
4.	1.	4.	4.	10.	6.	4.	4.	7.	3.	3.	6.
3.	6.	0.	2.	3.	3.	4.	2.	4.	2.	5.	3.
4.	4.	3.	2.	0.	2.	1.	1.	5.	0.	3.	1.
1.	17.	16.	14.	13.	6.	7.	20.	8.	10.	6.	5.
5.	8.	8.	4.	3.	3.	3.	3.	1.	4.	7.	3.
2.	4.	5.	4.	6.	4.	1.	11.	2.	3.	1.	5.
3.	2.	3.	4.	3.	5.	4.	3.	3.	2.	3.	5.
2.	3.	6.	2.	4.	1.	1.	2.	2.	3.	2.	4.
1.	2.	0.	2.	0.	16.	19.	15.	10.	17.	12.	13.
10.	6.	5.	5.	11.	10.	6.	5.	8.	6.	6.	4.
3.	5.	7.	3.	4.	4.	5.	5.	1.	0.	2.	6.
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1.	2.	5.	1.	2.	4.	2.	4.	1.	1.	2.	1.
3.	1.	4.	2.	2.	1.	0.	3.	0.	17.	19.	20.
18.	13.	5.	11.	4.	10.	6.	4.	5.	8.	3.	5.
3.	5.	4.	6.	7.	4.	4.	2.	3.	6.	2.	6.
2.	5.	3.	1.	5.	5.	6.	2.	1.	2.	1.	6.
2.	4.	1.	0.	2.	3.	2.	1.	2.	5.	0.	2.
2.	1.	0.	2.	5.	3.	5.	5.	4.	2.	0.	3.
0.	11.	16.	14.	11.	16.	8.	13.	8.	11.	7.	5.
1.	6.	4.	4.	4.	0.	1.	4.	3.	11.	5.	6.
4.	5.	0.	2.	4.	0.	1.	1.	2.	4.	2.	2.
3.	3.	3.	1.	2.	4.	1.	0.	2.	3.	2.	2.
5.	1.	2.	1.	1.	0.	3.	3.	1.	0.	3.	1.
1.	2.	1.	2.								

DISCRIM Output

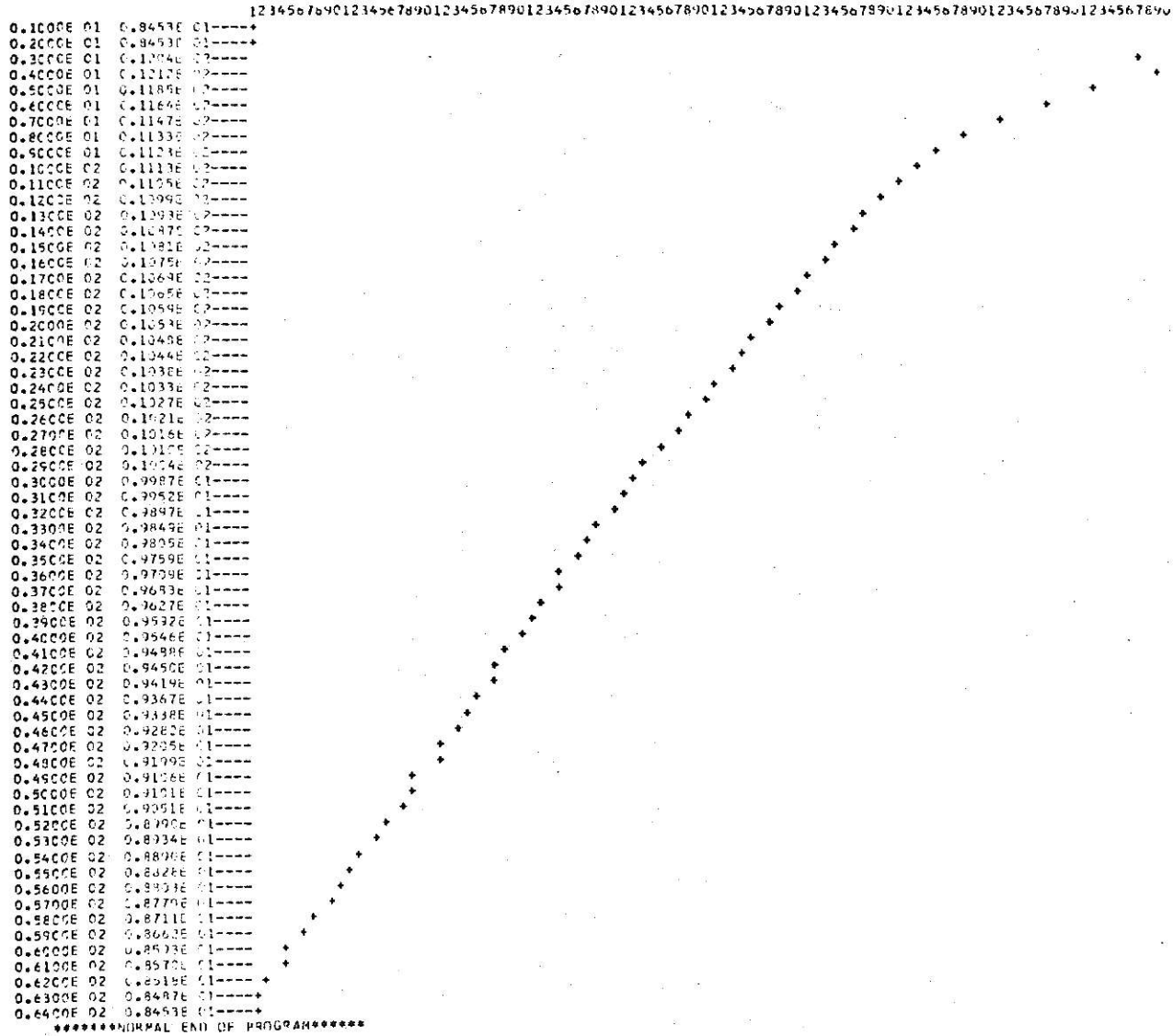
3 HG PUBE PGD 4-13-71 (500/200)

CHANNEL	NEUTRONS	CENTER CHANNEL OF PEAK	FWHM	GAMMAS	CENTER CHANNEL OF PEAK	FWHM	ITERATIONS
1	0.	0		0.	0		
2	0.	0		0.	0		
3	169457.	21.69	8.52	564921.	10.86	7.89	2
4	183129.	26.86	10.00	327295.	16.67	4.99	2
5	140680.	31.01	8.75	288070.	20.60	4.17	2
6	113737.	33.90	7.70	236934.	23.34	3.72	2
7	95684.	36.04	6.94	154128.	25.46	3.46	2
8	83374.	37.69	6.43	96960.	27.19	3.33	2
9	75240.	39.05	5.91	67975.	28.57	3.15	2
10	68263.	40.14	5.60	53219.	29.66	3.12	2
11	63139.	41.07	5.34	43334.	30.78	2.91	1
12	59357.	41.84	5.13	40878.	31.53	3.04	2
13	55631.	42.51	4.87	36699.	32.40	2.94	2
14	52455.	43.15	4.76	32444.	33.20	2.64	1
15	49451.	43.84	4.59	30633.	33.92	2.69	1
16	46726.	44.37	4.44	31853.	34.43	2.92	2
17	44051.	44.94	4.20	26520.	35.24	2.53	1
18	42071.	45.49	4.18	26096.	35.93	2.54	1
19	39885.	45.93	4.30	25960.	36.29	2.57	1
20	37517.	46.38	3.96	23895.	37.02	2.43	1
21	35719.	46.80	3.83	24910.	37.50	2.85	
22	34326.	47.17	3.70	23538.	37.98	2.60	
23	32256.	47.51	3.60	24025.	38.47	2.79	
24	30575.	47.88	3.63	22558.	38.91	2.56	
25	28865.	48.23	3.51	22081.	39.31	2.86	
26	27277.	48.51	3.36	18998.	39.71	2.58	
27	25879.	48.79	3.30	17236.	40.10	2.43	
28	24249.	49.09	3.28	15346.	40.48	2.26	
29	22952.	49.42	3.25	14624.	40.77	2.50	
30	21736.	49.71	3.15	12656.	41.08	2.29	
31	20995.	50		10858.	41		
32	19861.	50		9866.	42		
33	18945.	50		9527.	42		
34	18117.	50		8874.	42		
35	17314.	51		8694.	43		
36	16472.	51		8628.	43		
37	16035.	51		8512.	43		
38	15173.	51		8165.	43		
39	14650.	51		8078.	43		
40	13990.	51		7808.	44		
41	13204.	52		7646.	44		
42	12710.	52		7362.	44		
43	12322.	52		7324.	44		
44	11695.	52		7159.	44		
45	11357.	52		7014.	45		
46	10743.	52		7007.	45		
47	9943.	52		6943.	45		
48	9892.	53		6651.	45		
49	9010.	53		6510.	45		
50	8962.	53		6481.	46		
51	8525.	53		6296.	46		
52	8029.	53		6260.	46		
53	7568.	53		6160.	46		
54	7259.	53		5910.	46		
55	6825.	53		5827.	46		
56	6657.	54		5812.	46		
57	6436.	54		5709.	47		
58	6072.	54		5598.	47		
59	5777.	54		5439.	47		
60	5396.	54		5493.	47		
61	5273.	54		5444.	47		
62	5004.	54		5244.	47		
63	4851.	54		5249.	47		
64	4687.	54		5126.	48		

SEMILOG PLOT OF CALCULATED NEUTRON PULSE HEIGHT SPECTRA

3 HG PUBE FGD 4-11-71 (500/200)

THE SCALE OF THIS GRAPH IS 1 DIVISION = 0.36654E-01UNITS



*******NORMAL END OF PROGRAM*******

B-2.0 Data Binning Code, DATABIN

This special purpose code is used to combine the high and low gain pulse height spectra from the DISCRIM code into a single set of data with the same gain. Since the high gain data has a gain 2.5 times greater than the low gain data, the code "stretches" the low gain data by a factor of 2.5. The high gain and stretched low gain data are then combined into a single set of data of 160 channels by replacing the first 64 channels of data in the stretched low gain data by the high gain data.

In this work, the normal 1024 channel range of the analyzer is reduced by a factor of 16 to just 64 channels by altering the format selector on the analyzer. In order to make the data from the TAC spectrometer applicable to analysis by existing computer codes, the DATABIN code is also used to further "stretch" the combined spectrum to the required 1024 channels (a "stretch factor" of $6.4 = \frac{1024}{160}$). In general, the DATABIN code can be used to "stretch" or "bin" the original data into a new spectrum which has from 1 to 2500 channels.

B-2.1 DATABIN Input Data Format

Card	Format	Variable and Description
1	1X,F4.0,40H	1. STOP = 0 if this is a data set.
		= 1 if no more data is to be read in; i.e., put a card with a 1 in column 5 behind the last set of data to terminate the program.
		2. LABEL = An arbritrary alphanumeric label to identify the data.
2	3F10.0	1. GCHIN = Channel where Co-60 tail falls in high gain input data.
		2. GCHOUT = Channel where Co-60 tail is to be shifted to in the output data; i.e., data is shifted by a factor of GCHOUT/GCHIN.
		3. BKG = 0 if background is not be be subtracted.
		= 1 if background is to be subtracted.
3	4F10.0	1. SF1 = Relative fluence for high gain foreground data.
		2. SF2 = Relative fluence for low gain foreground data.
		3. SF3 = Relative fluence for high gain Background data, if any.
		4.SF4 = Relative fluence for low gain background data, if any.

4 (Deck)	1X, 10F7.0		High gain foreground data (64 channels)
5 (Deck)	1X,10F7.0		Low gain foreground data (64 channels)
6 (Deck)	1X,10F7.0		High gain background data, if any.
7 (Deck)	1X,10F7.0		Low gain background data, if any.
8 (Deck)	----		Other data sets, if any (cards 1-7)
9	1X,F4.0	1. STOP	= 1 Put a card with a 1 in column 2-5 as described in card 1 to stop the program after the last data set.

B-2.2 DATABIN Code Listing

```
$JOB            RES
C      PUT DATA IN THIS FORM.......
C
C         1) ALPHANUMERIC TITLE IN COLUMNS 5 - 50. COLUMNS 1 - 5 MUST BE BLANK.
C         2) GCHIN, GCHOUT, BKG (3F10.0)
C         3) SF1,SF2,SF3,SF4  (4F10.0)
C         4) HIGH GAIN FOREGROUND DATA (64 CHANNELS IN 6X,12F6.0 FORMAT)
C         5) LOW GAIN FOREGROUND DATA  (64 CHANNELS IN 6X,12F6.0 FORMAT)
C         6) HIGH GAIN BACKGROUND DATA IF ANY.
C         7) LOW GAIN BACKGROUND DATA IF ANY.
C
C         8) ANY OTHER DATA SETS (EACH DATA SET SAME AS 1 - 7)
C
C         9) PUT A CARD WITH A NONZERO DIGIT IN COL 2 - 5 BEHIND ALL THE DATA
C              TO STOP THE PROGRAM.
C
C
C      "GCHIN" IS THE CHANNEL WHERE THE HIGH GAIN CO-60 TAIL LIES.
C      "GCHOUT" IS THE CHANNEL WHERE THE CO-60 TAIL IS TO BE SHIFTED TO.  (I.E.
C               THE DATA IS STRETCHED OR COMPRESSED)
C      "BKG" IS A CODE TO INDICATE IF BACKGROUND DATA IS TO BE SUBTRACTED FROM
C               THE FOREGROUND DATA. (MAKE NONZERO IF BKG IS TO BE SUBTRACTED)
C      "SF1,SF2,SF3, AND SF4" ARE THE RELATIVE INTEGRATED FLUXES FOR THE
C               HIGH GAIN FOREGROUND, LOW GAIN FOREGROUND, HIGH GAIN BKG, AND
C               LOW GAIN BKG RESPECTIVELY.
C
C
 1          DIMENSION XFL(64),XFH(64),XBL(64),XBH(64),XT(2500),XL(64),XH(64)
 2          INTEGER STOP
 3        1 READ 52,STOP
 4          IF(STOP.GT.0) GO TO 20
 5          PRINT 57
 6          PRINT 52,STOP
 7          PRINT 55
 8          READ 50,GCHIN,GCHOUT,BKG
 9          IF(GCHOUT.EQ.0) GCHOUT = GCHIN
10          READ 50,SF1,SF2,SF3,SF4
11          READ 51,XFH
12          READ 51,XFL
13          PRINT 55
14          PRINT 59
15          PRINT 55
16          PRINT 51,XFH
17          PRINT 55
18          PRINT 51,XFL
19          IF(BKG.EQ.0.) GO TO 3
20          READ 51,XBH
21          READ 51,XBL
22          PRINT 55
23          PRINT 55
24          PRINT 60
25          PRINT 55
26          PRINT 51,XBH
27          PRINT 55
28          PRINT 51,XBL
29          DO 2 I=1,64
30          XH(I)= (XFH(I)/SF1) - (XBH(I)/SF3)
31        2 XL(I)=(XFL(I)/SF2) - (XBL(I)/SF4)
32          GO TO 5
33        3 DO 4 I=1,64
```

```
      XH(I)= XFH(I)/SF1
    4 XL(I)= XFL(I)/SF2
    5 SF=GCHOUT/GCHIN
      NCHOUT= SF*2.5*64.
      DO 10 I=1,NCHOUT
      XI=I
      XU=XI/SF  + 1.0
      XLO=XL - (1.0/SF)
      JL=XLO
      JU=XU
      IF(JL.LT.1) JL=1
      IF(JU.GT.64) GO TO 6
      CALL BINHI(XH,XU,XLO,JU,JL,XT(I))
      GO TO 7
    6 CALL BINLO(XL,XU,XLO,JU,JL,XT(I))
    7 IF(XT(I).LT.1.E5) GO TO 10
      XT(I)=XT(I) - 1.E5
      GO TO 7
   10 CONTINUE
      PRINT 55
      PRINT 55
      PRINT 61
      PRINT 55
      PRINT 53,NCHOUT,GCHIN,GCHOUT
      PRINT 55
      PRINT 58,(XT(I), I=1,NCHOUT)
      PUNCH 54
      PUNCH 55
      PUNCH 56,NCHOUT,GCHOUT
      PUNCH 52,STOP
      PUNCH 58,(XT(I), I=1,NCHOUT)
      PUNCH 55
      GO TO 1
   20 STOP
   50 FORMAT(7F10.3)
   51 FORMAT(1X,10F7.0)
   52 FORMAT(1X,I4,'                                                                ')
   53 FORMAT(1X,I10,' CHANNELS OF DATA WITH GAMMA TAIL SHIFTED FROM CHAN
     1NEL',F9.3,' TO CHANNEL',F9.3)
   54 FORMAT(1X,'AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA')
   55 FORMAT(1H )
   56 FORMAT(1X,I4,F10.3,2X,3H1.0)
   57 FORMAT(1H1)
   58 FORMAT(6X,12F6.0)
   59 FORMAT(1X,'UNSHIFTED HIGH THEN LOW GAIN FOREGROUND DATA')
   60 FORMAT(1H ,'UNSHIFTED HIGH THEN LOW GAIN BACKGROUND DATA')
   61 FORMAT(1X,'SHIFTED NET COUNTS')
      END

      SUBROUTINE BINHI(XH,XU,XL,JU,JL,XT)
      DIMENSION XH(64)
      XT=0.0
      J=JL
      IF(JU.NE.JL) GO TO 1
      XT= (XU - XL) * XH(JL)
      RETURN
    1 J=J+1
      X2=J
      F=X2 - XL
      XT=F*XH(J-1)
```

```
 92       10 IF(J.EQ.JU) GO TO 3
 93          XT=XT+XH(J)
 94          J=J+1
 95          GO TO 10
 96        3 X=JU
 97          XT=XT + (XU-X)*XH(JU)
 98          RETURN
 99          END

1CC          SUBROUTINE BINLO(XL,XU,XLO,JL,JL,XT)
1C1          DIMENSION XL(64)
1C2          XU=XU*C.4
1C3          XLO=XLC*0.4
1C4          JUP=XL
1C5          JLO=XLC
1C6          CALL BINHI(XL,XU,XLO,JUP,JLO,XT)
1C7          RETURN
1C8          END

      $ENTRY
```

B-2.3 Sample Data Set and Results

DATABIN Input Data Set

```
1634. 1634. 1634. 1634. 1605. 1488. 1486. 1488. 1488. 1488. 1488. 1329.
1289. 1289. 1289. 1289. 1289. 1188. 1035. 1035. 1035. 1035. 1035. 1035.
 735.  735.  735.  735.  735.  735.  555.  434.  434.  434.  434.  434.
 400.  265.  265.  265.  265.  265.  265.  195.  178.  178.  178.  178.
 178.  169.  155.  155.  155.  155.  155.  155.  126.  126.  126.  126.
 126.  126.  109.   99.   99.   99.   99.   99.   98.   96.   96.   96.
  96.   96.   96.   88.   86.   86.   86.   86.   86.   85.   85.   85.
  85.   85.   85.   85.   79.   79.   79.   79.   79.   79.   75.   72.
  72.   72.   72.   72.   69.   55.   55.   55.   55.   55.   55.   57.
  58.   58.   58.   58.   58.   60.   64.   64.   64.   64.   64.   64.
  62.   62.   62.   62.   62.   62.   64.   65.   65.   65.   65.   65.
  64.   58.   58.   58.   58.   58.   58.   54.   53.   53.   53.   53.
  53.   55.   58.   58.   58.   58.   58.   58.   56.   56.   56.   56.
  56.   56.   62.   66.   66.   66.   66.   66.   65.   61.   61.   61.
  61.   61.   61.   63.   64.   64.   64.   64.   64.   64.   64.   64.
  64.   64.   64.   64.   56.   56.   56.   56.   56.   56.   60.   63.
  63.   63.   63.   63.   63.   61.   61.   61.   61.   61.   61.   58.
  57.   57.   57.   57.   57.   61.   67.   67.   67.   67.   67.   67.
  57.   57.   57.   57.   57.   57.   64.   70.   70.   70.   70.   70.
  67.   59.   59.   59.   59.   59.   59.   69.   71.   71.   71.   71.
  71.   58.   61.   61.   61.   61.   61.   61.   61.   61.   61.   61.
  61.   61.   61.   61.   61.   57.   52.   52.   52.   52.   52.   52.
  52.   52.   52.   52.   52.   52.   52.   52.   52.   54.   58.   58.
  58.   58.   58.   58.   58.   58.   58.   58.   58.   58.   58.   58.
  58.   56.   53.   53.   53.   53.   53.   53.   53.   53.   53.   53.
  53.   53.   53.   53.   53.   54.   56.   56.   56.   56.   56.   56.
  56.   56.   56.   56.   56.   56.   56.   56.   56.   54.   52.   52.
  52.   52.   52.   52.   52.   52.   52.   52.   52.   52.   52.   52.
  52.   53.   54.   54.   54.   54.   54.   54.   54.   54.   54.   54.
  54.   54.   54.   54.   54.   52.   50.   50.   50.   50.   50.   50.
  50.   50.   50.   50.   50.   50.   50.   50.   50.   48.   46.   46.
  46.   46.   46.   46.   46.   46.   46.   46.   46.   46.   46.   46.
  46.   45.   43.   43.   43.   43.   43.   43.   43.   43.   43.   43.
  43.   43.   43.   43.   43.   44.   45.   45.   45.   45.   45.   45.
  45.   45.   45.   45.   45.   45.   45.   45.   45.   41.   33.   33.
  33.   33.   33.   33.   33.   33.   33.   33.   33.   33.   33.   33.
  33.   35.   38.   38.   38.   38.   38.   38.   38.   38.   38.   38.
  38.   38.   38.   38.   38.   38.   39.   39.   39.   39.   39.   39.
  39.   39.   39.   39.   39.   39.   39.   39.   39.   36.   32.   32.
  32.   32.   32.   32.   32.   32.   32.   32.   32.   32.   32.   32.
  32.   29.   26.   26.   26.   26.   26.   26.   26.   26.   26.   26.
  26.   26.   26.   26.   26.   26.   26.   26.   26.   26.   26.   26.
  26.   26.   26.   26.   26.   26.   26.   26.   26.   27.   28.   28.
  28.   28.   28.   28.   28.   28.   28.   28.   28.   28.   28.   28.
  28.   27.   25.   25.   25.   25.   25.   25.   25.   25.   25.   25.
  25.   25.   25.   25.   25.   24.   23.   23.   23.   23.   23.   23.
  23.   23.   23.   23.   23.   23.   23.   23.   23.   22.   21.   21.
  21.   21.   21.   21.   21.   21.   21.   21.   21.   21.   21.   21.
  21.   21.   22.   22.   22.   22.   22.   22.   22.   22.   22.   22.
  22.   22.   22.   22.   22.   21.   18.   18.   18.   18.   18.   18.
  18.   18.   18.   18.   18.   18.   18.   18.   18.   17.   17.   17.
  17.   17.   17.   17.   17.   17.   17.   17.   17.   17.   17.   17.
  17.   16.   14.   14.   14.   14.   14.   14.   14.   14.   14.   14.
  14.   14.   14.   14.   14.   13.   12.   12.   12.   12.   12.   12.
  12.   12.   12.   12.   12.   12.   12.   12.   12.   11.   10.   10.
  10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
  10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.   10.
  10.   10.   10.   10.   10.    8.    5.    5.    5.    5.    5.    5.
   5.    5.    5.    5.    5.    5.    6.    7.    7.
   7.    7.    7.    7.    7.    7.    7.    7.    7.    7.    7.    7.
   7.    6.    5.    5.    5.    5.    5.    5.    5.    5.    5.    5.
   5.    5.    5.    5.    5.    5.    5.    5.    5.    5.    5.    5.
   5.    5.    5.    5.    5.    5.    5.    5.    5.    5.    4.    4.
   4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
   4.    4.    3.    3.    3.    3.    3.    3.    3.    3.    3.    3.
   3.    3.    3.    3.    3.    4.    5.    5.    5.    5.    5.    5.
   5.    5.    5.    5.    5.    5.    5.    5.    5.    4.    3.    3.
   3.    3.    3.    3.    3.    3.    3.    3.    3.    3.    3.    3.
   3.    2.    2.    2.    2.    2.    2.    2.    2.    2.    2.    2.
   2.    2.    2.    2.    2.    3.    3.    3.    3.    3.    3.    3.
   3.    3.    3.    3.    3.    3.    3.    3.    3.    4.    4.    4.
   4.    4.    4.
```

DATABIN Output

0 0-2 PENETRATION DATA 4-6-71

UNSHIFTED HIGH THEN LOW GAIN FOREGROUND DATA

```
    0.     0.     0. 97001. 94522. 81219. 65379. 49695. 42315. 38289.
36482. 33011. 30782. 29140. 27312. 26484. 25849. 25223. 24937. 23694.
22810. 21413. 19621. 18245. 17103. 15705. 14603. 13323. 11768.  9736.
 7544.  5341.  4016.  3235.  2920.  2582.  2353.  2101.  1925.  1800.
 1678.  1517.  1411.  1283.  1258.  1177.  1205.  1095.  1041.  1026.
 1013.  1000.   988.   930.   929.   897.   855.   888.   827.   844.
  799.   809.   771.   805.

    0.     0.133212. 97566. 94913. 83818. 74366. 64530. 56627. 47582.
38757. 29031. 15574.  8163.  6152.  4835.  3829.  3202.  2888.  2519.
 2366.  2284.  2124.  2036.  1908.  1874.  1698.  1660.  1531.  1528.
 1391.  1399.  1262.  1121.  1015.   999.   847.   856.   861.   721.
  614.   595.   601.   526.   487.   452.   460.   369.   345.   299.
  277.   232.   211.   149.   169.   134.   120.    93.    92.    96.
   79.    58.    74.    76.
```

UNSHIFTED HIGH THEN LOW GAIN BACKGROUND DATA

```
    0.     0.     0. 85138. 75382. 61004. 50847. 35265. 28534. 24079.
21603. 19344. 16980. 14674. 12485. 11026. 10490.  9386.  8376.  7506.
 6884.  6162.  5604.  5146.  4892.  4221.  3878.  3551.  3287.  2911.
 2656.  2395.  2170.  1960.  1804.  1662.  1610.  1390.  1286.  1176.
 1097.   986.   993.   855.   791.   728.   737.   679.   655.   610.
  611.   543.   559.   488.   483.   504.   420.   464.   432.   387.
  407.   340.   367.   328.

    0.     0.106548. 77701. 71638. 61744. 38754. 33802. 25597. 26160.
12499.  9978.  7801.  5881.  4720.  3867.  3000.  2558.  2229.  1929.
 1653.  1548.  1312.  1258.  1100.   986.   951.   813.   761.   708.
  619.   600.   522.   438.   372.   319.   351.   290.   269.   249.
  228.   212.   177.   155.   142.   141.   125.    97.    95.    87.
  102.    86.    56.    70.    63.    58.    42.    40.    41.    26.
   39.    27.    22.    21.
```

SHIFTED NET COUNTS

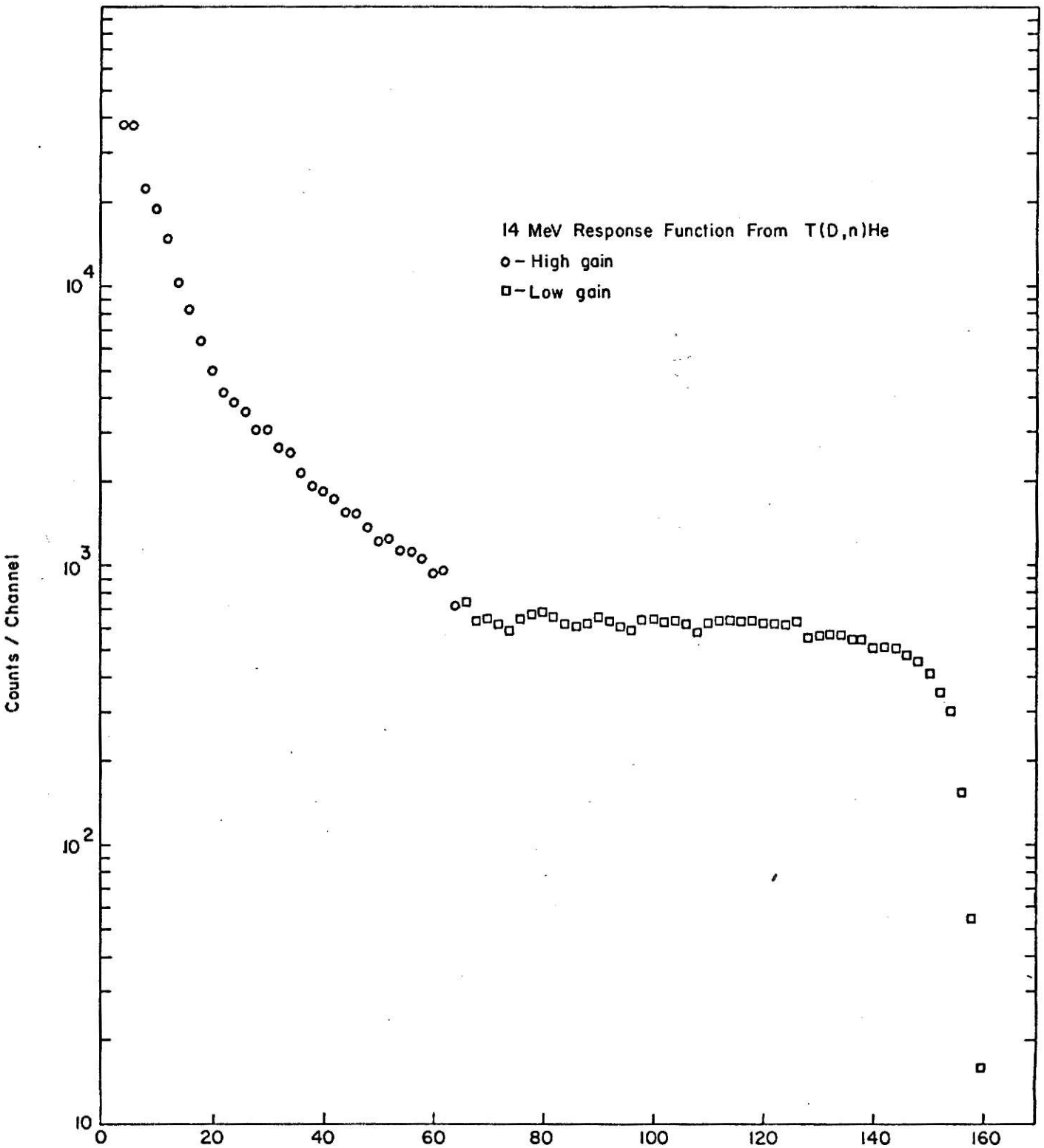
1023 CHANNELS OF DATA WITH GAMMA TAIL SHIFTED FROM CHANNEL 31.250 TO CHANNEL 200.000

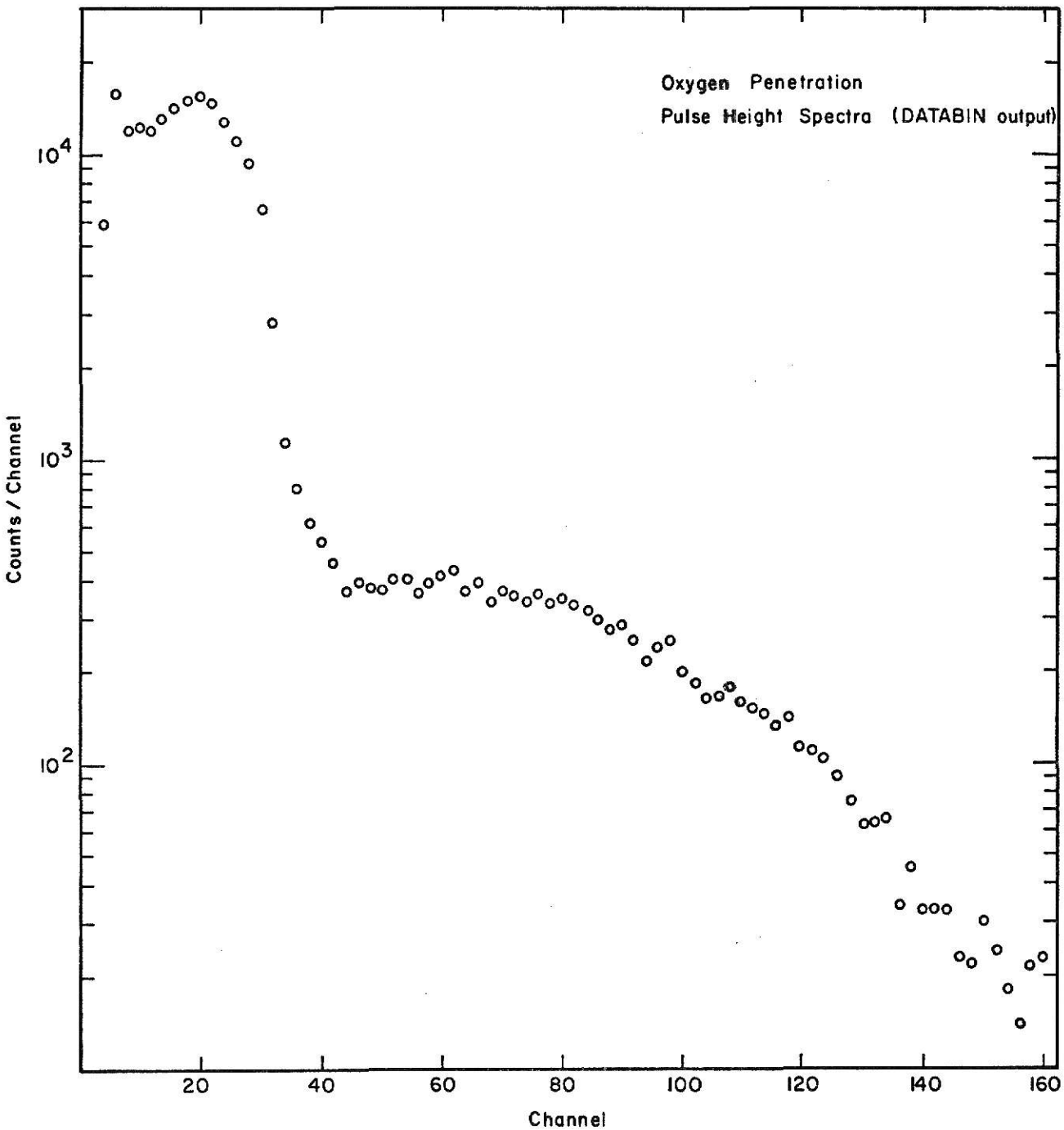
```
   0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
   0.    0.    0.    0.    0.    0.    0.  743.  929.  929.  929.  929.
 929. 1426. 2172. 2172. 2172. 2172. 2172. 2172. 2496. 2496. 2496. 2496.
2496. 2496. 2029. 1718. 1718. 1718. 1718. 1718. 1749. 1872. 1872. 1872.
1872. 1872. 1872. 1974. 2000. 2000. 2000. 2000. 2000. 1983. 1959. 1959.
1959. 1959. 1959. 1959. 2090. 2090. 2090. 2090. 2090. 2090. 1991. 1925.
1925. 1925. 1925. 1925. 1935. 1972. 1972. 1972. 1972. 1972. 1972. 2075.
2101. 2101. 2101. 2101. 2101. 2133. 2181. 2181. 2181. 2181. 2181. 2181.
2296. 2296. 2296. 2296. 2296. 2296. 2290. 2286. 2286. 2286. 2286. 2286.
2303. 2373. 2373. 2373. 2373. 2373. 2373. 2472. 2497. 2497. 2497. 2497.
2497. 2477. 2448. 2448. 2446. 2448. 2448. 2448. 2414. 2414. 2414. 2414.
2414. 2414. 2355. 2316. 2316. 2316. 2316. 2316. 2279. 2129. 2129. 2129.
2129. 2129. 2129. 2019. 1991. 1991. 1991. 1991. 1991. 1936. 1855. 1855.
1855. 1855. 1855. 1855. 1749. 1749. 1749. 1749. 1749. 1749. 1680. 1634.
```

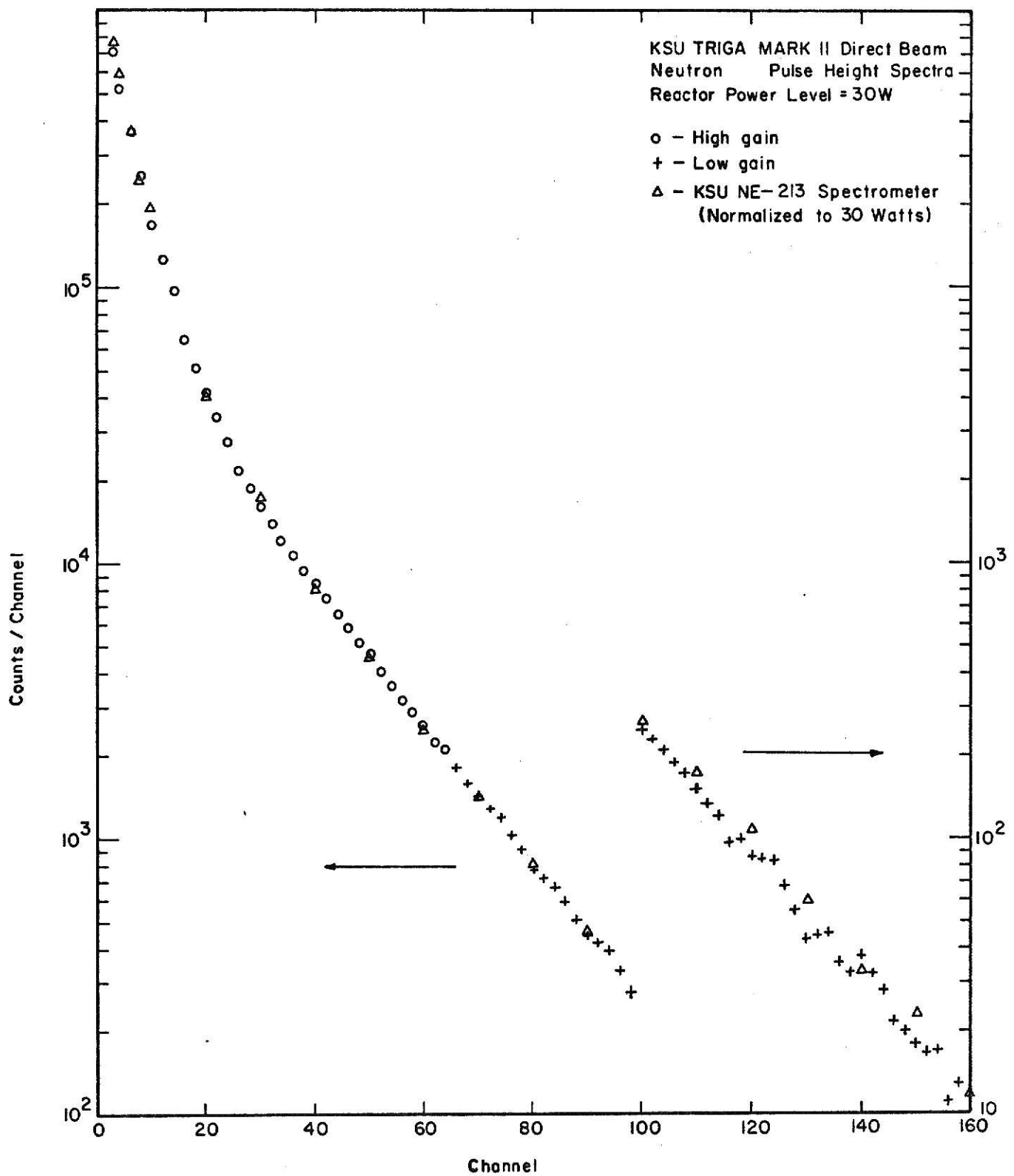
APPENDIX C

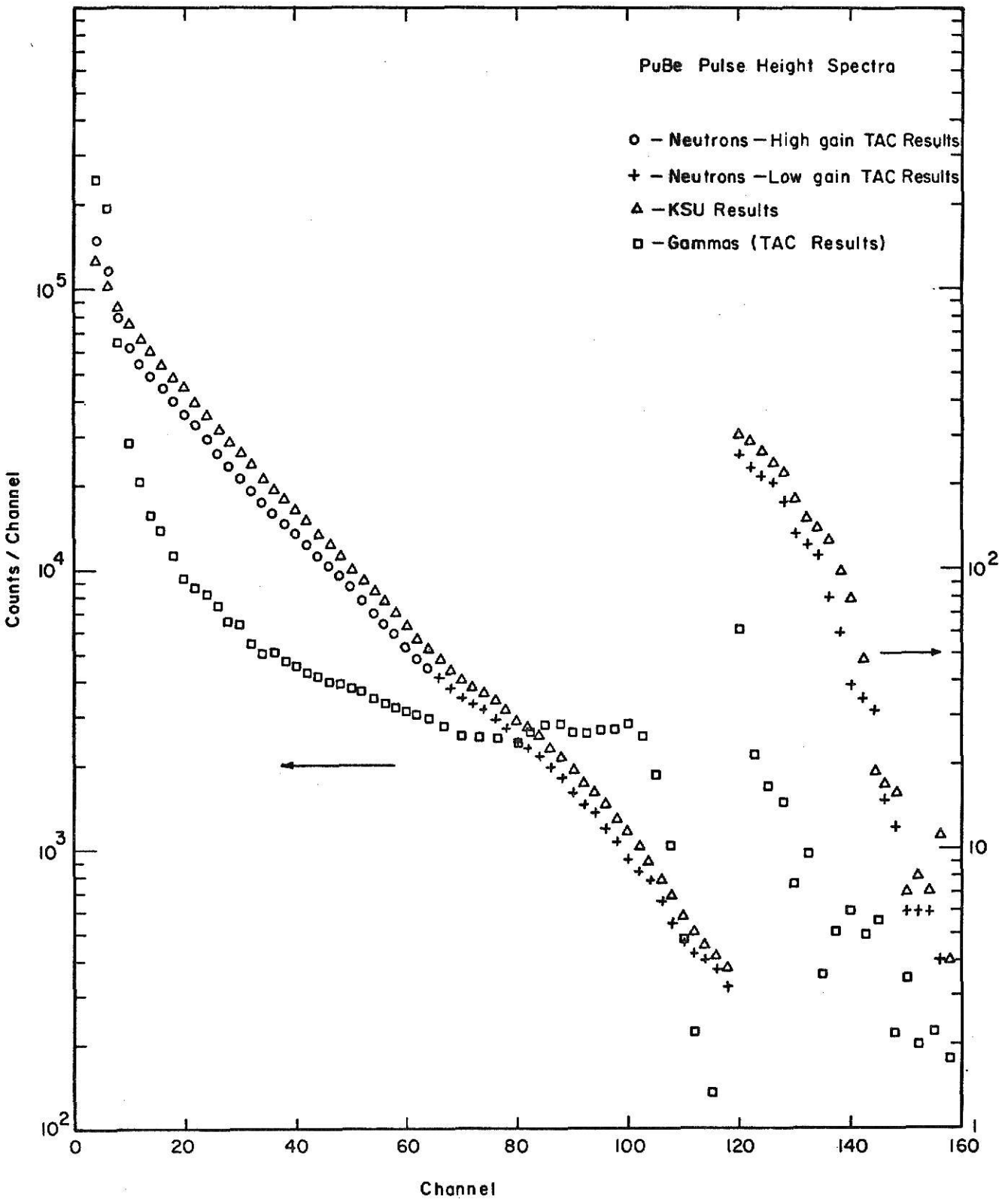
Raw Pulse Height Spectra

Presented in this section are the pulse height spectra calculated by the DISCRIM code for the neutron spectra measured in this study.


14 MeV Response Function From T(D,n)He
o – High gain
□ – Low gain
Counts / Channel
10^4
10^3
10^2
10
0
20
40
60
80
100
120
140
160


Oxygen Penetration
Pulse Height Spectra (DATABIN output)
Counts / Channel
10^4
10^3
10^2
20
40
60
80
100
120
140
160
Channel


KSU TRIGA MARK II Direct Beam
Neutron Pulse Height Spectra
Reactor Power Level = 30W
o – High gain
+ – Low gain
Δ – KSU NE–213 Spectrometer
(Normalized to 30 Watts)
Counts / Channel
Channel
10^5
10^4
10^3
10^2
10^3
10^2
10
0
20
40
60
80
100
120
140
160


PuBe Pulse Height Spectra
o – Neutrons – High gain TAC Results
+ – Neutrons – Low gain TAC Results
Δ – KSU Results
□ – Gammas (TAC Results)
Counts / Channel
Channel
10^5
10^4
10^3
10^2
10^2
10
1
0
20
40
60
80
100
120
140
160

APPENDIX D

Sample FERDOR Input Data and Results

```
DYNM    1000 10 ?1A6,I6,10F6.0,1A6<
 HIGH GAIN NET COUNTS
 REH       1  6011.  5916.  5821.  5727.  5632.  5537.  5443.  5348.  5253.  5159.  40
 REH      11  5064.  4969.  4875.  4780.  4685.  4591.  4496.  4401.  4307.  4212.  40
 REH      21  4117.  4023.  4023.  3703.  2867.  2769.  2769.  2820.  3017.  3017.  40
 REH      31  3017.  3076.  3212.  3223.  3223.  3205.  3157.  3157.  3157.  3219.  40
 REH      41  3368.  3368.  3368.  3277.  3107.  3102.  3102.  3130.  3178.  3178.  40
 REH      51  3178.  3262.  3381.  3386.  3386.  3439.  3515.  3515.  3515.  3597.  40
 REH      61  3700.  3700.  3700.  3693.  3684.  3684.  3684.  3754.  3825.  3824.  40
 REH      71  3824.  3930.  4024.  4024.  4024.  3980.  3945.  3945.  3945.  3913.  40
 REH      81  3891.  3891.  3891.  3793.  3733.  3733.  3724.  3546.  3431.  3431.  40
 REH      91  3431.  3281.  3209.  3209.  3202.  3060.  2989.  2990.  2990.  2864.  40
 REH     101  2819.  2819.  2817.  2678.  2633.  2633.  2620.  2460.  2398.  2398.  40
 RLH     111  2398.  2134.  2077.  2077.  2041.  1765.  1668.  1668.  1668.  1241.  40
 REH     121  1184.  1184.  1138.   789.   699.   699.   675.   466.   427.   427.  40
 REH     131   416.   301.   286.   286.   281.   255.   249.   249.   248.   203.  40
 REH     141   203.   203.   194.   164.   159.   159.   158.   154.   154.   154.  40
 REH     151   151.   139.   138.   138.   137.   137.   137.   137.   135.   127.  40
 REH     161   127.   127.   124.   116.   116.   116.   110.    88.    88.    88.  40
 REH     171    95.    93.    93.    93.    95.   103.   103.   103.   102.    99.  40
 REH     181    99.    99.   101.   104.   104.   104.   100.    93.    93.    93.  40
 REH     191    90.    85.    85.    85.    88.    93.    93.    93.    91.    90.  40

DYNM    2000 10 ?1A6,I6,10F6.0,1A6<
 LOW GAIN NET COUNTS
 REL       1     0. 20437. 33033. 31652. 32184. 34179. 37254. 39561. 37067. 31228.  40
 REL      11 26280. 18741.  7692.  2779.  1707.  1380.  1104.   977.   997.   898.  40
 REL      21   995.  1008.   977.   984.  1012.  1038.   896.   896.   885.   883.  40
 REL      31   861.   858.   828.   763.   710.   714.   596.   586.   623.   550.  40
 REL      41   447.   419.   442.   416.   379.   346.   350.   306.   277.   237.  40
 REL      51   200.   168.   161.    97.   106.    86.    80.    67.    51.    75.  40
 REL      61    53.    34.    46.    30.    20.    20.    10.    10.     0.     0.  40
 REL      71     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL      81     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL      91     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     101     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 RFL     111     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     121     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     131     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     141     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     151     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     161     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     171     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     181     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
 REL     191     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.  40
```

LOW + C C V > F P 4 E C O D $3

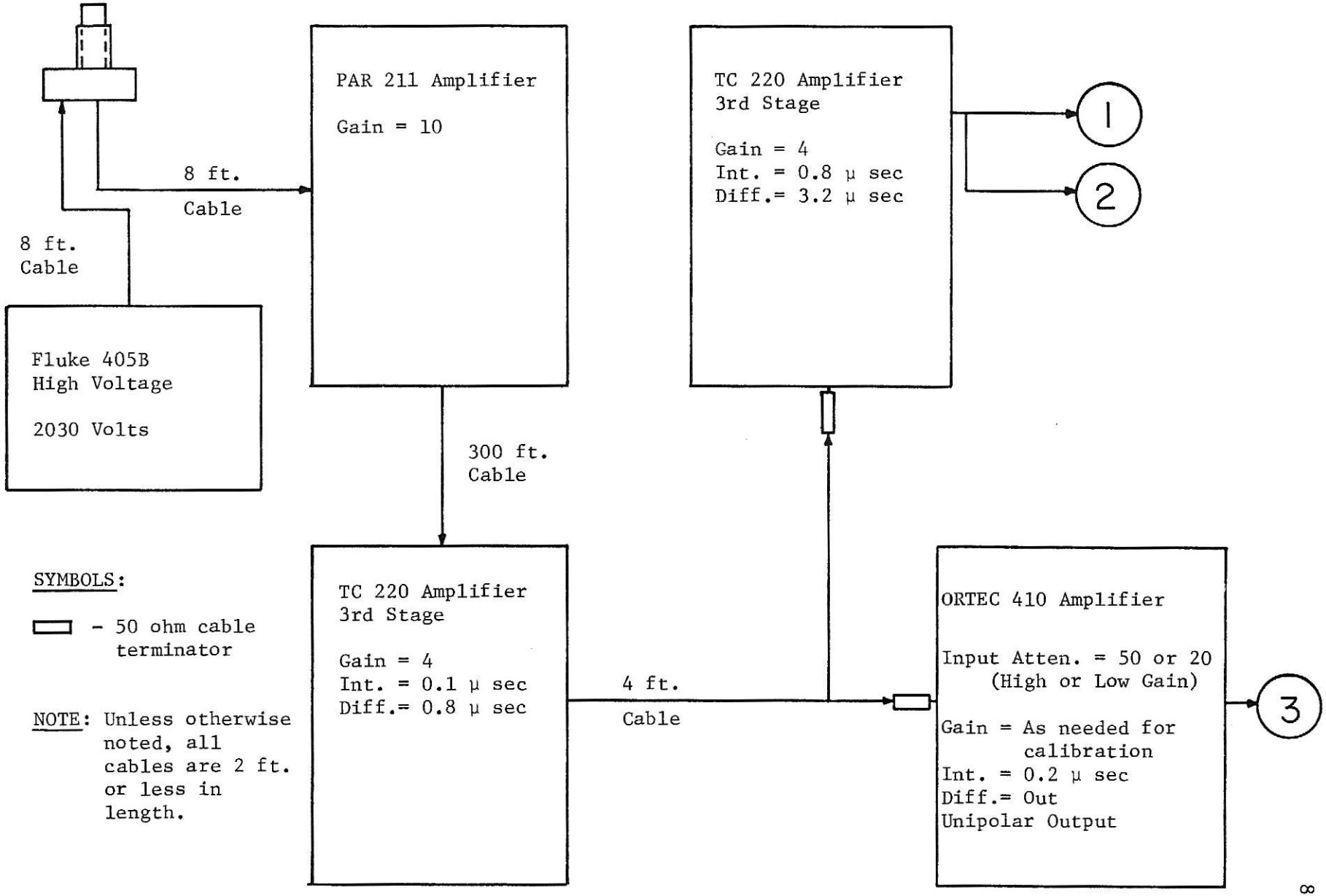
ENERGY		PLO	PUP	PAVE	RUNSUM	RUNERR	PCT %	ERR1	ERR2
0.800E 06	1	0.183E 03	0.207E 03	0.195E 03	0.0	0.795E 09	38.40	0.103E 02	0.188E 01
0.900E 06	2	0.326E 02	0.632E 02	0.509E 02	0.50876860E 07	0.847E 09	36.00	0.109E 02	0.130E 01
0.100E 07	3	-0.158E 03	-0.132E 03	-0.145E 03	-0.93334670E 07	0.916E 09	33.60	0.117E 02	0.106E 01
0.110E 07	4	-0.119E 03	-0.935E 02	-0.106E 03	-0.20023008E 08	0.977E 09	32.40	0.118E 02	0.111E 01
0.120E 07	5	-0.159E 02	0.938E 01	-0.327E 01	-0.20350320E 08	0.101E 10	31.20	0.117E 02	0.906E 00
0.130E 07	6	-0.106E 02	0.199E 02	0.467E 01	-0.19883232E 08	0.127E 10	30.00	0.142E 02	0.100E 01
0.140E 07	7	-0.941E 02	-0.533E 02	-0.737E 02	-0.27254832E 08	0.175E 10	28.80	0.187E 02	0.170E 01
0.150E 07	8	-0.218E 03	-0.175E 03	-0.197E 03	-0.46911440E 08	0.189E 10	27.60	0.203E 02	0.116E 01
0.160E 07	9	-0.334E 03	-0.289E 03	-0.311E 03	-0.78042064E 08	0.203E 10	26.40	0.219E 02	0.727E 00
0.170E 07	10	-0.350E 03	-0.283E 03	-0.306E 03	-0.10869083E 09	0.219E 10	25.80	0.226E 02	0.899E 00
0.180E 07	11	-0.181E 03	-0.133E 03	-0.157E 03	-0.12434728E 09	0.231E 10	25.20	0.227E 02	0.124E 01
0.190E 07	12	0.945E 02	0.130E 03	0.107E 03	-0.11362341E 09	0.226E 10	24.60	0.218E 02	0.936E 00
0.200E 07	13	0.476E 03	0.517E 03	0.496E 03	-0.63977328E 08	0.214E 10	24.00	0.203E 02	0.595E 00
0.210E 07	14	0.100E 04	0.104E 04	0.102E 04	0.38091728E 08	0.194E 10	23.40	0.180E 02	0.581E 00
0.220E 07	15	0.155E 04	0.159E 04	0.157E 04	0.19517592E 09	0.172E 10	22.80	0.154E 02	0.634E 00
0.230E 07	16	0.188E 04	0.191E 04	0.189E 04	0.38431283E 09	0.151E 10	22.56	0.131E 02	0.620E 00
0.240E 07	17	0.186E 04	0.188E 04	0.187E 04	0.57114522E 09	0.135E 10	21.96	0.114E 02	0.649E 00
0.250E 07	18	0.151E 04	0.153E 04	0.152E 04	0.72328627E 09	0.110E 10	21.60	0.906E 01	0.476E 00
0.260E 07	19	0.106E 04	0.107E 04	0.107E 04	0.83005338E 09	0.846E 09	21.36	0.666E 01	0.458E 00
0.270E 07	20	0.658E 03	0.668E 03	0.663E 03	0.89635405E 09	0.637E 09	20.76	0.496E 01	0.380E 00
0.280E 07	21	0.376E 03	0.384E 03	0.380E 03	0.93435750E 09	0.533E 09	20.40	0.407E 01	0.316E 00
0.290E 07	22	0.205E 03	0.213E 03	0.209E 03	0.95522944E 09	0.508E 09	20.16	0.373E 01	0.351E 00
0.300E 07	23	0.101E 03	0.109E 03	0.105E 03	0.96574618E 09	0.510E 09	19.68	0.368E 01	0.376E 00
0.310E 07	24	0.128E 02	0.204E 02	0.166E 02	0.96963517E 09	0.495E 09	19.20	0.353E 01	0.253E 00
0.320E 07	25	-0.148E 02	-0.699E 01	-0.109E 02	0.96688154E 09	0.527E 09	18.60	0.374E 01	0.179E 00
0.330E 07	26	-0.153E 02	-0.665E 01	-0.110E 02	0.96468813E 09	0.596E 09	18.00	0.413E 01	0.191E 00
0.340E 07	27	0.121E 00	0.914E 01	0.463E 01	0.96561459E 09	0.635E 09	17.40	0.430E 01	0.215E 00
0.350E 07	28	0.131E 02	0.223E 02	0.177E 02	0.96915456E 09	0.654E 09	16.80	0.444E 01	0.127E 00
0.360E 07	29	0.149E 02	0.236E 02	0.193E 02	0.97300634E 09	0.649E 09	16.56	0.426E 01	0.125E 00
0.370E 07	30	0.198E 02	0.285E 02	0.241E 02	0.97783296E 09	0.649E 09	15.96	0.421E 01	0.125E 00
0.380E 07	31	0.331E 02	0.415E 02	0.373E 02	0.98529971E 09	0.640E 09	15.60	0.408E 01	0.108E 00
0.390E 07	32	0.435E 02	0.517E 02	0.476E 02	0.99482189E 09	0.640E 09	15.36	0.395E 01	0.132E 00
0.400E 07	33	0.474E 02	0.554E 02	0.514E 02	0.10051023E 10	0.649E 09	15.12	0.390E 01	0.135E 00
0.410E 07	34	0.502E 02	0.581E 02	0.542E 02	0.10159396E 10	0.640E 09	14.64	0.386E 01	0.870E-01
0.420E 07	35	0.504E 02	0.581E 02	0.542E 02	0.10267873E 10	0.640E 09	14.40	0.383E 01	0.354E-01
0.430E 07	36	0.472E 02	0.548E 02	0.510E 02	0.10369838E 10	0.642E 09	14.28	0.369E 01	0.820E-01
0.440E 07	37	0.489E 02	0.563E 02	0.526E 02	0.10475087E 10	0.634E 09	13.92	0.358E 01	0.107E 00
0.450E 07	38	0.595E 02	0.664E 02	0.630E 02	0.10601004E 10	0.605E 09	13.80	0.333E 01	0.103E 00
0.460E 07	39	0.712E 02	0.776E 02	0.744E 02	0.10749804E 10	0.562E 09	13.44	0.310E 01	0.681E-01
0.470E 07	40	0.744E 02	0.802E 02	0.773E 02	0.10904440E 10	0.518E 09	13.20	0.284E 01	0.383E-01
0.480E 07	41	0.661E 02	0.714E 02	0.689E 02	0.11041946E 10	0.483E 09	12.96	0.260E 01	0.547E-01
0.490E 07	42	0.518E 02	0.564E 02	0.541E 02	0.11150139E 10	0.434E 09	12.84	0.226E 01	0.516E-01
0.500E 07	43	0.386E 02	0.427E 02	0.407E 02	0.11231457E 10	0.382E 09	12.60	0.200E 01	0.340E-01
0.510E 07	44	0.302E 02	0.337E 02	0.320E 02	0.11295388E 10	0.337E 09	12.36	0.175E 01	0.265E-01
0.520E 07	45	0.264E 02	0.294E 02	0.279E 02	0.11351155E 10	0.292E 09	12.24	0.149E 01	0.273E-01
0.530E 07	46	0.240E 02	0.265E 02	0.253E 02	0.11401736E 10	0.246E 09	12.12	0.122E 01	0.358E-01
0.540E 07	47	0.201E 02	0.222E 02	0.212E 02	0.11444122E 10	0.209E 09	12.00	0.102E 01	0.256E-01
0.550E 07	48	0.142E 02	0.160E 02	0.151E 02	0.11474281E 10	0.177E 09	11.76	0.869E 00	0.158E-01
0.560E 07	49	0.804E 01	0.932E 01	0.868E 01	0.11491633E 10	0.130E 09	11.64	0.619E 00	0.222E-01
0.570E 07	50	0.365E 01	0.440E 01	0.402E 01	0.11499674E 10	0.774E 08	11.52	0.355E 00	0.205E-01
0.580E 07	51	0.131E 01	0.171E 01	0.151E 01	0.11502692E 10	0.422E 08	11.40	0.188E 00	0.143E-01
0.590E 07	52	0.321E 00	0.608E 00	0.464E 00	0.11503619E 10	0.303E 08	11.28	0.134E 00	0.914E-02
0.600E 07	53	-0.170E-01	0.255E 00	0.119E 00	0.11503854E 10	0.290E 08	11.16	0.123E 00	0.631E-02
0.620E 07	54	-0.113E 00	0.164E 00	0.257E-01	0.11503905E 10	0.299E 08	11.04	0.133E 00	0.581E-02
0.940E 07	55	-0.138E 00	0.148E 00	0.485E-02	0.11503913E 10	0.312E 08	10.92	0.136E 00	0.634E-02
0.960E 07	56	-0.147E 00	0.149E 00	0.862E-03	0.11503913E 10	0.326E 08	10.80	0.140E 00	0.725E-02

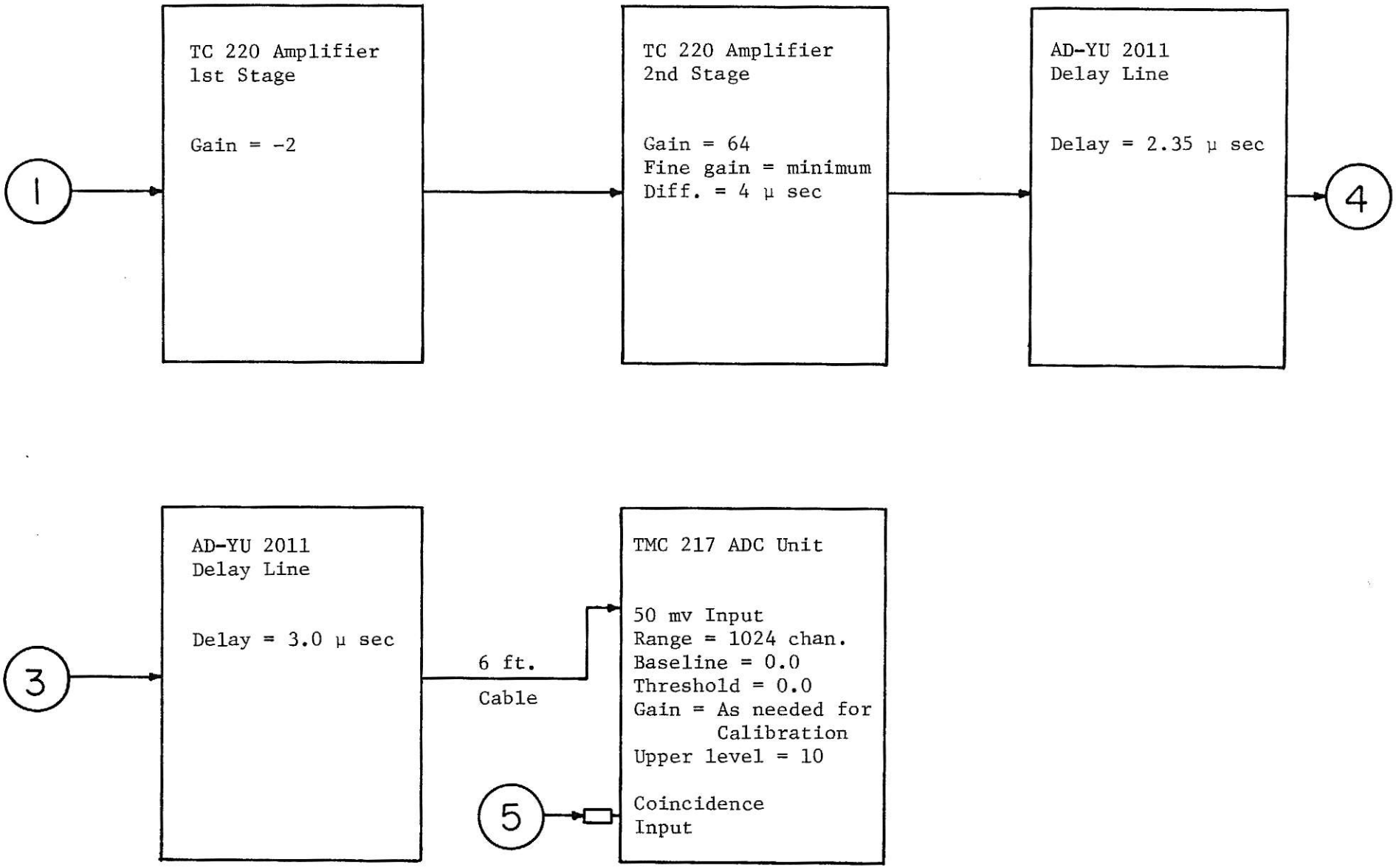
0.980E 07	57	-0.152E 00	0.153E 00	0.762E-04	0.11503913E 10	0.340E 08	10.68	0.145E 00	0.776E-02
0.100E 08	58	-0.157E 00	0.157E 00	-0.150E-03	0.11503910E 10	0.352E 08	10.56	0.149E 00	0.762E-02
0.102E 08	59	-0.161E 00	0.161E 00	-0.585E-04	0.11503910E 10	0.364E 08	10.44	0.153E 00	0.743E-02
0.104E 08	60	-0.164E 00	0.165E 00	0.299E-03	0.11503910E 10	0.376E 08	10.32	0.157E 00	0.729E-02
0.106E 08	61	-0.169E 00	0.170E 00	0.358E-03	0.11503910E 10	0.391E 08	10.20	0.162E 00	0.765E-02
0.108E 08	62	-0.177E 00	0.177E 00	-0.295E-03	0.11503908E 10	0.410E 08	10.08	0.168E 00	0.888E-02
0.110E 09	63	-0.186E 00	0.184E 00	-0.111E-02	0.11503905E 10	0.432E 08	9.96	0.175E 00	0.105E-01
0.112E 08	64	-0.194E 00	0.191E 00	-0.103E-02	0.11503903E 10	0.452E 08	9.84	0.182E 00	0.109E-01
0.114E 08	65	-0.198E 00	0.198E 00	-0.158E-03	0.11503903E 10	0.468E 08	9.72	0.188E 00	0.101E-01
0.116E 08	66	-0.203E 00	0.205E 00	0.746E-03	0.11503903E 10	0.484E 08	9.60	0.194E 00	0.993E-02
0.118E 08	67	-0.206E 00	0.206E 00	0.283E-03	0.11503903E 10	0.496E 08	9.60	0.196E 00	0.101E-01
0.120E 08	68	-0.208E 00	0.207E 00	-0.306E-03	0.11503900E 10	0.509E 08	9.60	0.197E 00	0.166E-01
0.122E 08	69	-0.209E 00	0.209E 00	0.107E-03	0.11503900E 10	0.521E 08	9.60	0.197E 00	0.117E-01
0.124E 08	70	-0.207E 00	0.209E 00	0.110E-02	0.11503900E 10	0.528E 08	9.60	0.195E 00	0.147E-01
0.126E 08	71	-0.202E 00	0.205E 00	0.138E-02	0.11503903E 10	0.525E 08	9.60	0.192E 00	0.121E-01
0.128E 08	72	-0.200E 00	0.201E 00	0.514E-03	0.11503903E 10	0.524E 08	9.60	0.191E 00	0.111E-01
0.130E 08	73	-0.200E 00	0.198E 00	-0.715E-03	0.11503900E 10	0.528E 08	9.60	0.187E 00	0.116E-01
0.132E 08	74	-0.197E 00	0.194E 00	-0.133E-02	0.11503898E 10	0.528E 08	9.60	0.184E 00	0.112E-01
0.134E 08	75	-0.192E 00	0.190E 00	-0.109E-02	0.11503895E 10	0.523E 08	9.60	0.181E 00	0.103E-01
0.136E 08	76	-0.186E 00	0.186E 00	-0.456E-03	0.11503892E 10	0.517E 08	9.60	0.177E 00	0.965E-02
0.138E 08	77	-0.183E 00	0.183E 00	0.674E-04	0.11503892E 10	0.517E 08	9.60	0.176E 00	0.880E-02
0.140E 08	78	-0.181E 00	0.182E 00	0.285E-03	0.11503892E 10	0.519E 08	9.60	0.174E 00	0.756E-02
0.142E 08	79	-0.180E 00	0.181E 00	0.253E-03	0.11503892E 10	0.523E 08	9.60	0.173E 00	0.731E-02
0.144E 08	80	-0.179E 00	0.179E 00	0.984E-04	0.11503892E 10	0.527E 08	9.60	0.172E 00	0.669E-02
0.146E 09	81	-0.179E 00	0.179E 00	-0.463E-04	0.11503892E 10	0.533E 08	9.60	0.173E 00	0.620E-02
0.148E 08	82	-0.180E 00	0.179E 00	-0.480E-04	0.11503892E 10	0.543E 08	9.60	0.173E 00	0.627E-02
0.150E 08	83	-0.180E 00	0.181E 00	0.173E-03	0.11503892E 10	0.553E 08	9.60	0.173E 00	0.770E-02
0.152E 08	84	-0.177E 00	0.179E 00	0.558E-03	0.11503892E 10	0.551E 08	9.60	0.169E 00	0.854E-02
0.154E 08	85	-0.165E 00	0.167E 00	0.913E-03	0.11503892E 10	0.522E 08	9.60	0.156E 00	0.103E-01
0.156E 08	86	-0.146E 00	0.148E 00	0.103E-02	0.11503892E 10	0.470E 08	9.60	0.138E 00	0.981E-02
0.158E 08	87	-0.128E 00	0.130E 00	0.822E-03	0.11503892E 10	0.417E 08	9.60	0.121E 00	0.797E-02
0.160E 08	88	-0.120E 00	0.121E 00	0.370E-03	0.11503892E 10	0.393E 08	9.60	0.115E 00	0.627E-02
0.162E 08	89	-0.120E 00	0.120E 00	-0.144E-03	0.11503890E 10	0.396E 08	9.60	0.116E 00	0.468E-02
0.164E 08	90	-0.120E 00	0.119E 00	-0.550E-03	0.11503887E 10	0.400E 08	9.60	0.114E 00	0.357E-02
0.166E 08	91	-0.111E 00	0.110E 00	-0.761E-03	0.11503885E 10	0.375E 08	9.60	0.104E 00	0.695E-02
0.168E 08	92	-0.942E-01	0.926E-01	-0.784E-03	0.11503882E 10	0.321E 08	9.60	0.862E-01	0.721E-02
0.170E 08	93	-0.729E-01	0.715E-01	-0.679E-03	0.11503880E 10	0.251E 08	9.60	0.657E-01	0.640E-02
0.172E 08	94	-0.518E-01	0.508E-01	-0.520E-03	0.11503877E 10	0.180E 08	9.60	0.463E-01	0.501E-02
0.174E 08	95	-0.342E-01	0.335E-01	-0.361E-03	0.11503875E 10	0.120E 08	9.60	0.305E-01	0.355E-02
0.176E 08	96	-0.211E-01	0.206E-01	-0.230E-03	0.11503872E 10	0.750E 07	9.60	0.189E-01	0.231E-02
0.178E 08	97	-0.122E-01	0.119E-01	-0.137E-03	0.11503869E 10	0.440E 07	9.60	0.107E-01	0.140E-02
0.180E 08	98	-0.670E-02	0.655E-02	-0.766E-04	0.11503869E 10	0.244E 07	9.60	0.563E-02	0.797E-03
0.182E 09	99	-0.349E-02	0.341E-02	-0.405E-04	0.11503869E 10	0.128E 07	9.60	0.302E-02	0.428E-03
0.184E 08	100	-0.174E-02	0.170E-02	-0.204E-04	0.11503869E 10	0.646E 06	9.60	0.150E-02	0.218E-03
0.186E 08	101	-0.829E-03	0.809E-03	-0.982E-05	0.11503869E 10	0.311E 06	9.60	0.713E-03	0.106E-03
0.188E 08	102	-0.381E-03	0.371E-03	-0.454E-05	0.11503869E 10	0.144E 06	9.60	0.336E-03	0.497E-04
0.190E 08	103	-0.169E-03	0.165E-03	-0.202E-05	0.11503869E 10	0.647E 05	9.60	0.144E-03	0.224E-04
0.192E 08	104	-0.724E-04	0.707E-04	-0.873E-06	0.11503869E 10	0.281E 05	9.60	0.618E-04	0.973E-05
0.194E 08	105	-0.302E-04	0.294E-04	-0.365E-06	0.11503869E 10	0.118E 05	9.60	0.257E-04	0.412E-05

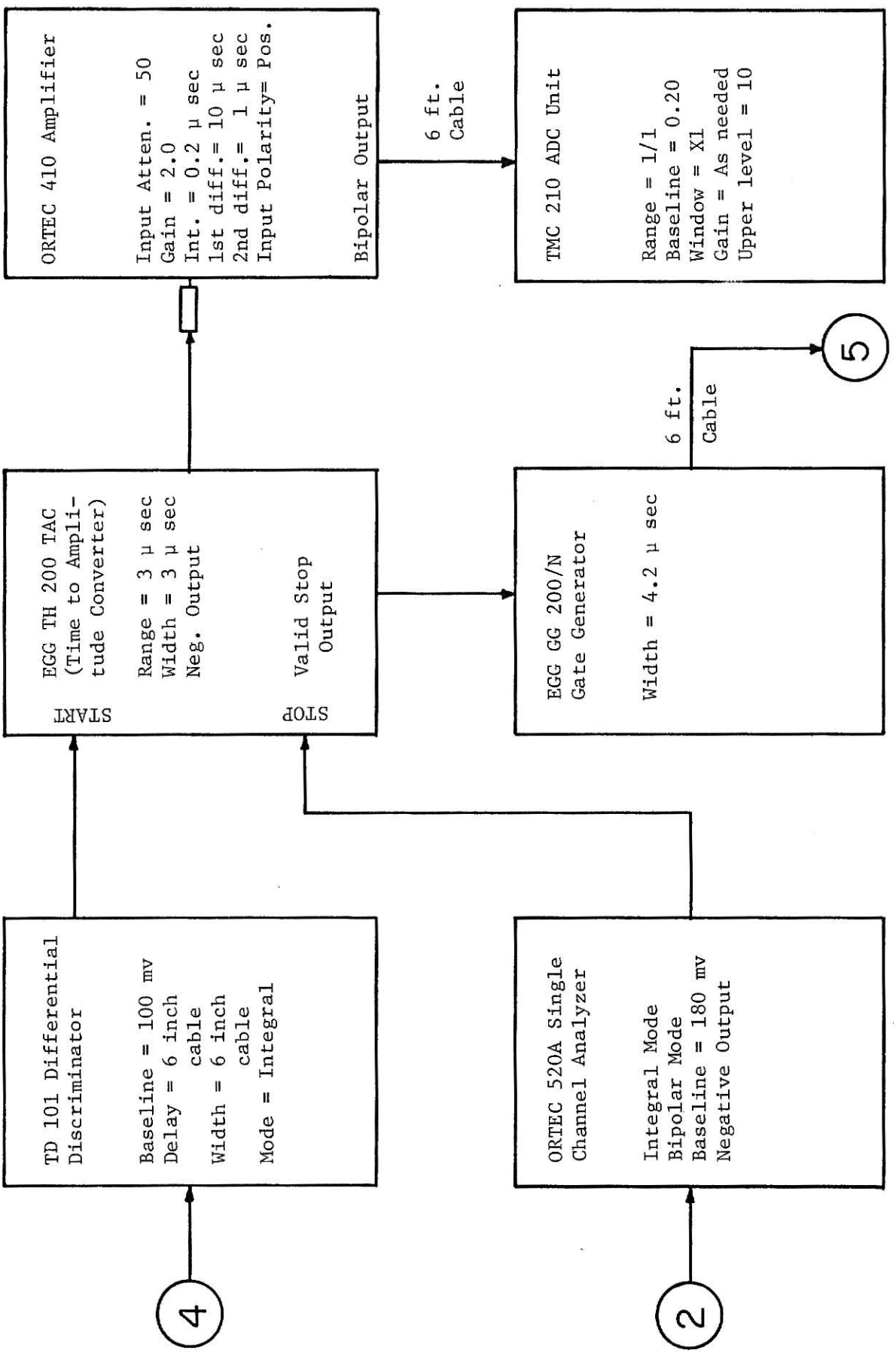
APPENDIX E

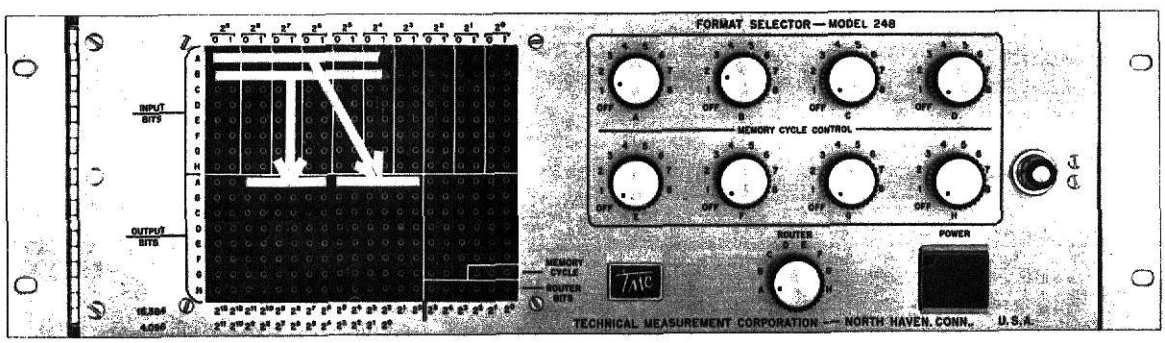
Detailed Block Diagram of NE-213 Fast-Neutron TAC Spectrometer System

Presented in this section is a detailed block diagram of the NE-213 fast-neutron TAC spectrometer system giving the exact settings of all the electronic components of the system. Also included is a diagram of the patchboard wiring on the TMC model 248 format selector necessary to alter the operation of the TMC 4096 multiparameter analyzer to a two parameter mode.


PAR 211 Amplifier
Gain = 10
8 ft.
Cable
8 ft.
Cable
Fluke 405B
High Voltage
2030 Volts
300 ft.
Cable
TC 220 Amplifier
3rd Stage
Gain = 4
Int. = 0.8 μ sec
Diff.= 3.2 μ sec
1
2
TC 220 Amplifier
3rd Stage
Gain = 4
Int. = 0.1 μ sec
Diff.= 0.8 μ sec
4 ft.
Cable
ORTEC 410 Amplifier
Input Atten. = 50 or 20
(High or Low Gain)
Gain = As needed for
calibration
Int. = 0.2 μ sec
Diff.= Out
Unipolar Output
3
SYMBOLS:
- 50 ohm cable terminator
NOTE: Unless otherwise noted, all cables are 2 ft. or less in length.


1
TC 220 Amplifier
1st Stage
Gain = -2
TC 220 Amplifier
2nd Stage
Gain = 64
Fine gain = minimum
Diff. = 4 μ sec
AD-YU 2011
Delay Line
Delay = 2.35 μ sec
4
3
AD-YU 2011
Delay Line
Delay = 3.0 μ sec
6 ft.
Cable
TMC 217 ADC Unit
50 mv Input
Range = 1024 chan.
Baseline = 0.0
Threshold = 0.0
Gain = As needed for
Calibration
Upper level = 10
5
Coincidence
Input


ORTEC 410 Amplifier
Input Atten. = 50
Gain = 2.0
Int. = 0.2 μ sec
1st diff.= 10 μ sec
2nd diff.= 1 μ sec
Input Polarity= Pos.
Bipolar Output
6 ft.
Cable
TMC 210 ADC Unit
Range = 1/1
Baseline = 0.20
Window = Xl
Gain = As needed
Upper level = 10
EGG TH 200 TAC
(Time to Amplitude Converter)
START
Range = 3 μ sec
Width = 3 μ sec
Neg. Output
STOP
Valid Stop
Output
EGG GG 200/N
Gate Generator
Width = 4.2 μ sec
6 ft.
Cable
5
TD 101 Differential
Discriminator
Baseline = 100 mv
Delay = 6 inch
cable
Width = 6 inch
cable
Mode = Integral
ORTEC 520A Single
Channel Analyzer
Integral Mode
Bipolar Mode
Baseline = 180 mv
Negative Output
4
2



Note: Set "MEMORY CYCLE CONTROL" switches A and B to position 1 and switches C through H to the OFF position. Set the "ROUTER" switch to position A.

Figure 16. Schematic wiring diagram for patchboard of model 248 FORMAT SELECTOR Of TMC 4096 multiparameter analyzer operated in a two parameter mode

DEVELOPMENT OF AN NE-213 FAST-NEUTRON TAC SPECTROMETER SYSTEM UTILIZING OFF-LINE GAMMA-RAY DISCRIMINATION

by

RICHARD EARL SECK

B.S., Kansas State University, 1970

AN ABSTRACT OF 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

An NE-213 fast-neutron, TAC spectrometer system utilizing off-line gamma-ray discrimination has been developed and used to measure four different neutron spectra. The TAC system developed in this study identified each detector pulse by its pulse height and by a zero cross-over technique and then stored this information in a two parameter array in a multiparameter analyzer. A special purpose computer code, DISCRIM, written during the course of this work was used to optimize the separation of the neutron and gamma-ray information in the array of data obtained from the TAC system. The resulting neutron pulse height spectra were unfolded using both the FERDOR and DUFOLD unfolding procedures.

Measurements of monoenergetic 14 MeV neutrons and fission spectra after transmission through a thick oxygen absorber indicate that the TAC spectometer system has an energy resolution comparable to the 2 in. KSU NE-213 spectrometer system and significantly better resolution than that reported by Verbinski for an NE-213 spectrometer system at ORNL.

Measurement of a packaged PuBe source and the incident beam from the fast beam port of the KSU TRIGA Mark II reactor with the TAC spectrometer system were in good agreement at energies above 1.5 MeV with similar measurements made with the 2 in. KSU NE-213 spectrometer system. Below 1.5 MeV the TAC results differed significantly from the 2 in. KSU results and from measurements of similar PuBe sources made by Lehman who used nuclear emulsion techniques.