NEUTRON SPECTRA MEASUREMENTS WITH MINIATURE NE-213 SPECTROMETERS

by

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1.0 INTRODUCTION

An extensive fast-neutron spectrometry research program began in the Department of Nuclear Engineering at Kansas State University in 1966. The initial development was the construction of an NE-213 fast-neutron spectrometer system similar in design to a system developed by Oak Ridge National Laboratory. The present refined NE-213 system has been used to obtain angular and energy dependent penetration and reflection data in the energy range 1 to 14 MeV for a variety of materials. These data are collected in air with a 2 inch diameter by 2 inch high NE-213 detector and associated electronics with neutrons from the fast beam port of the KSU TRIGA Mark II nuclear reactor. With the advent of the fast reactor and other new and different reactor types, the need for fast-neutron spectra information has increased. A submersible neutron detector is needed for radiation effects studies and could also be used to check core design neutron transport codes. Using a 1 inch diameter, 1 inch high detector, M. J. Coolbaugh (1) designed and constructed a watertight NE-213 spectrometer system capable of making aqueous media spectral measurements. This new dimension of the KSU research program allows data to be taken in aqueous media up to twenty feet deep.

In combined neutron and gamma-ray environments, organic scintillators such as NE-213 are suitable for neutron spectrum determinations from energies above approximately 0.8 MeV where measurements are restricted to relatively low gamma-ray fluxes (less than 20 mr/hr). This restriction is a result of the NE-213 scintillator's high efficiency for detection of gamma radiation. Electronic discrimination techniques based on the differences in induced light pulse shapes for neutrons and gamma-rays must be employed to obtain a response to neutrons alone. All gamma interactions, however, may not be completely discriminated against. Therefore the watertight NE-213 assembly may be used only where the residual gamma-ray flux is low.

For this research the watertight NE-213 spectrometer has been refined and modified for use in higher gamma-ray fluxes. Slight modifications have been made to Coolbaugh's existing 1 inch NE-213 assembly and selected measurements were made with the refined system. The lengthy procedures for the calibration of the detector are outlined in detail. Additional work described here includes the design and assembly of a ½ inch NE-213 detector system. Since detector efficiency is proportional to detector volume a smaller detector permits neutron spectrum measurements to be made in areas with higher residual gamma-ray flux. Selected spectrum measurements made with the ½ inch detector assembly are presented.

2.0 THEORETICAL CONSIDERATIONS

2.1 Basic Characteristics of the NE-213 Scintillator

NE-213, an organic scintillator made by Nuclear Enterprises, is a particular combination of a xylene-naphthalene solution plus activators and POPOP wave shifter. The scintillation solution responds to incident radiation indirectly through recoil protons, Compton electrons, and carbon nuclei scattering interactions. Neutron cross sections for hydrogen and carbon are shown in Figure 1. Neutrons incident on the solution interact to produce recoil protons and carbon scattering events. The only evident gamma-ray interaction in the solution produces Compton electrons (2). It has been shown by Owen (3) that the pulse shape of light pulses from a scintillation producing event can be expressed as the sum of two exponentials with different decay characteristics. Neutrons and gamma rays produce light pulses of different pulse shape since the pulses are produced by different mechanisms. A more detailed description of the response of NE-213 to radiation including determination of distortion and angular distribution effects is given in a KSU dissertation by Coolbaugh (1).

Once produced, light pulses in the NE-213 scintillator are subsequently detected by a photomultiplier tube. From the photomultiplier tube the signals are amplified and shaped. Most gamma rays are removed by requiring coincidence between pulses coming from an electronic pulse shape discrimination circuit and an undistorted linear energy (linear signal) signal taken from the photomultiplier tube (see Section 3.2 for a discussion of the operating principles). The raw pulse height data are collected in a multichannel analyzer.

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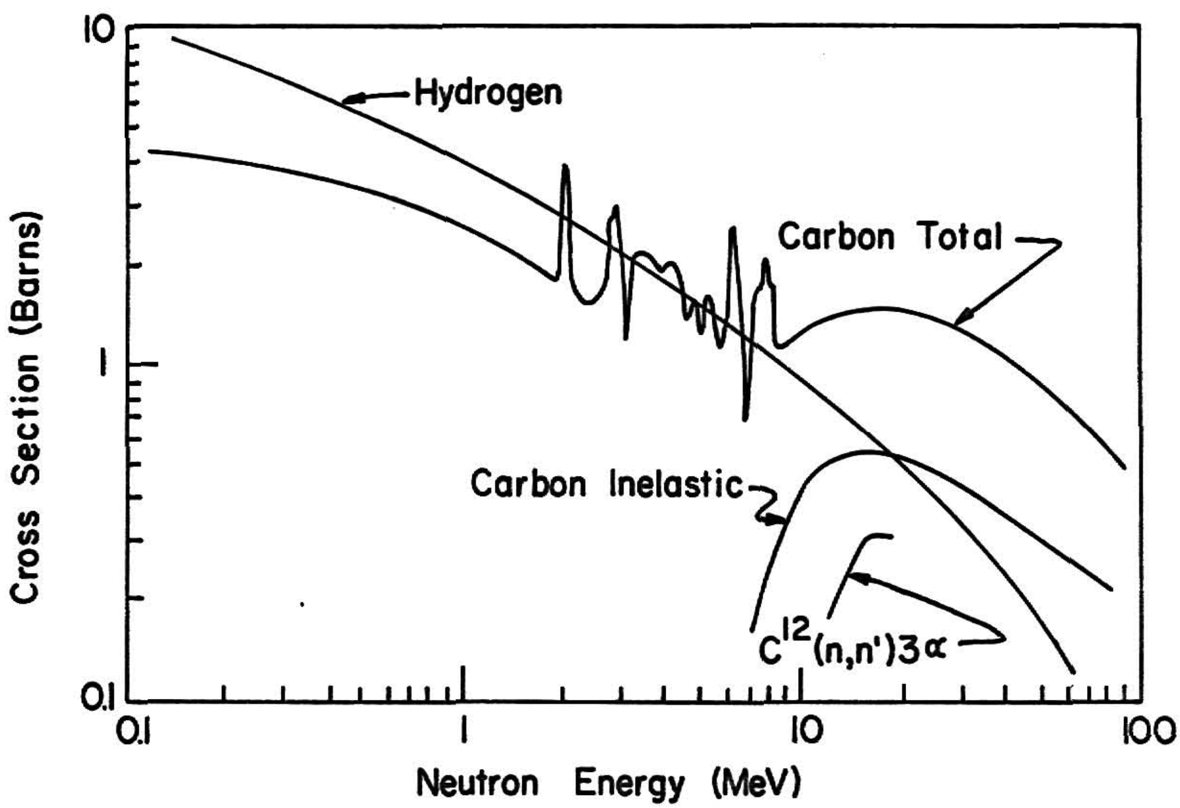

Figure 1. Neutron Cross Sections for Hydrogen and Carbon.

2.2 Unfolding of Measured Pulse Height Spectra

During a neutron-proton interaction only a fraction of the neutron energy is transferred to the proton. The spectra collected using a proton recoil spectrometer are recoil proton spectra as opposed to neutron spectra. The collected spectra are considerably different from the neutron spectra. It is therefore necessary to analyze the experimentally determined proton recoil spectrum to obtain the spectrum of the incident neutrons. The analysis process is commonly referred to as unfolding.

Most unfolding techniques are based on the principle that monoenergetic neutron responses can be determined for a spectrometer, either by direct measurement or by calculations. The response functions once determined are then applied to the analysis of experimentally measured pulse height spectra. The often used FERDOR code, developed by Burrus (4) at Oak Ridge National Laboratory, uses this method to unfold pulse height spectra obtained with 2 and 5 inch NE-213 detectors.

In this work, however, the size of the detector has been reduced from 2 inches, and thus the possibility of multiple neutron scattering is reduced, while the possibility of edge effects is increased. Therefore response functions developed for 2 inch detectors may not be used universally for every size detector. If the FERDOR code should be applied to the analysis of data measured with miniature NE-213 detectors, the amount of multiple interactions will be overestimated and the edge distorting effects will be underestimated.

The DUFOLD unfolding code developed by Coolbaugh (1) is based on a derivative procedure that does not required measured monoenergetic response functions. Scintillator size is considered in the DUFOLD code, and hence the code may be adapted for use with NE-213 detector sizes other than 1 inch. The measured pulse height spectrum, its derivative, and data parameters for nonlinear light response are combined in DUFOLD along with various correction factors for distortion and detector size to give the spectrum of the incident neutrons. The DUFOLD code used as the primary unfolding procedure in this work is completely discussed by Coolbaugh (1). A derivative unfolding code, NEUPST, has also been developed by Toms (5). Data unfolded by NEUPST are included in Section 6.1.

Mutone (6) has developed a stochastic model for unfolding experimental proton recoil spectra and making smooth estimates of the resulting spectra. The Mutone model is based on the precept that the spectrum of a neutron source is the probability density function of the energy with which the neutrons are emitted. Time series analysis is used to smooth the spectrum estimates. The unfolding code STUNFO is discussed in detail with examples and comparisons in a KSU dissertation by Mutone (6). The code STUNFO is used in this work with the other unfolding codes, FERDOR, NEUPST and DUFOLD to compare spectra obtained with the NE-213 detectors of different sizes.

3.0 EXPERIMENTAL APPARATUS

3.1 Miniature NE-213 Detectors

The 1 inch diameter by 1 inch high glass cell (shown in Figure 2) was fabricated by Glaresco Corporation. The cell has a glass stem leading from the main part of the cell to a small expansion chamber which is half-filled with an inert gas to act as an expansion medium. The detector stem is constricted along part of its length to retard movement of the gas from the expansion chamber to the main detector cell volume. The cells used in this work were filled with deoxygenated NE-213 by Nuclear Enterprises Corporation, sealed under an inert atmosphere, and coated on all surfaces except for the optical face with NE-560, a white reflective paint made with titanium dioxide. This coating is reported by Nuclear Enterprises (7) to cause a greater amount of light to be reflected out of the cell than when the cell is covered with aluminum foil (an aluminium foil covering is used on the KSU 2 inch detector).

Some light emissions caused by neutron and gamma interactions in the expansion tube travel to the 1 inch glass cell and also reach the optical surface. Five MeV protons travel approximately 0.3 mm in the NE-213 fluid (8). Therefore medium energy neutrons can deposit their energy in the ¼ inch, thin walled, NE-213 filled expansion tube and produce unwanted light emissions. Reflection by the paint on the expansion tube walls can also cause distortion of the unwanted light emissions. Removing the NE-560 reflective paint from the expansion tube allows some light produced in the expansion tube to leave the cell before transmission into the 1 inch glass cell detector volume (experimental evidence of the phenomenon will be presented later).

The ½ inch diameter by ½ inch high glass cell (shown in Figure 3) was fabricated and filled with deoxygenated NE-213 by Nuclear Enterprises

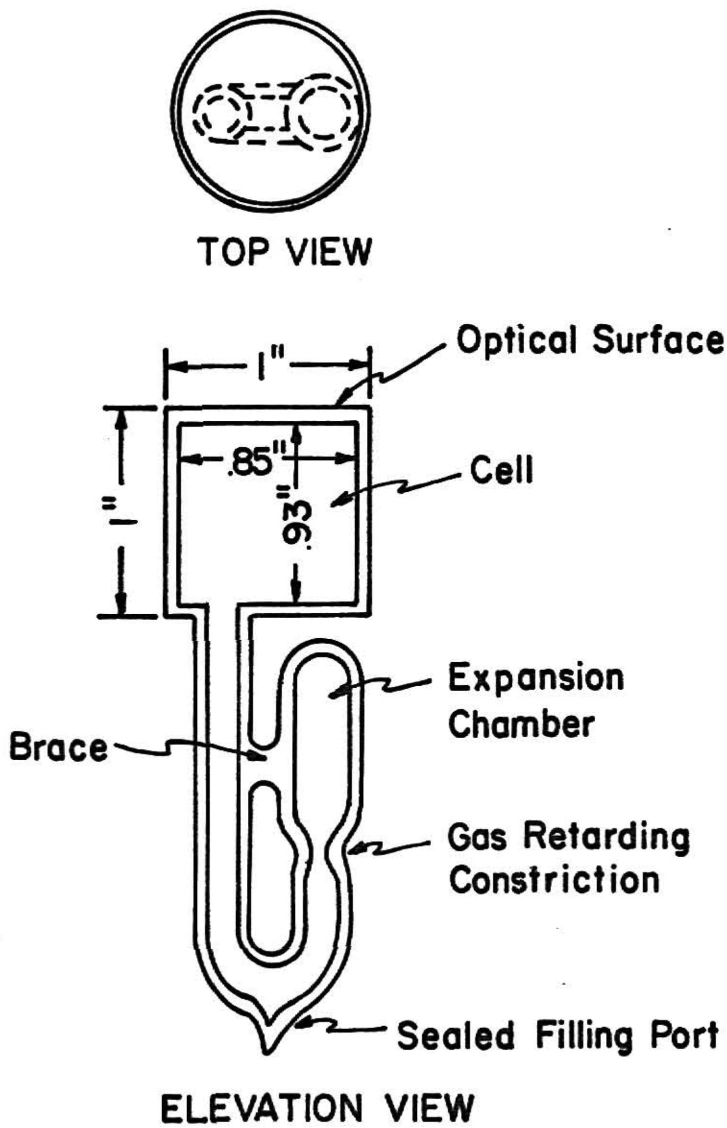

Figure 2. NE-213 1 Inch Scintillator Cell.

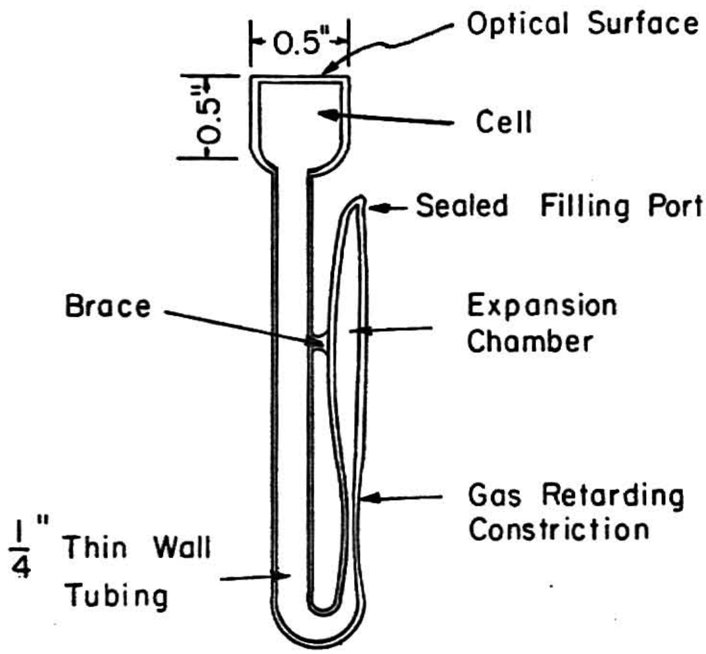

Figure 3. NE-213 ½ Inch Scintillator Cell With Thin Wall Expansion Tube.

Corporation. The cell was covered with aluminum foil. As with the 1 inch detector, light emissions in the expansion tube may reach the optical surface. Even left uncoated and uncovered, the expansion tube may still be the origin of unwanted distorting light emissions. For the cell shown in Figure 3 there is a greater volume of NE-213 fluid in the expansion tube than in the ½ inch diameter by ½ inch high detector cell. Experimental evidence indicates that a sufficient number of light emissions generated in the expansion tube reach the optical surface to severely distort measured neutron spectra. No meaningful data can be collected with a cell of the design shown in Figure 3.

To decrease the volume of NE-213 in the expansion tube, a modified detector design incorporating a 6-7 mm O.D. capillary tube to replace the thin walled ¼ inch expansion tube was prepared. The cell modified by the addition of the capillary tubing is shown in Figure 4.

To reduce the rate of radiation damage it is desirable to keep the spectrometer system components other than the detector cell remote from the photomultiplier tube and associated electronics. To accomplish this an acrylic light pipe constructed for Coolbaugh (1) is used to transmit the scintillation light from the detector cell to the photomultiplier tube. The light pipe constructed by Pilot Chemicals of hydrogenous UVT Acrylic does not disturb the neutron spectrum in water as do light pipes made of other substances (1). The light pipe consists of a 2 inch long by 2 inch diameter cylinder with a special 45 degree taper to an 18 inch long by 1 inch diameter rod. Both ends are highly polished. When the ½ inch detector is used, an acrylic light pipe reducer constructed by Pilot Chemicals is attached to the 1 inch light pipe (shown in Figure 5). The exponential light pipe spiral is designed to improve the efficiency of the light pulse transmission system.

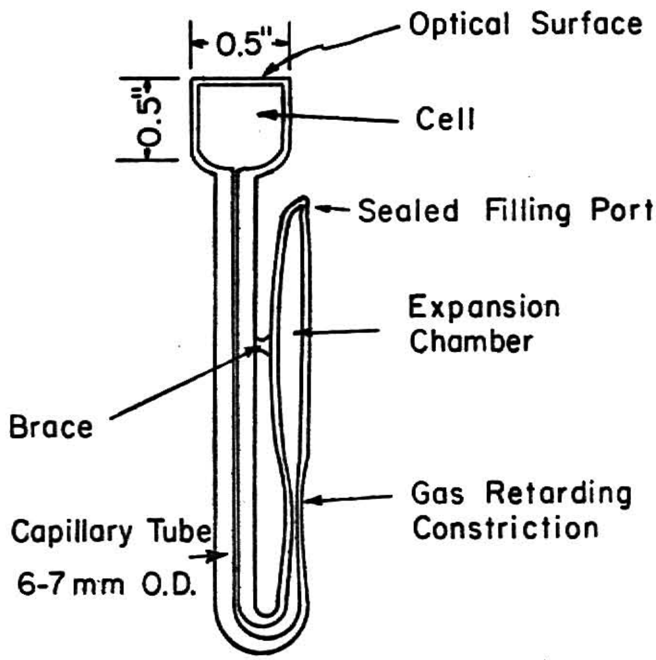

Figure 4. NE-213 ½ Inch Scintillator Cell With Capillary Expansion Tube.

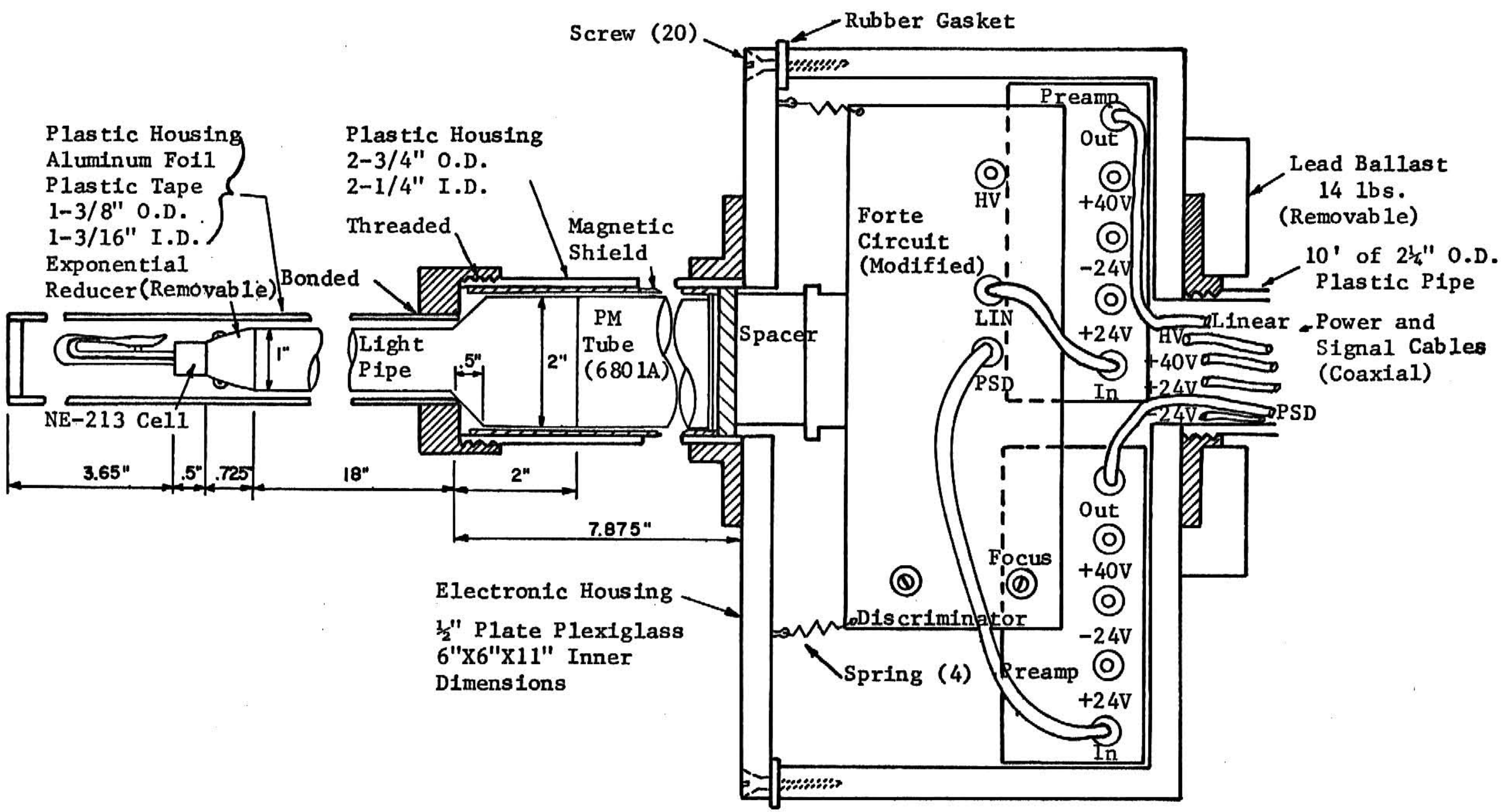

Figure 5. NE-213 ½ Inch Spectrometer Sectional View.

This spiral is made of the same material as the light pipe. Connection ears are bonded to the spiral to produce a mechanically stable connection. See Appendix 10.1 for a detailed drawing of the light pipe spiral. Pilot Chemicals is now capable of constructing the light pipe spiral on a production basis using the KSU design of M. J. Coolbaugh and W. Meyer. The light pipe reducer and glass cell are attached with nylon twine to acrylic tabs on the light pipe. The acrylic tabs are fused to the light pipe with an acetic acid, acetone mixture. On a spare piece of light pipe, the tabs have held under stress for over six months without failing.

All optical couplings are performed by placing Dow Corning 10^6 centistokes silicone compound on one of the surfaces joined and then moving the contacted surfaces in a rotary manner until all bubbles are eliminated. The optically-coupled cell (either 1 inch or ½ inch) is then enclosed in a light tight housing of aluminum foil and black plastic electrician's tape.

The detector and light pipe assembly are optically coupled to the photomultiplier tube and held in place by wrapping both the entire 2 inch diameter portion of the light pipe with aluminum foil and plastic tape. During submerged operation the photomultiplier tube, and associated electronics are sealed in a shielded, water tight housing constructed by Coolbaugh (1). This housing is sealed with Dow Corning Silicon Rubber Sealer and allowed to cure in air for 24 hours before submersion.

3.2 Operating Principle of the Spectrometer

The tube-base gamma-ray discrimination circuit assembly shown in Figure 6 is similar to that developed by Verbinski (9). In the circuit, energy dependent linear pulses containing both neutrons and gamma-ray induced pulses are taken from the 11th dynode of the photomultiplier tube.

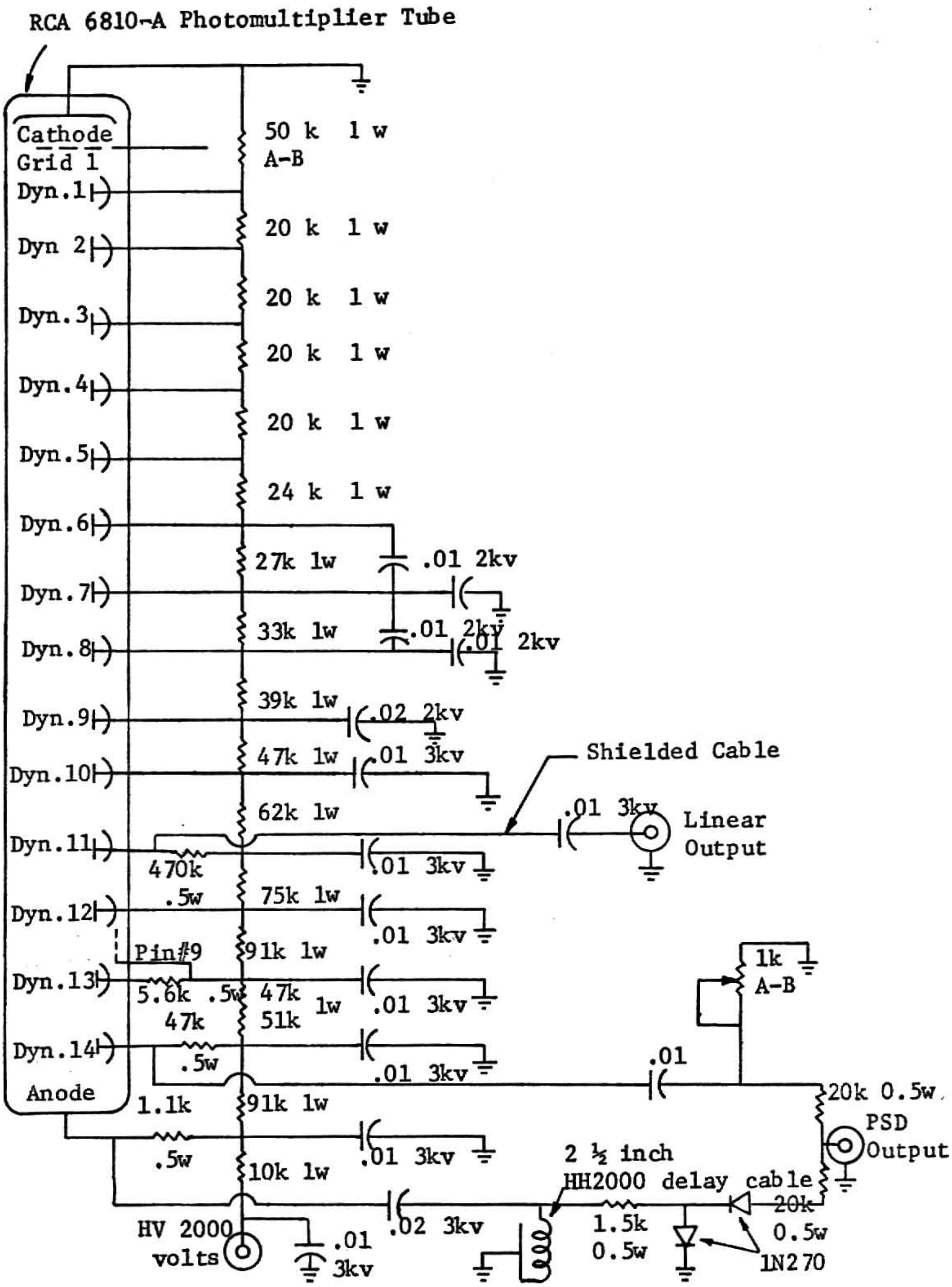

Figure 6. Photomultiplier Electronics and Pulse Shape Discrimination Circuit.

A second signal containing both fast and slow decay component information obtained at the 14th dynode and anode is electronically treated using a modified Forte circuit (10). The Forte circuit signal, hereafter called the PSD (pulse shape discrimination) signal, has characteristics which allow distinction between gamma-ray and neutron induced pulses. Figures 7 and 8 show photographs and drawings of the PSD signals from a PuBe source after shaping with an Ortec 410 amplifier. The PSD signal is also shaped by adjustment of the focus and discrimination circuits of the Forte circuit. With the aid of an oscilloscope the Ortec 410 amplifier is used to roughly shape the PSD signal. Next the focus is adjusted until all gamma-ray induced pulses cross over at one point (shown in Figures 7 and 8). Fine adjustments of the focus and discriminator are often necessary if slight distortions in collected spectra are observed.

Figure 9 is a block diagram of the entire spectrometer circuitry developed by Coolbaugh (1) for 1 inch detectors, and used in this work for both 1 inch and ½ inch detectors. Two Larson (11) preamplifiers (see Figure 10) are located in the sealed watertight housing, and transmit the linear and PSD signals through 330 feet of 50 ohm cable to external electronics. A Fluke 310B power supply is used to provide the high voltage power to the photomultiplier tube, and 3 Lambda LP 412 power supplies provide the power required for the preamplifiers. Next, the preamplifier signal is transmitted through 300 feet of cable from the KSU TRIGA Mark II Reactor Bay to the remainder of the electronic equipment in Ward Hall, Room 142. The transmitted linear signal is split with a "T" connector and one of the signals is led through a 50 ohm feed-through to an Ortec 410 amplifier which amplifies the signal, inverts it, and shapes it so that it will be compatible with the requirements of the

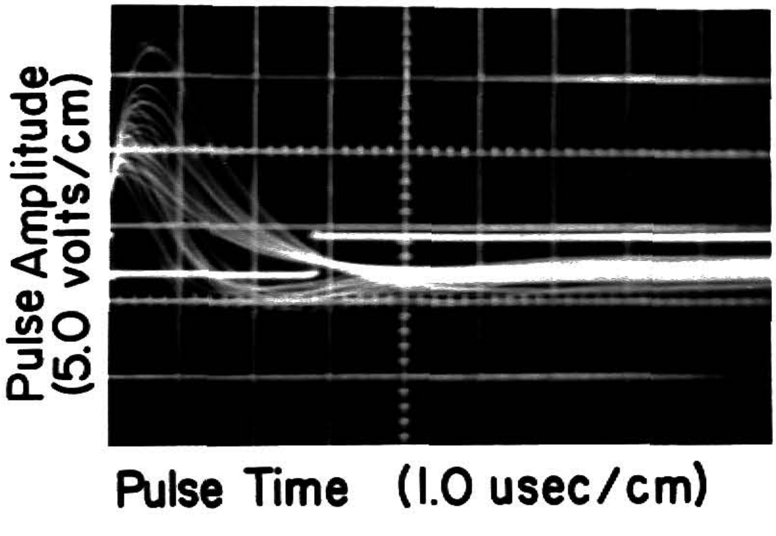

Figure 7a. Photograph of PSD PuBe Gamma-Ray and Neutron Induced Pulses, 1 Inch Detector.

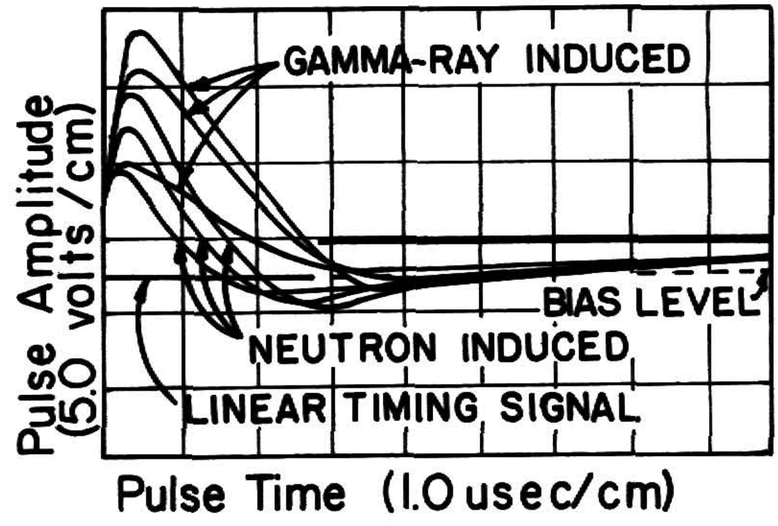

Figure 7b. Skematic Diagram of PSD PuBe Gamma-Ray and Neutron Induced Pulses, 1 Inch Detector.

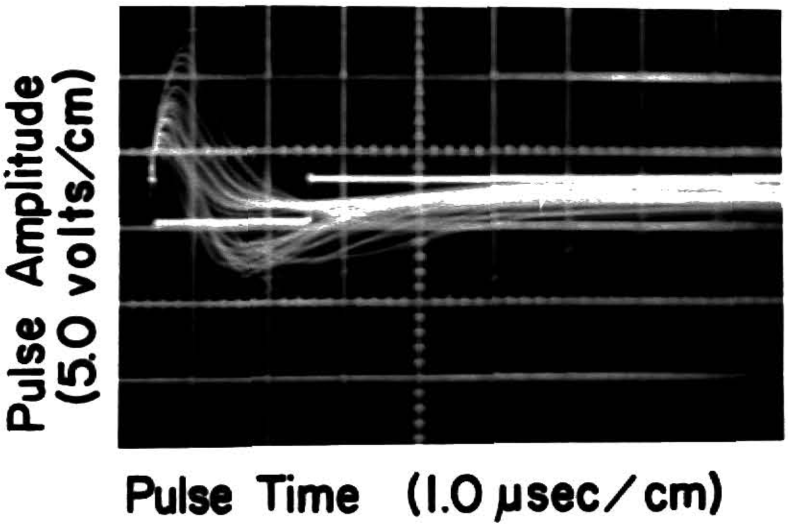

Figure 8a. Photograph of PSD PuBe Gamma-Ray and Neutron Induced Pulses, ½ Inch Detector.

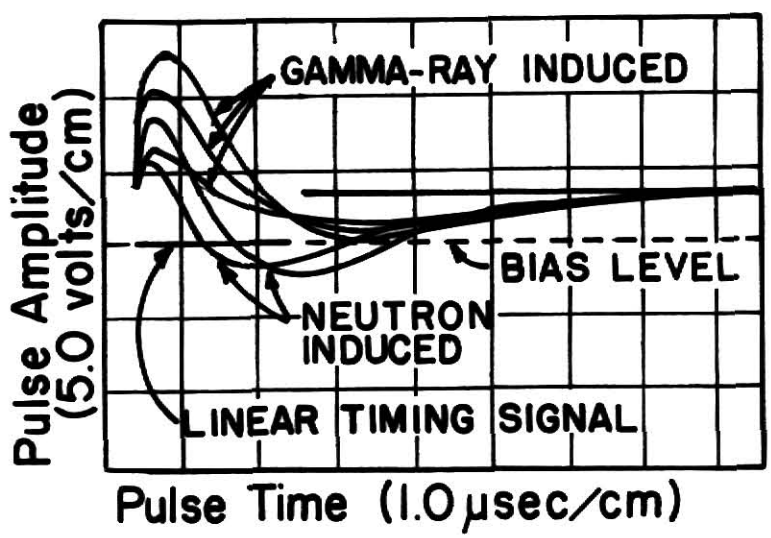

Figure 8b. Skematic Diagram of PSD PuBe Gamma-Ray and Neutron Induced Pulses, ½ Inch Detector.

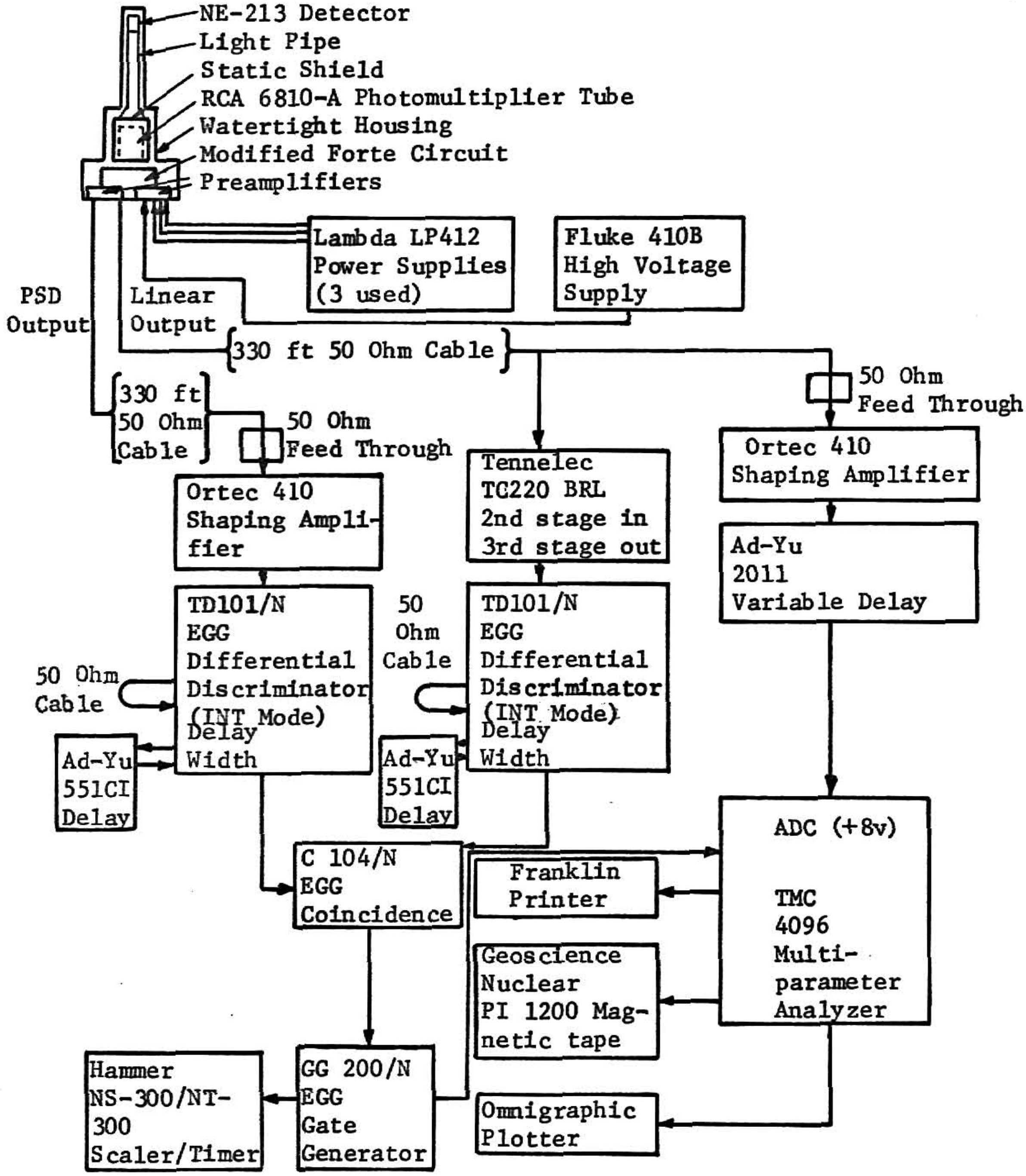

Figure 9. Block Diagram of the NE-213 Fast Spectrometer Electronics for the Miniature Detectors.

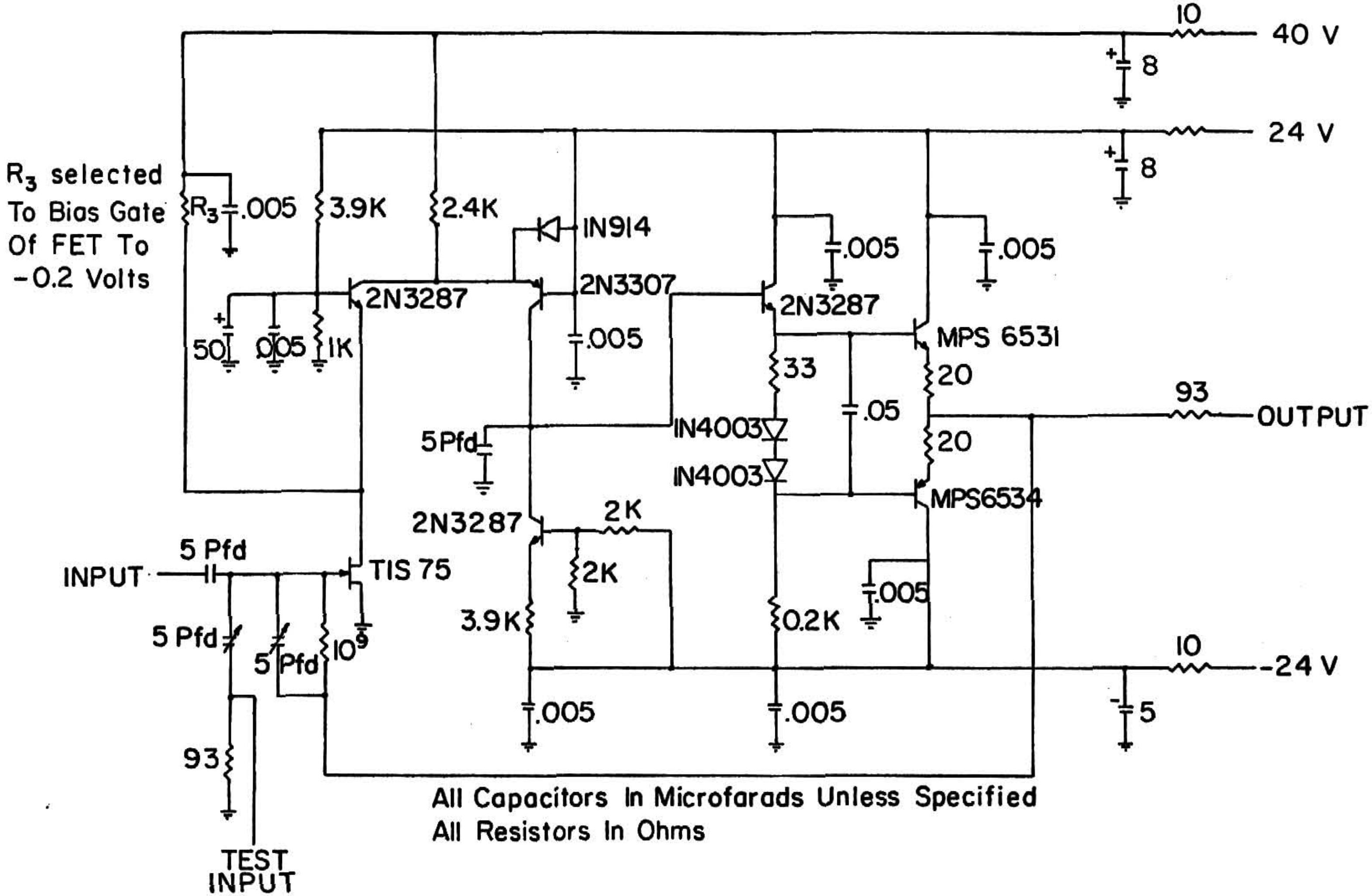

Figure 10. Preamplifier Diagram Showing the Basic Diagram from Larson (11) with Additional Capacitors.

multichannel analyzer. Since the +8 V input of the multichannel analyzer requires 10 per cent to 90 per cent of the rise time to be between 0.1 and 0.7 μsec, and the decay time to be between 0.1 to 5 μsec, the linear pulse is shaped to have approximately a 0.5 μsec. rise time and a 2 to 3 μsec decay time. This shaped signal is then transmitted through a short 93 ohm cable to an Ad-Yu 2011 variable delay which delays the signal 1.3 μsec. before it enters the multichannel pulse height analyzer (MCPHA). This delay is necessary because the coincidence gating pulse used must precede the linear input by at least 250 nsec.

The second linear signal is fed to the second input of a Tennelec TC 220 BLR linear amplifier operated in the Bipolar mode where it is greatly amplified to insure that even the smallest proton recoil pulses will produce a timing signal in the circuitry described below. After amplification, the signal is taken from the third output and transmitted to an EGG TD 101/N differential discriminator operating in the Integral (INT) mode. This mode generates timing signals when the input exceeds the set level. The amplification of the input signal and the discrimination setting on the TD 101/N are adjusted until the linear PuBe source signal collected in the MPCHA (as displayed on the MCPHA oscilloscope) are free from electronic noise. The width of the linear timing signal produced by the TD 101/N, is set roughly by displaying the linear timing signal on an oscilloscope at the same time as the PSD signal (shown in Figures 7 and 8). Fine adjustment is possible only after looking at plots of data collected from a PuBe source. If abnormal "gamma-ray induced bumps" appear in the PuBe raw data, the linear timing signal must be shortened. If high energy data are missing in the raw PuBe spectrum, the linear timing signal must be lengthened to permit collection of the high energy neutron pulses. Appendices 10.2 and 10.3 give the width of the linear timing signal and all of the other electronic settings used in this work.

The PSD signal pulses are amplified until the gain limitations of the amplifier are attained. Timing is accomplished using an EGG TD 101/N differential discriminator operating in the Integral mode with a width of about 4.0 μsec. The discriminator level is set to remove the gamma-ray pulses but allow low energy neutron pulses to trigger a timing signal. The linear timing signal as shown in Figures 7 and 8 is placed at approximately the PSD discrimination level.

Timing pulses from both the linear and PSD differential discriminator are input to an EGG C 104A/N coincidence unit operating in the AND mode. The coincidence unit produces a signal if there is a PSD signal that becomes more negative than the bias level within about 2.8 μsec (with the 1 inch spectrometer) after the original pulse has triggered the linear discriminator. The coincidence signal is used to trigger an EGG GG 200/N gate generator which produces a signal of proper magnitude and width to satisfy the coincidence circuitry of the multichannel analyzer. When adjusted properly the discrimination circuitry accepts neutron induced pulses and accepts only a minimal number of gamma-ray induced pulses.

4.0 CALIBRATION OF THE SPECTROMETER

4.1 Critical Adjustment of the Electronics

The energy calibration or gain of the system is set in the same way as with all KSU NE-213 detectors, using a ^{60}Co source. Adjusting the gain settings on the linear Ortec 410 amplifier allows the placement of the linearly extrapolated tail channel of the Compton edge in Channel 200 (Figure 11 shows the ^{60}Co edge obtained with the 2 inch, 1 inch and ½ inch detectors).

When taking ^{60}Co data several observations can be made. Figure 12 shows 1 inch ^{60}Co spectra with and without distortions from expansion tube reflections present. If the NE-213 detector is tipped and held in the wrong position the expansion gas may lodge in the cylindrical cell detector. The compounded distortion caused by a gas bubble and expansion tube reflections is also shown in Figure 12.

Before each spectrum measurement, it may be necessary to make fine electronic adjustments. To do this a PuBe spectrum is collected with the MCPHA operating in the anticoincidence mode and both the gain and the discrimination level of the linear side of the discrimination circuitry are adjusted until it is evident that no desirable low energy pulse will be biased out with the linear circuitry. The peak channel is noted and the linear signal is then removed from coincidence, and the PSD is placed in coincidence. A PuBe spectrum is collected and both the gain and discrimination circuitry and the linear gate width are adjusted until the spectrum peaks smoothly in the same channel as the linear spectrum. The system is then placed in full coincidence and a PuBe spectrum is collected (normally

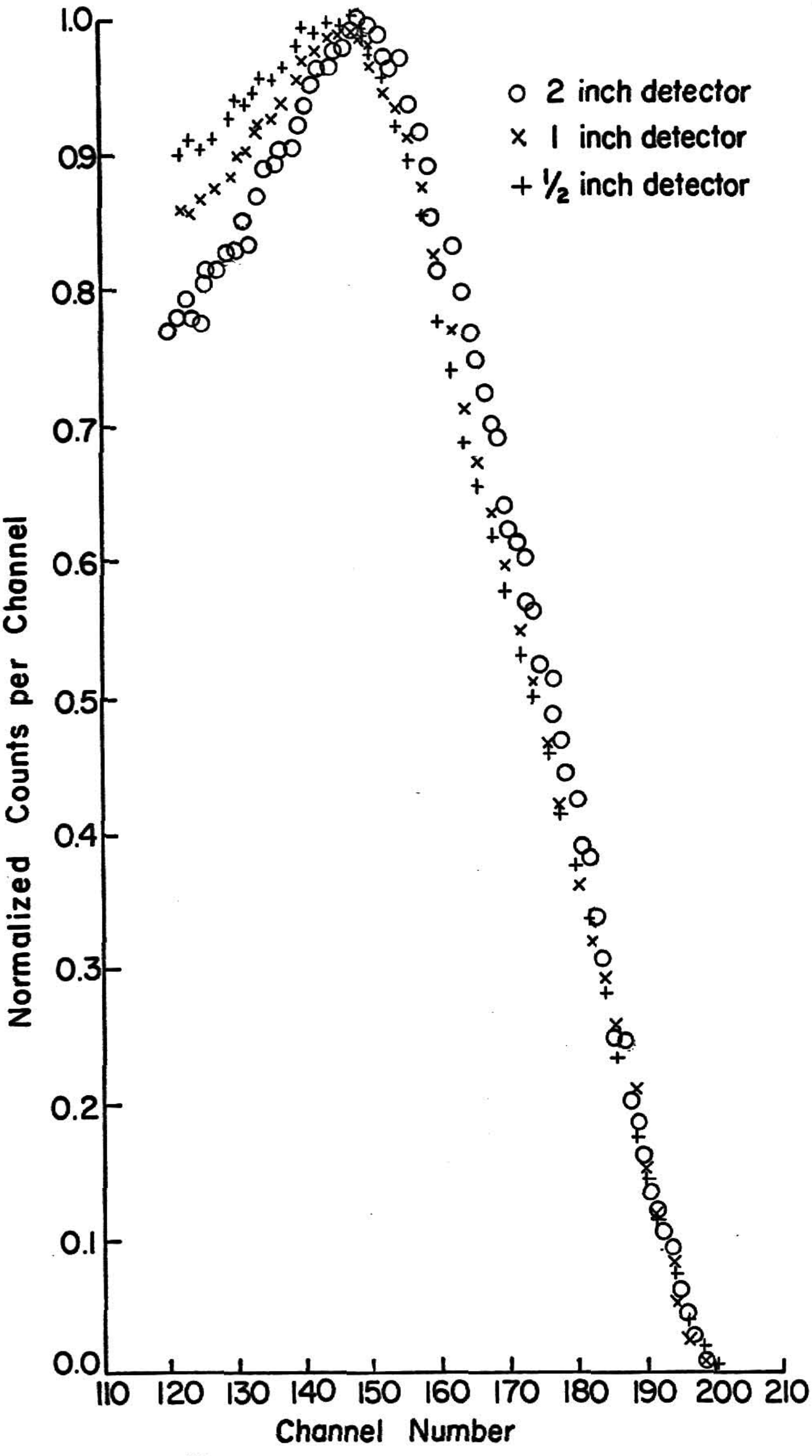

Figure 11, ^{60}Co Compton Edge for the 2 Inch, 1 Inch, and ½ Inch Detectors.

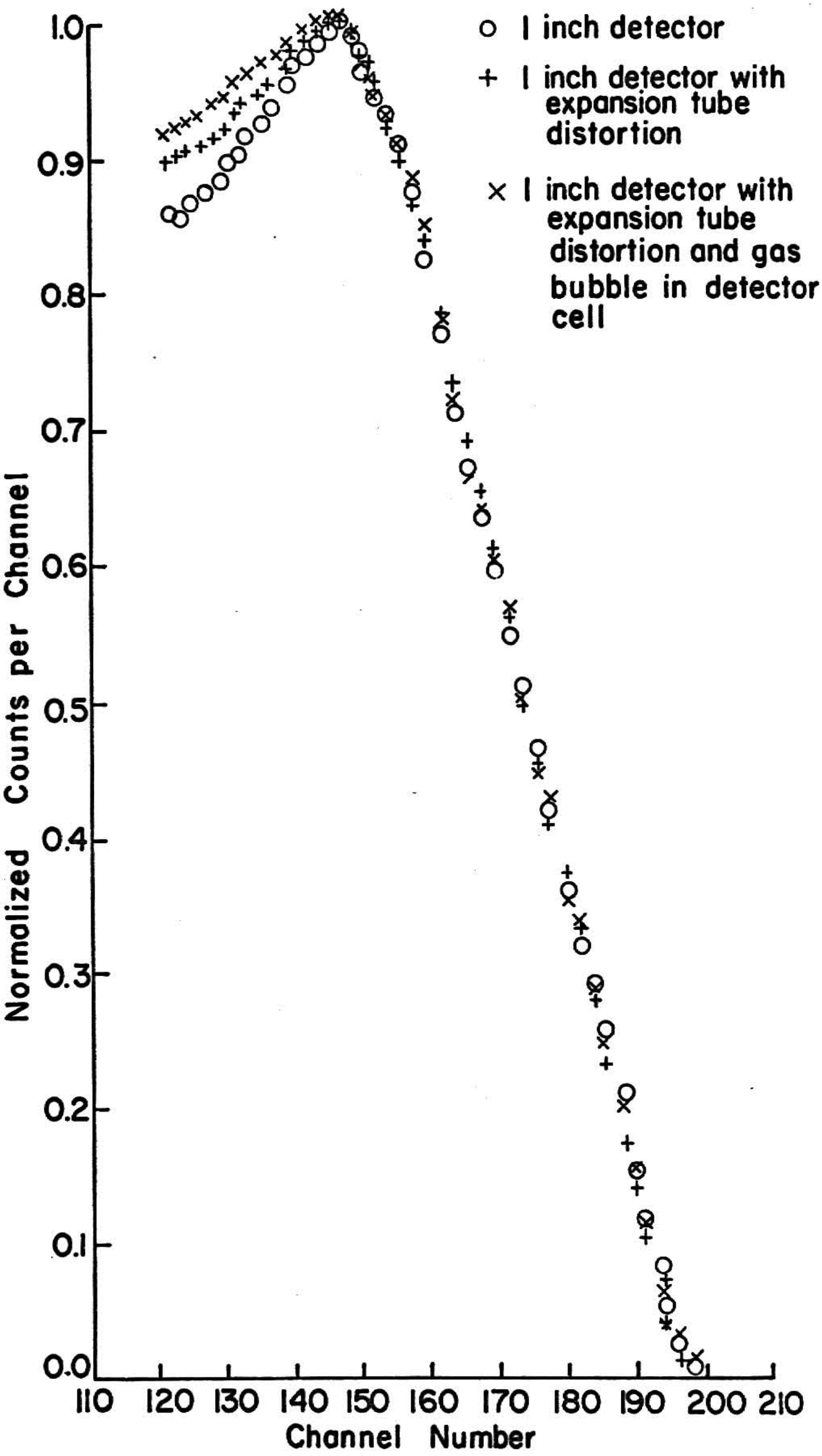

Figure 12. ^{60}Co Compton Edge for the 1 Inch Detector, with and without distortions.

for one hour) and compared to other PuBe spectra from which acceptable unfolded results have been obtained. Very small adjustments in the circuitry are then made, if necessary, until a good comparison in the low energy region (200 channels of pulse height data) is obtained with a standard PuBe spectrum. In this work, this is accomplished by comparison with both PuBe spectra collected with the 2 inch KSU NE-213 spectrometer system and the 1 inch NE-213 spectrometer system calibrated by Coolbaugh (1). Very slight changes at this final stage in the discriminator and focus settings of the Forte circuit, in the linear gate width, and in the discriminator levels may be necessary to obtain close agreement with a standard PuBe spectrum. When an acceptable PuBe spectrum has been collected, the system is considered to be acceptably calibrated. Unfolded PuBe pulse height spectra obtained using DUFOLD, the derivative unfolding code developed by Coolbaugh (1), are shown in Figure 13.

4.2 Calibration with Oxygen Penetration Spectra

This spectrometer has not been calibrated in the usual manner with accelerator produced monoenergetic neutrons. Oxygen penetration spectra are very nearly the responses to monoenergetic neutrons of 2.35 MeV energy. This is true because oxygen has a very narrow antiresonance cross section at 2.35 MeV (see Figure 14). Oxygen penetration spectra shown in Figure 15 indicate that there is little resolution difference in the detectors of different sizes.

The good agreement between the ^{60}Co spectra, the raw and unfolded PuBe spectra, and the oxygen penetration spectra shows that the three NE-213 detectors give results consistent to a degree that extensive calibration of the 1 inch and ½ inch detectors with a linear accelerator is not necessary.

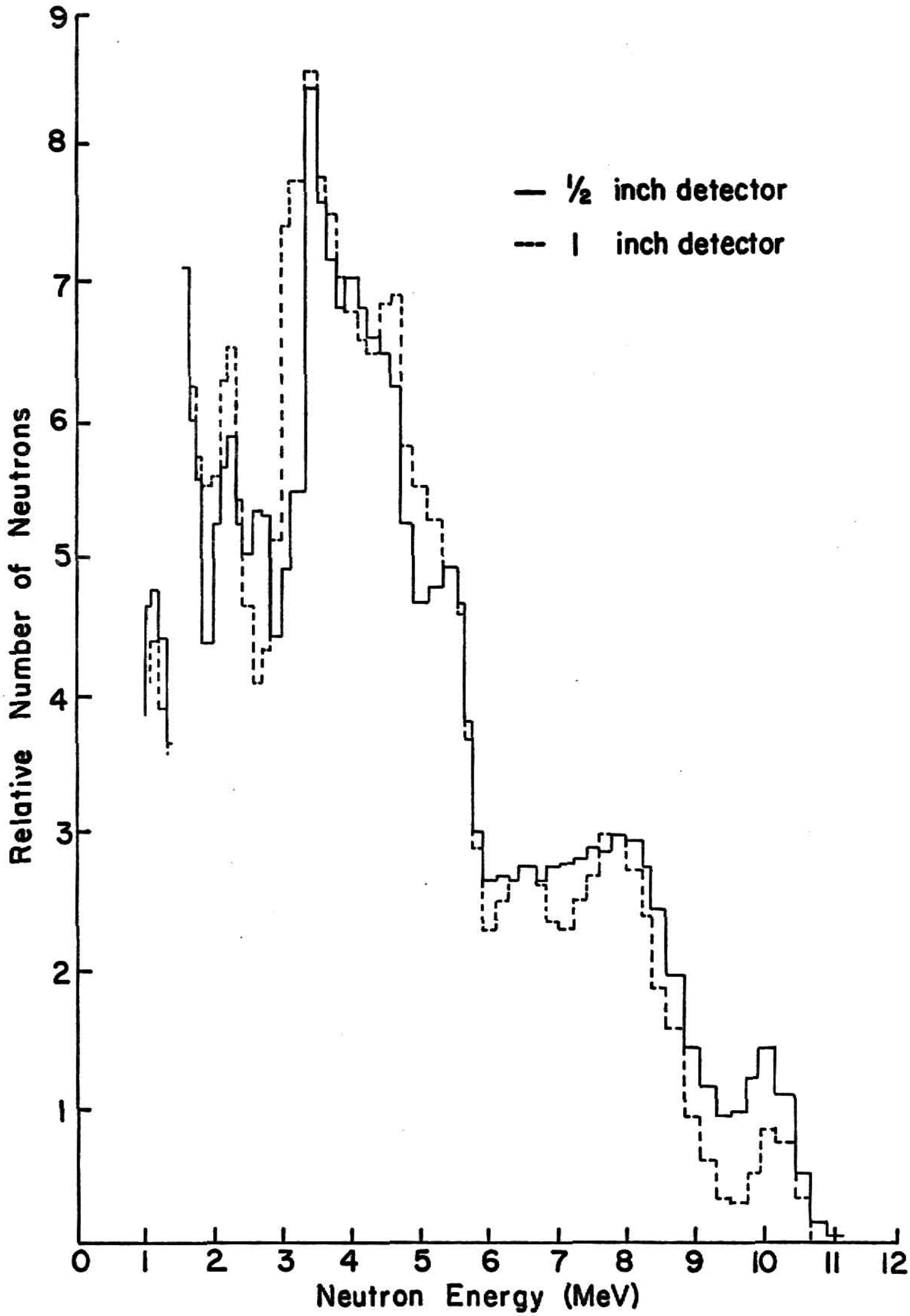

Figure 13. DUFOLD PuBe Spectra for the ½ and 1 Inch Detectors.

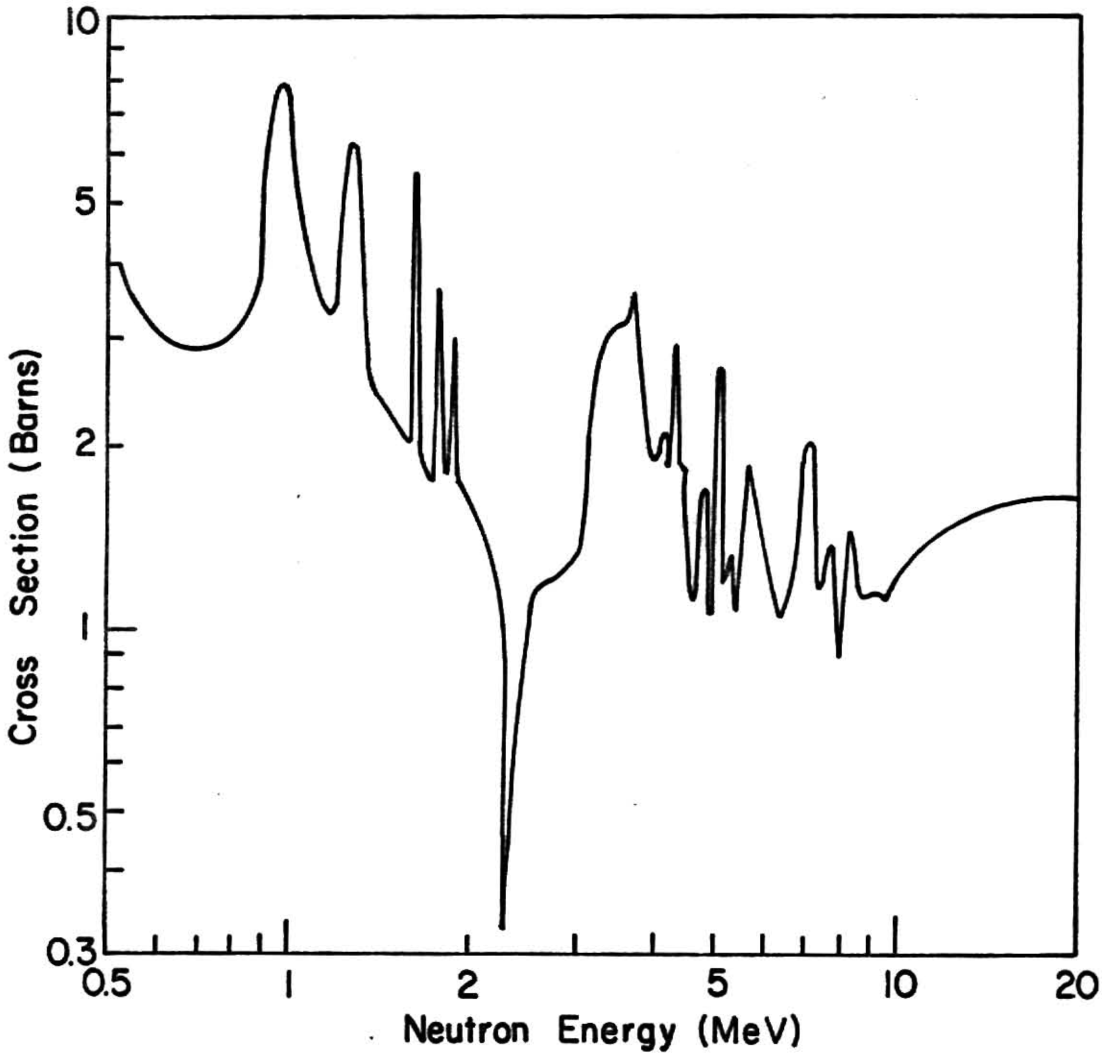

Figure 14. Oxygen Total Cross Sections.

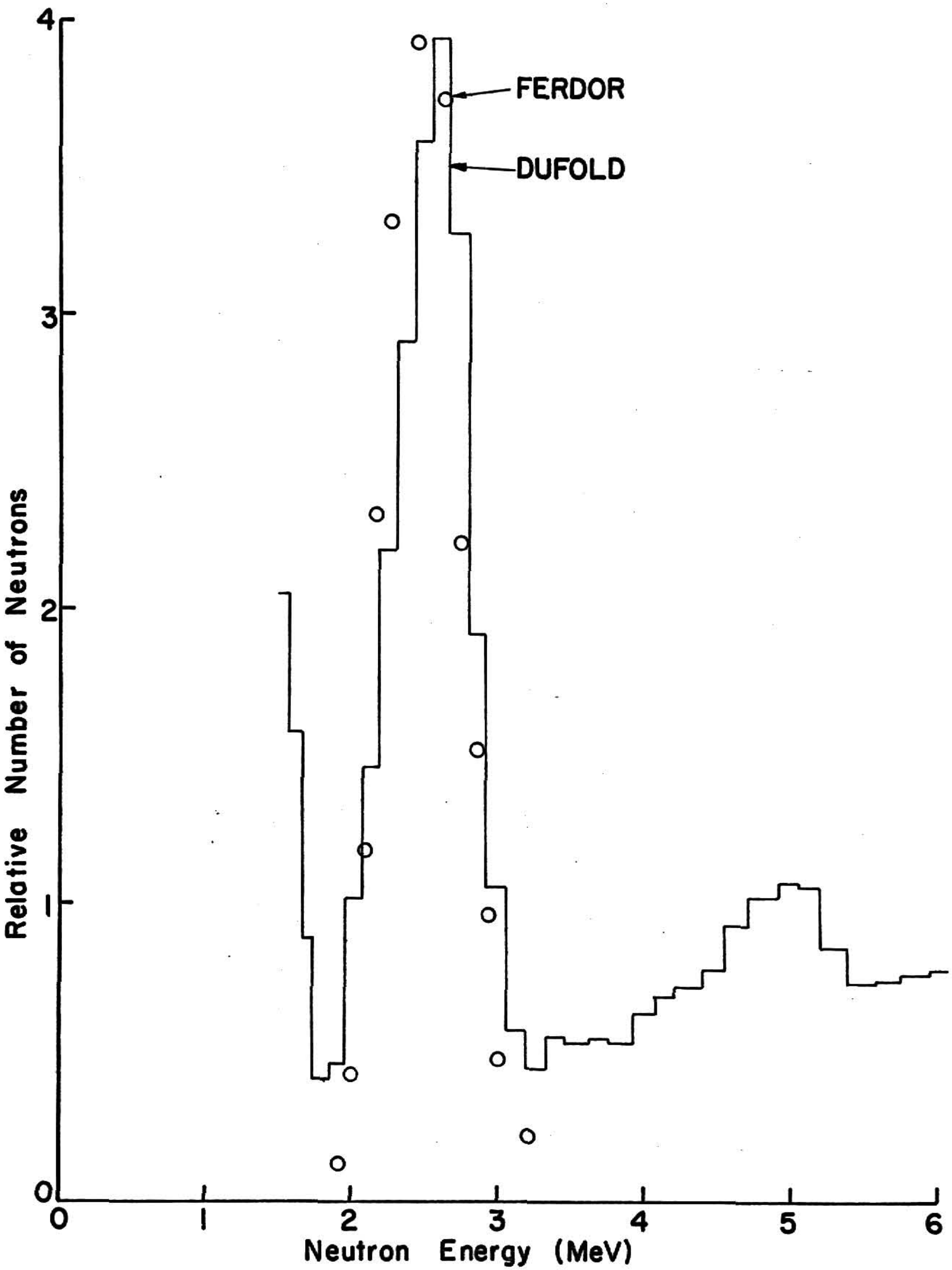

Figure 15. DUFOLD and FERDOR Oxygen Penetration Spectra with the ½ Inch and 2 Inch Detectors.

5.0 FISSION SPECTRA MEASUREMENTS

5.1 The Fueled Assembly

Because of the high residual gamma flux in the core of the KSU TRIGA Mark II Reactor, direct neutron spectrum core measurements are not possible with either the 1 inch or ½ inch NE-213 detectors. The 1 inch detector is saturated with gamma rays at approximately 8 feet.

A subcritical fueled assembly was constructed by Coolbaugh (1) for use in the TRIGA reactor bulk shielding facility. The fueled assembly corresponds exactly with the central thimble location and the B and C fuel element rings of the TRIGA reactor core. Thermal neutrons passing into the bulk shielding tank through the thermalizing column interact with the fueled assembly to simulate the reactor core.

The fuel elements, when originally used in the experiment, were new, and there was virtually no background activity present from the assembly. After storage in fuel storage racks in the reactor pool of the TRIGA reactor for 8 months there was measurable background activity. Using a thin window G-M tube measuring both beta and gamma radiation the most active fuel was monitored at 180 mr/hr (a gamma flux of about 120 mr/hr). Some of the fuel elements were stored at a greater distance from the core and their monitored fluxes were significantly lower. The measurements were made upon removal of the fuel from the reactor pool. It is assumed, however, that since the TRIGA reactor was shut down for 5 days prior to the fuel movement, the flux measured was not from quickly decaying isotopes. The 1 inch detector was placed in the fueled assembly, 5 days after movement of the fuel. The analyzer dead time in the anticoincidence mode was 89 per cent. The placement of lead sheets around the detector reduced the dead time to 70 per cent. In addition to the residual background, during the experiment there would be a significant amount of background activity from the core itself. Total background is defined for purposes of the experiment as any registered pulse in the spectrometer which is not caused by a fast fission neutron from the fueled assembly. Because of the high background, a fueled assembly experiment using the 1 inch detector was not conducted.

The ½ inch detector was placed in the same fueled assembly. The recorded dead time from residual activity was 40 per cent. The reduction in dead time with the ½ inch detector demonstrates that reduction of detector volume will allow work in higher level radiation environments. Unfortunately even the ½ inch detector is too sensitive to gamma radiation to function effectively in the fueled assembly with its high residual activity.

The fueled assembly experiment was conducted originally by Coolbaugh (1) in 1971 with completely "cold" fuel with the 1 inch detector using the equipment previously described. The fission spectrum obtained will be discussed later because of its similarity to ^{252}Cf spectra.

5.2 Underwater ^{252}Cf Spectral Measurements

The similarity between the ^{252}Cf spectra collected in air and the fueled assembly spectrum, the inability to repeat the fueled assembly experiment because of excessive induced activity, and the present availability at KSU of a large (∿40 mg.) ^{252}Cf source prompted the collection of underwater ^{252}Cf spectral measurements.

The KSU ^{252}Cf facility contains four ^{252}Cf sources approximately 10 mg. each. Figure 16 shows the facility which is located in the reactor bay of the KSU TRIGA reactor. Also shown in Figure 16 is the watertight NE-213

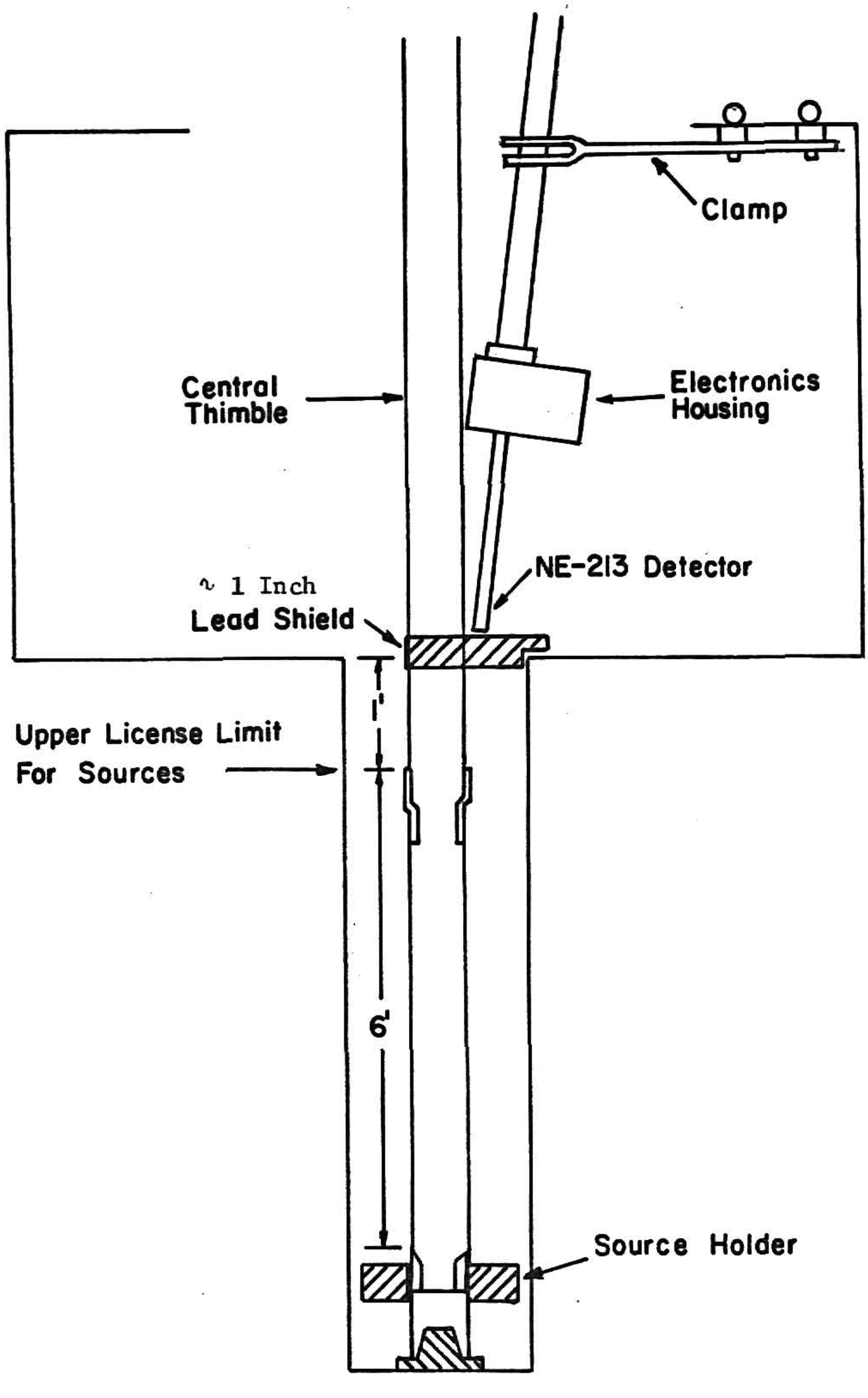

Figure 16. ^{252}Cf Geometry Showing Shielding Tank, Source Location and NE-213 Watertight Assembly.

assembly in the configuration that is used for the underwater spectral measurements. The ^{252}Cf sources can be raised together with the central thimble a distance of six feet to a level one foot below the shielding tank. With the NE-213 assembly located as shown in Figure 16, the ^{252}Cf sources are raised until an acceptable MCPHA dead time is reached with no excessive gamma distortion in the measured raw neutron spectrum at lower energies.

With the 1 inch detector the sources are raised 2½ feet from the bottom of the well (4½ feet from the detector). With the ½ inch detector the sources are raised 3½ feet from the bottom of the well (3½ feet from the detector). A lead gamma shield (of thickness two mean free paths for 1 MeV gamma-rays) is placed between the detector and the sources, allowing the sources to be raised to 4¼ feet from the bottom of the well (2-3/4 feet from the detector). The resulting spectra are discussed in Section 6.3.

5.3 Director Beam Measurement

Direct beam measurements from the fast beam port of the TRIGA reactor are obtained by aligning the NE-213 detector in the one inch by one inch square beam of neutrons. The direct beam spectrum is presented in Section 6.3.

6.0 RESULTS AND CONCLUSIONS

6.1 Development and Calibration

This study has resulted in the refinement of the electronic adjustment procedure for the miniature NE-213 detection system. The ½ inch NE-213 detector was designed and introduced into the existing watertight assembly. Experimental spectra obtained with the ½ inch detector are compared to new spectra obtained with the 1 inch detector and to existing 2 inch detector results. The ½ and 1 inch PuBe spectra unfolded with DUFOLD are shown in Figures 17 and 18. A 2 inch spectrum unfolded with DUFOLD is shown in Figure 19. These three PuBe spectra show increasing resolution with decreasing detector size. The 1 inch detector has better resolution in the 6 to 9 MeV region and has a stronger 10 MeV peak than does the 2 inch spectrum. The spectrum from the ½ inch detector shows for the first time with this spectrometer a 2.5 MeV peak, and in addition, shows the 5.5 MeV peak which appears only as a shoulder in the spectra from the larger detectors. With decreasing detector size, the amount of multiple interactions decreases, and the effect of edge distortions increases. The spectra in Figures 17, 18 and 19 indicate that the lessening of multiple interactions results in increased resolution, while the edge distortion effects are relatively unimportant. The STUNFO PuBe spectrum is presented for comparison in Figure 20.

The ½ inch detector DUFOLD PuBe spectrum is shown in Figure 21 with other PuBe spectra. The ½ inch detector DUFOLD peak locations are comparable with most of the other spectra presented. The Van der Zwan (12) spectrum is calculated, the Toms (5) stilbene detector spectrum is unfolded with NEUPST, the

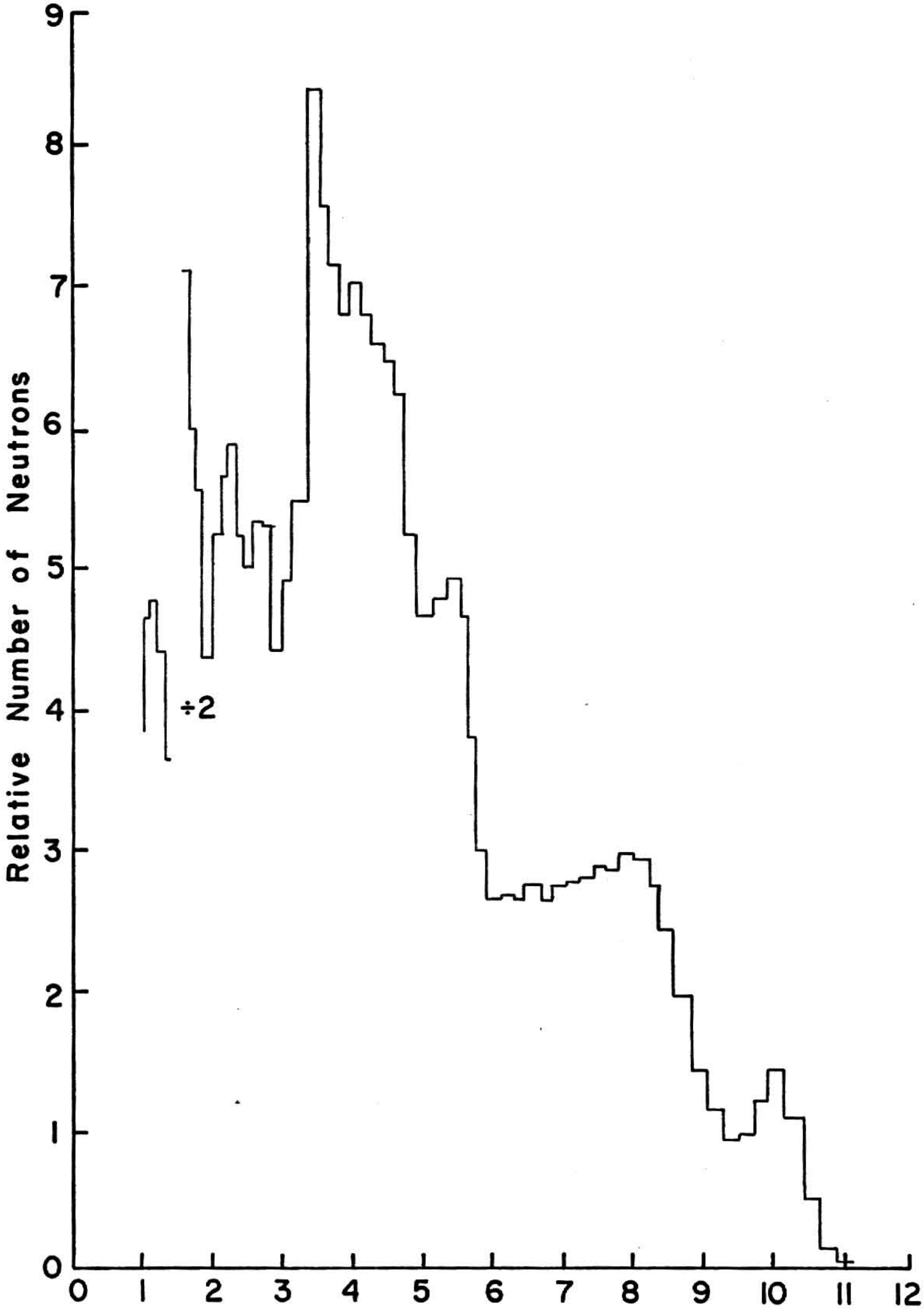

Figure 17. DUFOLD PuBe Spectrum for the ½ Inch Detector.

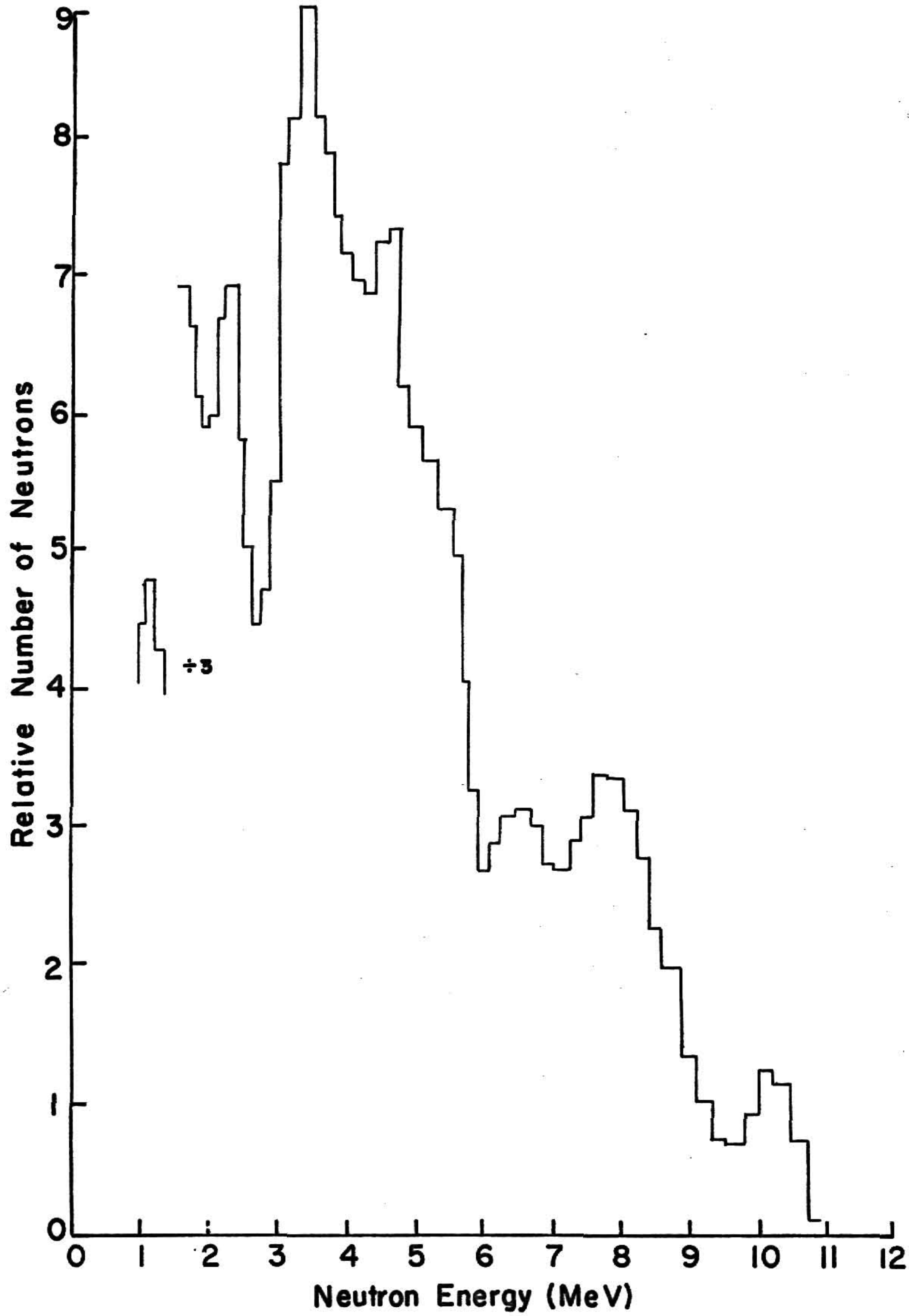

Figure 18. DUFOLD PuBe Spectrum for the 1 Inch Detector.

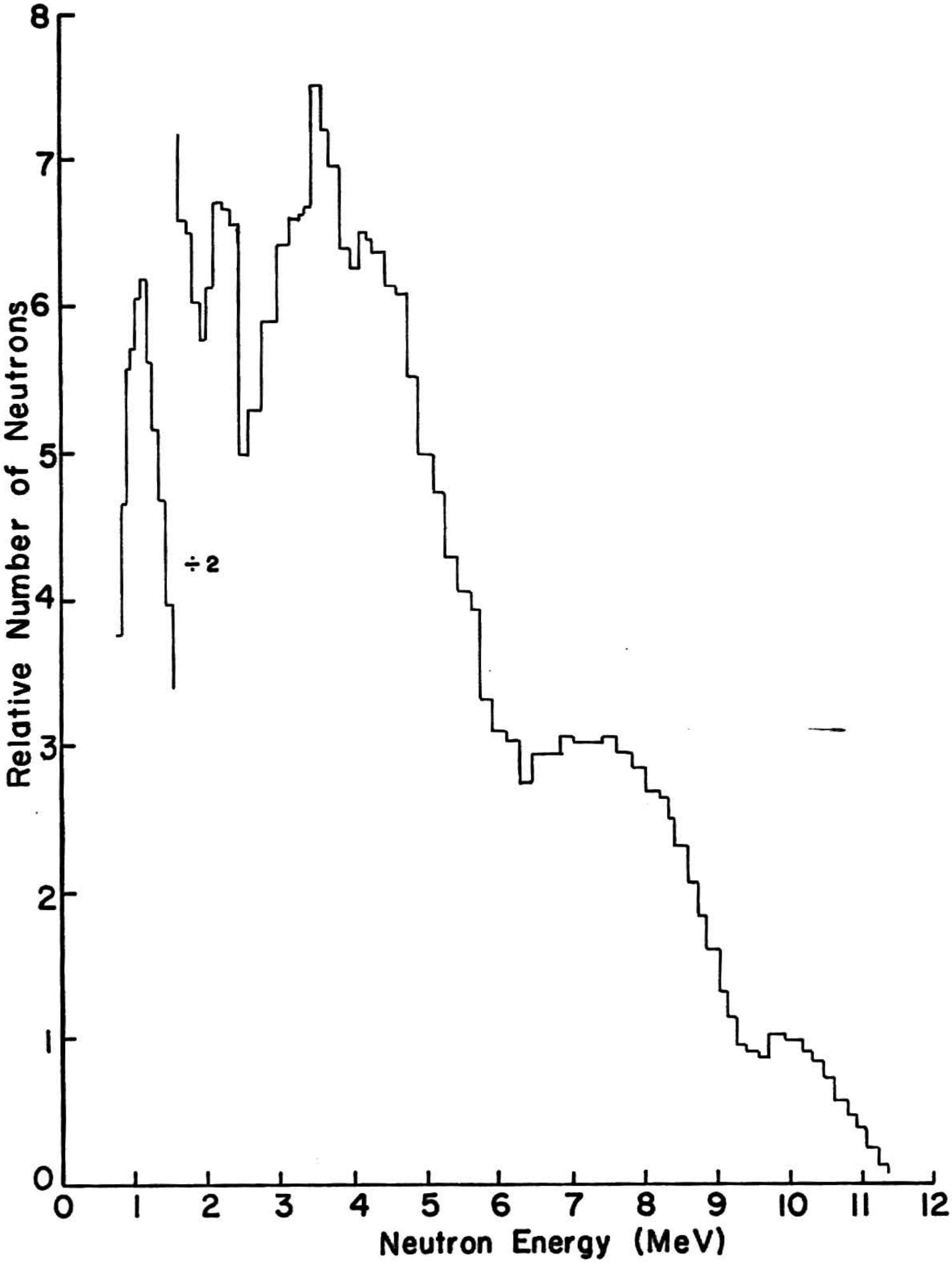

Figure 19. DUFOLD PuBe Spectrum for the 2 Inch Detector.

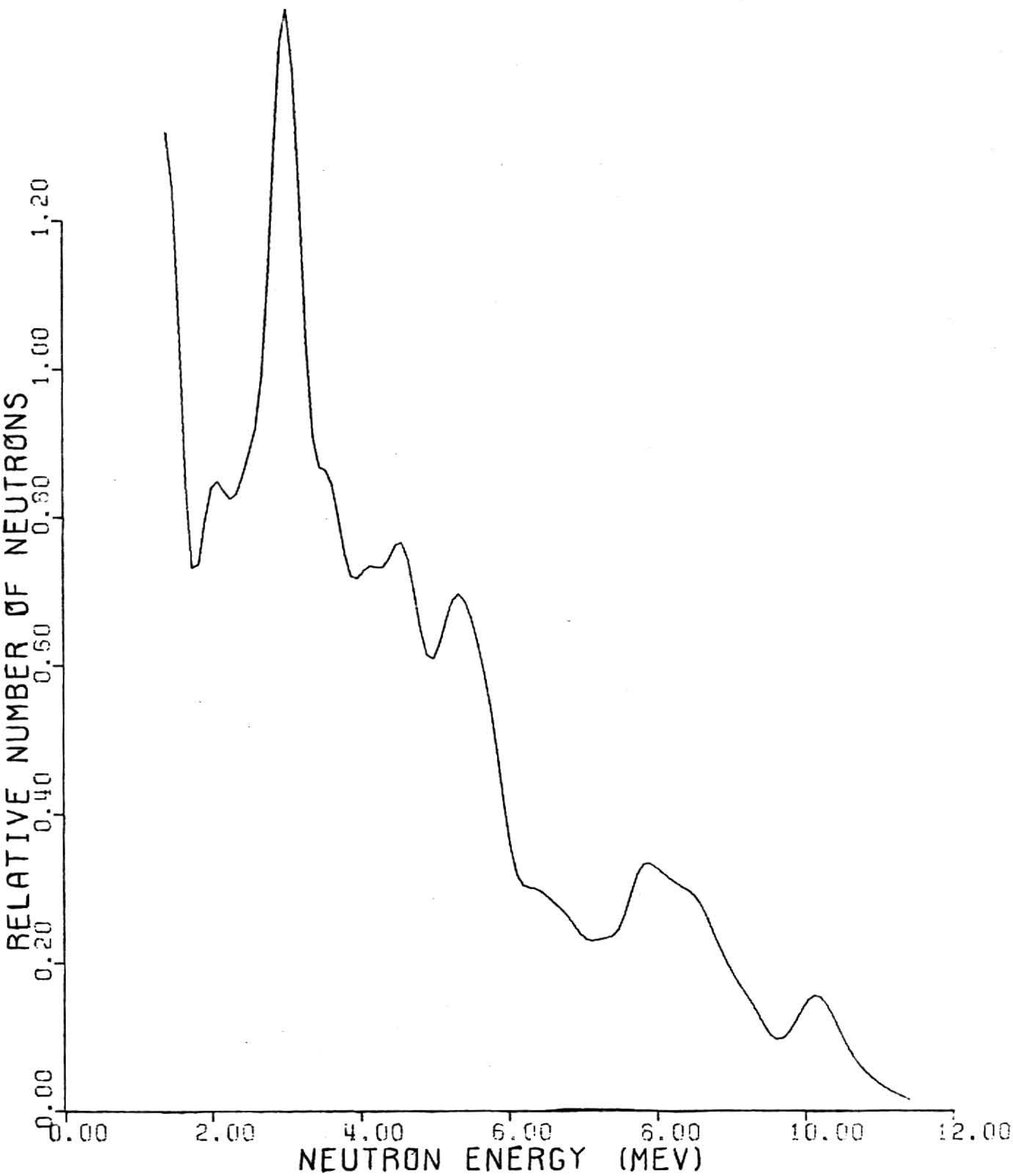

Figure 20. STUNFO PuBe Spectrum with the ½ Inch Detector.

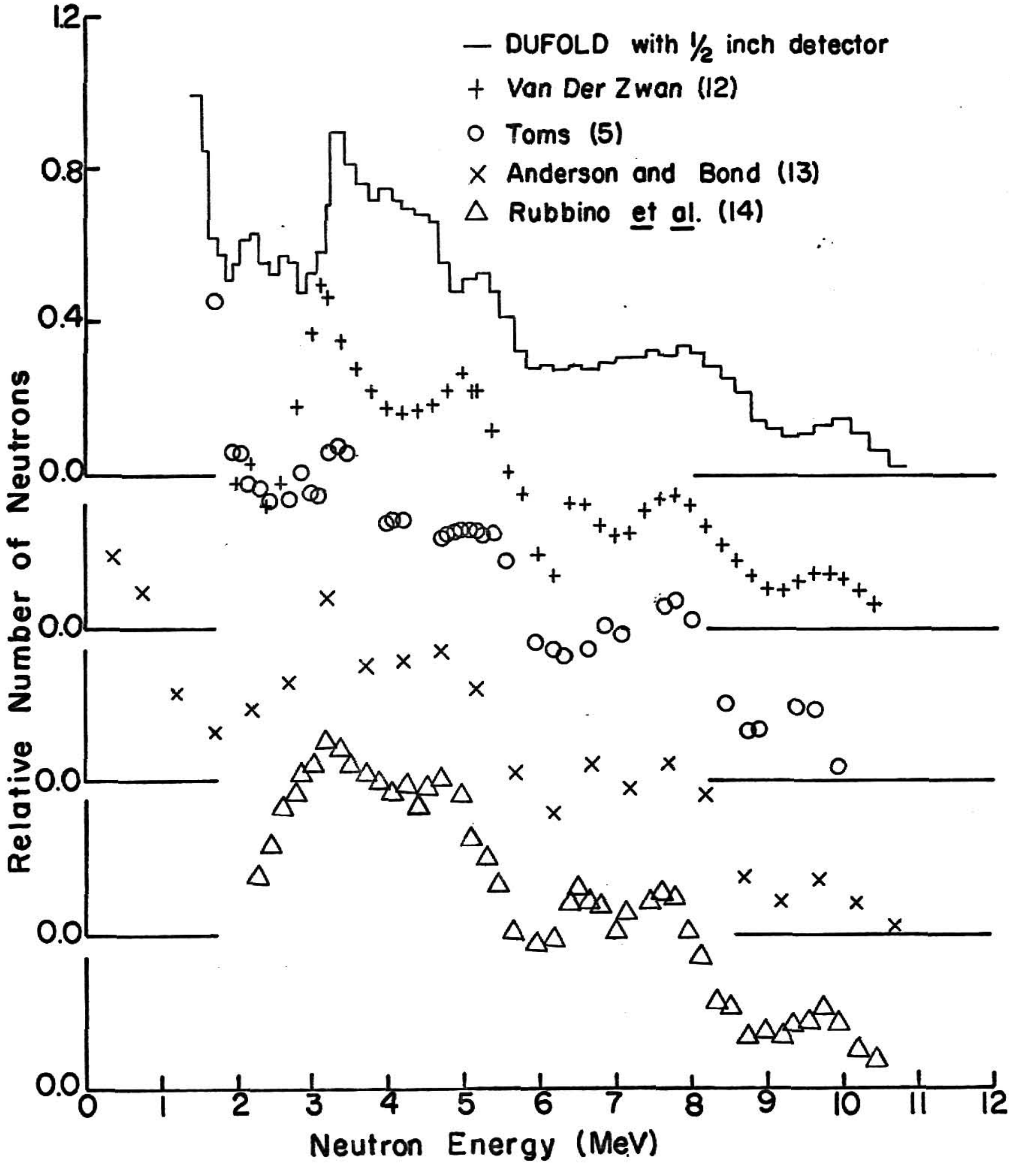

Figure 21. DUFOLD PuBe Spectrum with the ½ Inch Detector Compared to PuBe Spectra from Other Sources.

Anderson and Bond (13) spectrum is from nuclear emulsion data, and the Rubbino, Zubke, and Meixner (14) data were obtained with a neutron telescope.

6.2 Expansion Tube Sensitivity

The expansion tubes of miniature detectors are recognized for the first time as a problem area in miniature NE-213 detectors. The ½ inch detector as originally constructed was troubled with spectral distortion. Because the expansion tube contained more NE-213 fluid than did the cylindrical body of the cell, many light emissions from the expansion tube were included in the measured spectra. Spectra distortion is reduced to acceptable levels with the reduction of expansion tube volume.

The entire 1 inch detector (including the expansion tube) was originally coated with reflective paint by Nuclear Enterprises. Reflective paint tends to trap light in the expansion tube, and allow it to be transmitted to the photomultiplier tube. Removing the reflection paint from the expansion tube results in eased adjustment and calibration of the spectromter. The use of nylon twine for mechanical connection of the light pipe, light pipe spiral, and detector cell instead of black electricians tape also eases calibration. With both detectors the light produced in the expansion tube is allowed to escape into the light housing rather than being trapped in the cell and eventually reaching the photomultiplier tube.

6.3 Fission Spectra Measurements

As noted in the discussion of measurements with the fueled assembly, the reduction of dead time indicates the capability of a smaller detector to work in higher radiation environments.

The one inch detector placed in the KSU ^{252}Cf Facility yields a spectrum with a rapid drop in neutron intensity beyond 3 MeV. The water penetration in the Californium Facility considerably softened the fast fission spectrum present at the 4½ foot point where the 1 inch detector was located. Figure 22 also shows two ^{252}Cf spectra obtained with the ½ inch detector. One spectrum is water softened, and the other with a lead shield shows a virtually undistorted fission spectrum, the direct beam fission spectrum is shown for comparison in Figure 23. The fueled assembly fission spectrum collected by Coolbaugh (1) is shown in Figure 24. The underwater ^{252}Cf spectra compares favorably to both the direct beam and fueled assembly spectra.

The ^{252}Cf underwater spectrum is shown in Figure 25 with absolute flux obtained by intercalibrating the ½ inch detector with the KSU 2 inch absolute spectrometer. The ^{252}Cf spectra presented in Figure 22 further illustrate the decreased gamma sensitivity of the ½ inch detector as compared to the larger 1 inch detector.

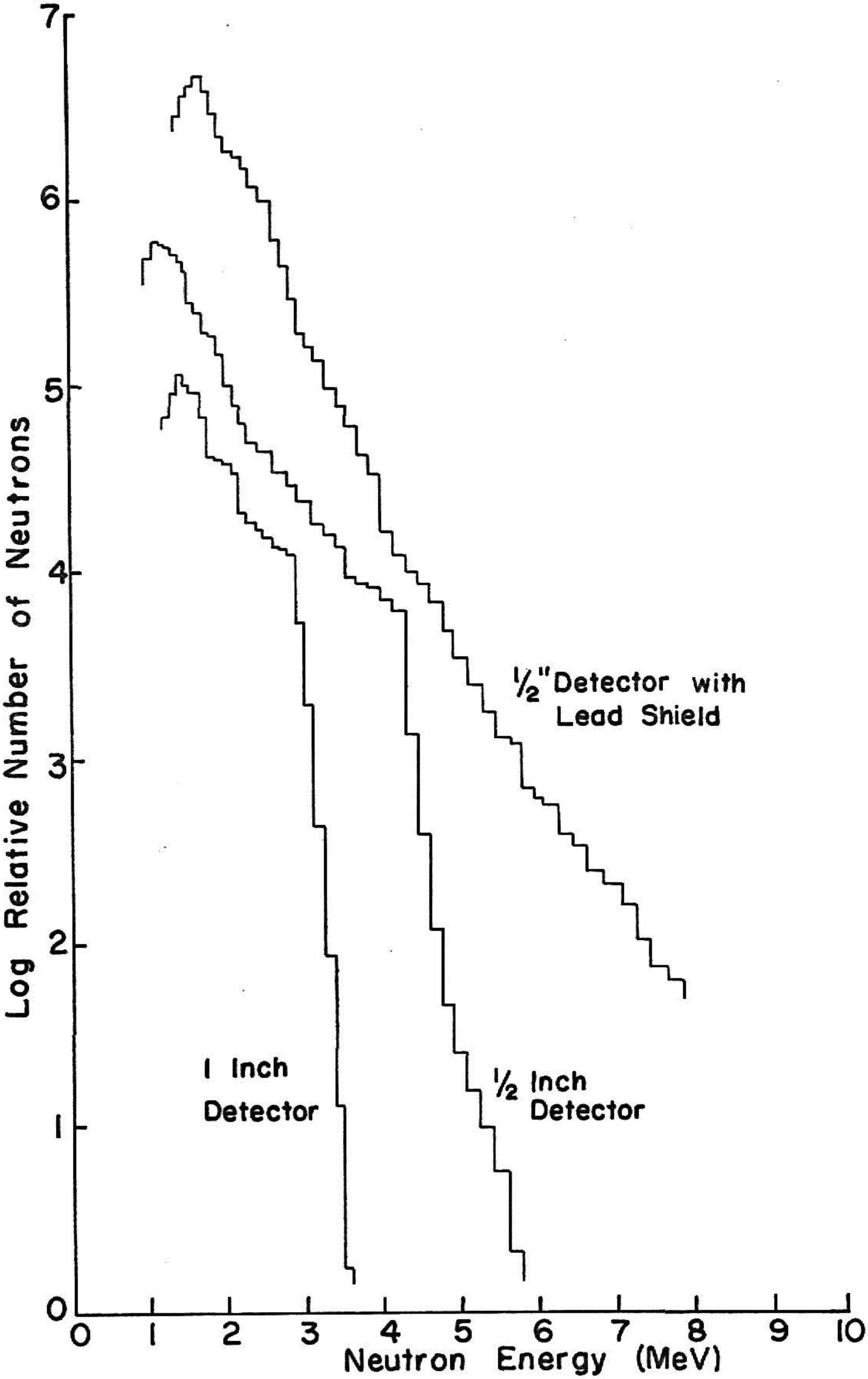

Figure 22. DUFOLD ^{252}Cf Spectra with the 1 Inch and ½ Inch Detectors, and the ½ Inch Detector with Lead Shield.

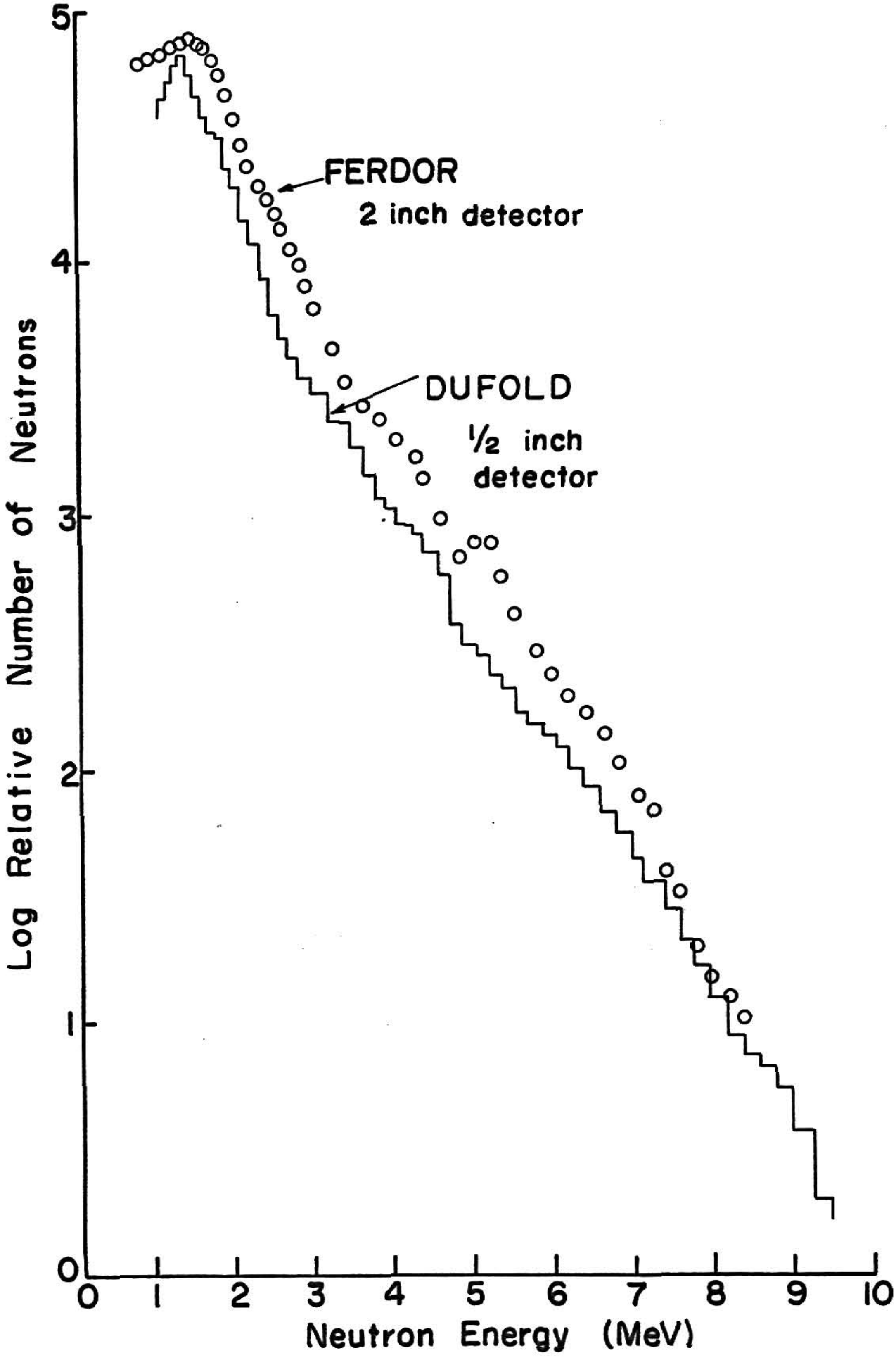

Figure 23. DUFOLD and FERDOR Fast Neutron Beam Port Spectra.

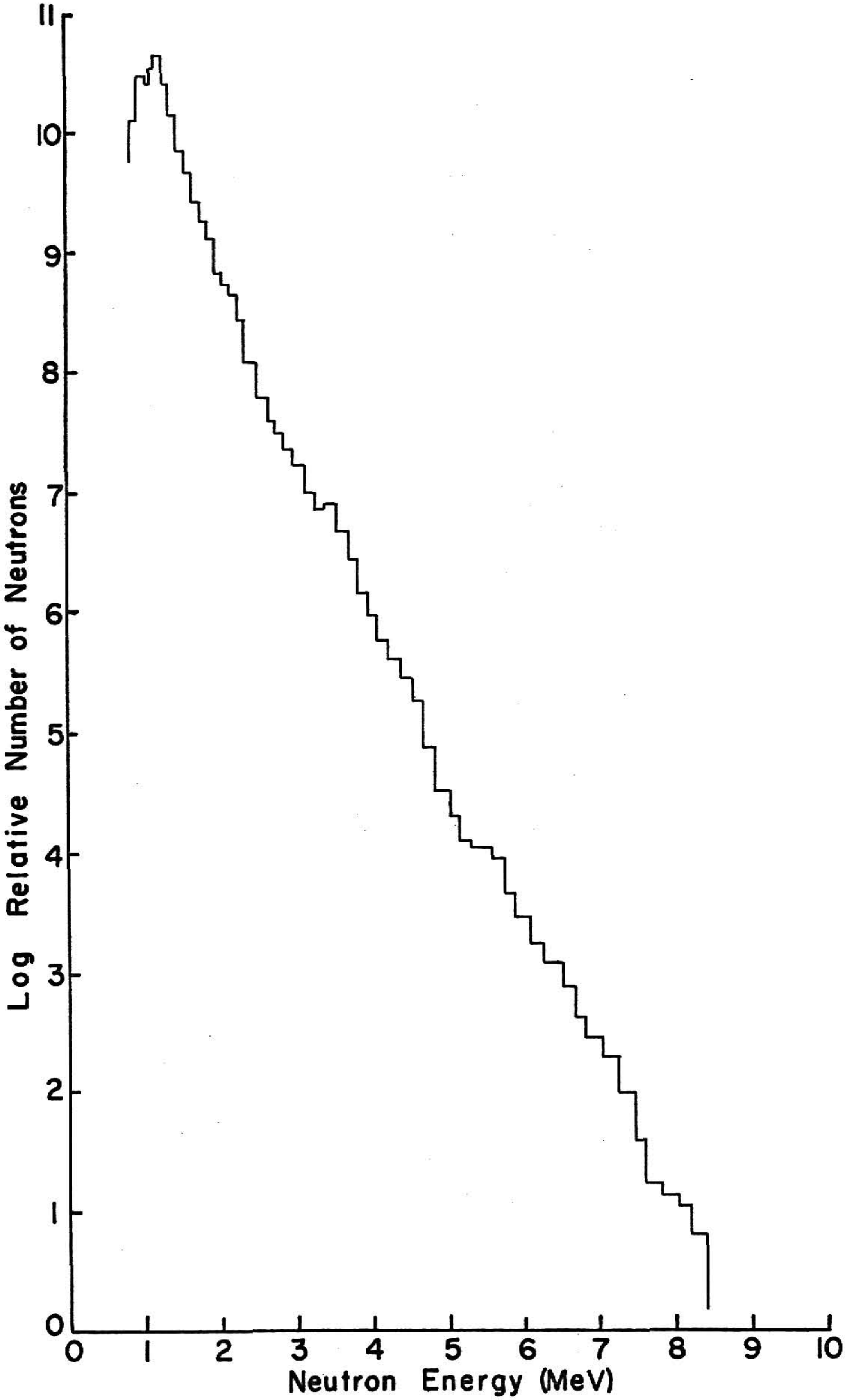

Figure 24. DUFOLD Fueled Assembly Spectrum of Coolbaugh (1).

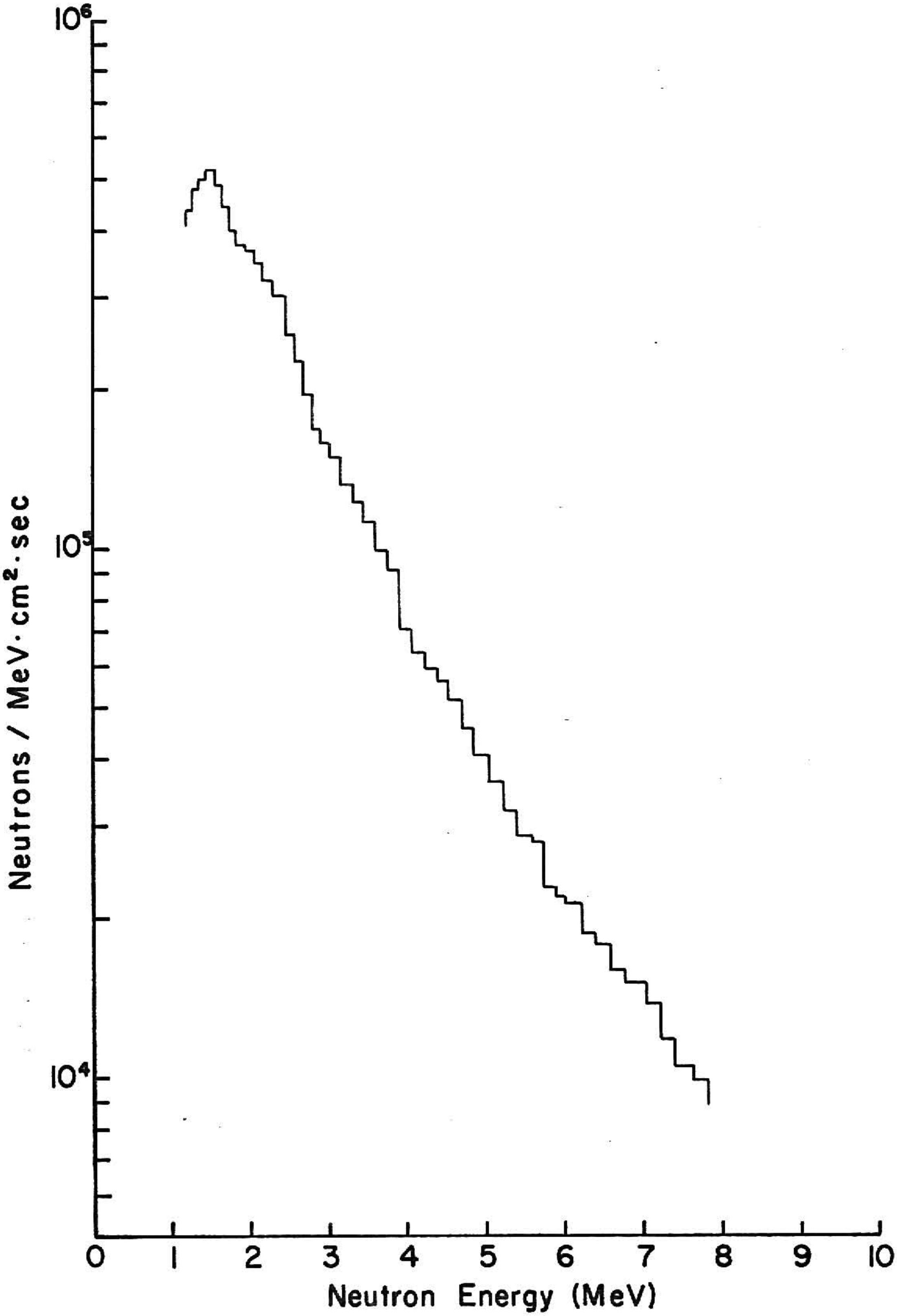

Figure 25. DUFOLD ^{252}Cf Fission Spectrum with ½ Inch Detector.

7.0 SUGGESTIONS FOR FURTHER STUDY

The similarity between the measured fuel assembly spectrum and the ^{252}Cf spectra would justify further data gathering using the KSU ^{252}Cf Facility and other ^{252}Cf sources. Coolbaugh (1) has suggested the determination of removal cross sections or similar parameters using the KSU ^{252}Cf Facility.

For short periods of time the ^{252}Cf sources of the KSU ^{252}Cf Facility may be separated with one source being placed on the bottom of the shielding tank (15). A special source holder is available for this purpose. Removal cross section determination could be made by placing slabs of material between a ^{252}Cf source on the bottom of the shielding tank and the watertight detector assembly. Smaller ^{252}Cf sources could probably be used more effectively for the same purpose in the bulk shielding tank of the TRIGA reactor.

8.0 ACKNOWLEDGEMENTS

The author wishes to thank Dr. Walter Meyer for directing this experimental effort, and for encouraging the author through both undergraduate and graduate studies.

Particular thanks are due Dr. Hermann J. Donnert, Director of Project Themis (under which support this research was conducted), and to the Atomic Energy Commission which supported this study under their traineeship program.

The support of the remaining faculty and staff of the Department of Nuclear Engineering is gratefully acknowledged.

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10.0 APPENDICES

10.1 Light Pipe Spiral

The light pipe spiral was constructed by Pilot Chemicals Division of New England Nuclear Corperation, Watertown, MA. Pilot Chemicals is now capable of making this spiral on a production basis based on the KSU design by Meyer and Coolbaugh.

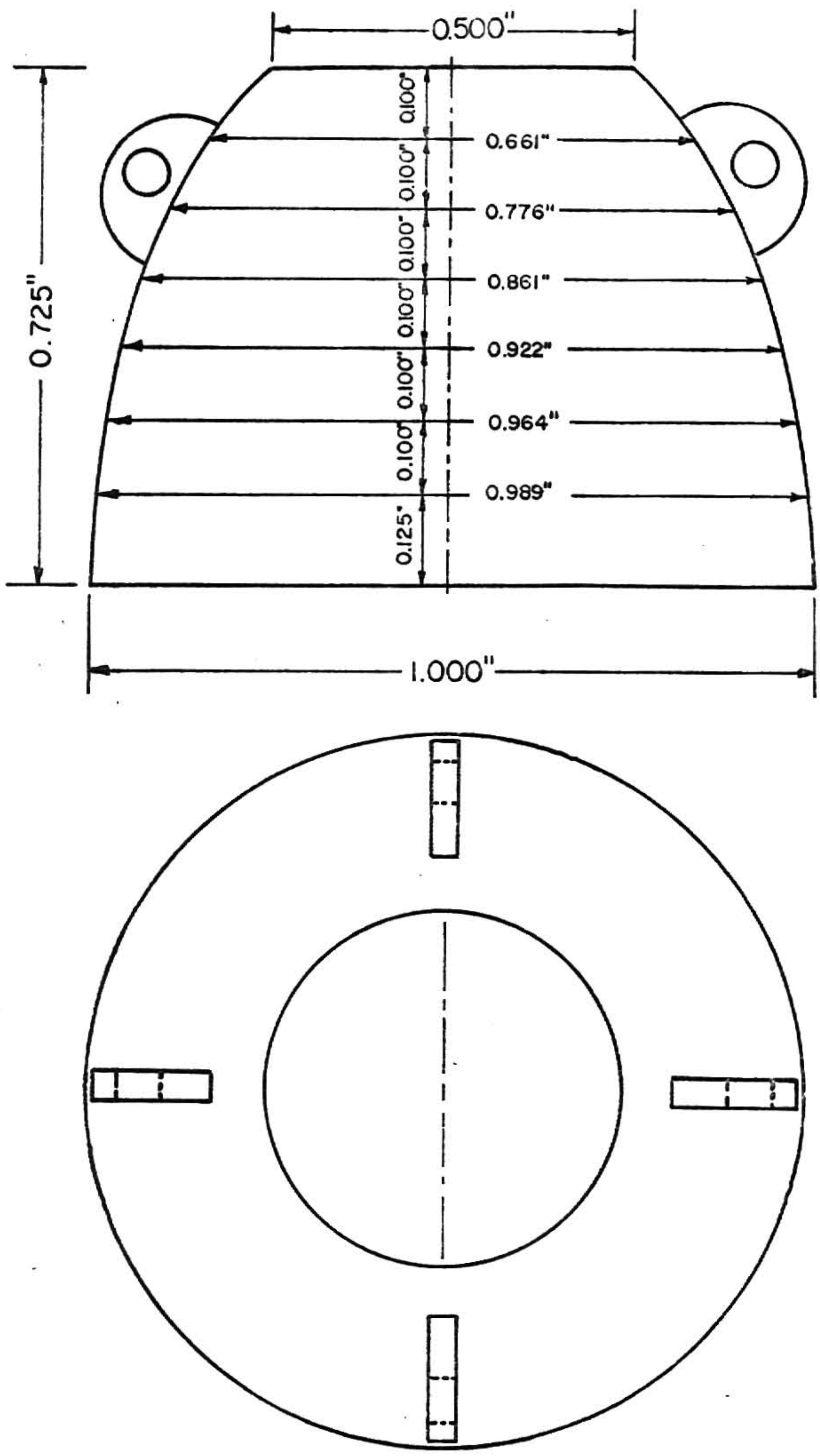

Figure 1A. Light Pipe Spiral.

10.2 Standard Electronic Configuration - 1 Inch Detector

The various settings of the electronics used for the spectra determinations with the 1 inch detector differ somewhat from the settings outlined by Coolbaugh (1) for the same type detector of 1 inch diameter. The differences are a result of reshaping of the PSD pulse with the Forte circuit focus and discriminator settings and the PSD Ortec 410 shaping amplifier. The change in shape necessitated the lengthening of the output pulses of linear and PSD TD 101/N signal discriminators and increasing the E bias level setting of the PSD TD 101/N discriminator. The reshaped PSD signal has a more definite gamma-ray crossover which results in simplified gamma discrimination, and a more stable system.

The linear signal did not undergo major adjustments, and the remainder of the electronics settings are virtually identical to those used by Coolbaugh.

APPENDIX

Standard Electronic Configuration

This section details the various settings used for the spectra determinations with the one inch detector. For a schematic of the system see Figure 9.

Fluke 410B HV Power Supply 2400 volts positive

Lambda LP412 Power Supplies (3) 40 volts positive, 24 volts positive, 24 volts negative

Tennelec TC 220 BLR Amplifier The linear signal is connected to the second stage (Input 2) which is connected internally to the third stage. The output is taken from the third stage. The settings are:

Course Gain	= 256	Fine Gain = 1.0
1st Differentiator	= minimum	Input 2
2nd Differentiator	= Hi Counting Rate	Output 3
Integrator	= 0.4 μsec	
BLR	= Bipolar Position	

Linear TD101/N Discriminator The output from the TC 220 BLR is the input to this unit. The settings are:

Ungated	INT Mode
ΔE = maximum	E = .200 mv
Width = 2.80 μsec	Delay = none

Linear Ortec 410 Amplifier The input to this unit is the linear signal through a 50 ohm feed-through. The output is taken from the 93 ohm Unipolar Output. The settings are:

Polarity = Negative	Attenuator = 5
Course Gain = 9	Fine Gain = 2.6 approximately
1st Differentiator = 0.5	Integrator = 2
2nd Differentiator = out	

Ad-Yu Variable Delay 2011 The input to this unit is the output from the Linear Ortec 410 Amplifier. The output is the input to the +8 V analyzer input. The setting is 1.30 μsec.

PSD Ortec 410 Amplifier The input to this unit is the PSD signal through a 50 ohm feed-through. The input is taken from the 93 ohm Unipolar Output. The settings are:

Polarity = Positive	Attenuator = 2
Coarse Gain = 9	Fine Gain = 1.7
1st Differentiator = 10	Integrator = 1
2nd Differentiator = out	

PSD TD101/N Discriminator The output from the PSD Ortec 410 Amplifier is the input to this unit. The settings are:

Ungated	INT Mode
Δe = maximum	E = .310 mv approximately
Width = 4.00 μsec	Delay = none

C104A/N Coincidence The inputs to this unit are the outputs from the two Discriminators. This unit is used in the AND mode to output a gating pulse when a neutron interacts in the detector.

GG 200/N Gate Generator The output from the C104A/N Coincidence unit is input to the LO terminal on this unit. The G output is input to the analyzer Coincidence Input and the $\bar{G}$ output drives the Hammer Scaler. The Width setting is 0.785 μsec.

<u>TMC 4096 Multiparameter Analyzer</u> The inputs to this unit are the linear signal from the Ad-Yu Variable Delay 2011 into the +8 V ADC input, and the coincidence signal from the GG 200/N Gate Generator into the ADC NORMAL COINCIDENCE Input.

10.3 Standard Electronic Configuration - ½ Inch Detector

APPENDIX

Standard Electronic Configuration

This section details the various settings used for the spectra determinations with the half inch detector. For a schematic of the system see Figure 9.

Fluke 410B HV Power Supply 2400 volts positive

Lambda LP412 Power Supplies (3) 40 volts positive, 24 volts positive, 24 volts negative

Tennelec TC 220 BLR Amplifier The linear signal is connected to the second stage (Input 2) which is connected internally to the third stage. The output is taken from the third stage. The settings are:

Course Gain	= 256	Fine Gain = 1.0
1st Differentiator	= minimum	Input 2
2nd Differentiator	= Hi Counting Rate	Output 3
Integrator	= 0.4 μsec	
BLR	= Bipolar Position	

Linear TD101/N Discriminator The output from the TC 220 BLR is the input to this unit. The settings are:

Ungated	INT Mode
ΔE = maximum	E = .690 mv
Width = 2.10 μsec	Delay = none

Linear Ortec 410 Amplifier The input to this unit is the linear signal through a 50 ohm feed-through. The output is taken from the 93 ohm Unipolar Output. The settings are:

Polarity	= Negative	Attenuator	= 5
Course Gain	= 9	Fine Gain	= 2.2 approximately
1st Differentiator	= 0.5	Integrator	= 2
2nd Differentiator	= out		

Ad-Yu Variable Delay 2011 The input to this unit is the output from the Linear Ortec 410 Amplifier. The output is the input to the +8 V analyzer input. The setting is 1.30 μsec.

PSD Ortec 410 Amplifier The input to this unit is the PSD signal through a 50 ohm feed-through. The input is taken from the 93 ohm Unipolar Output. The settings are:

Polarity	= Positive	Attenuator	= 2
Coarse Gain	= 9	Fine Gain	= 2.25
1st Differentiator	= 10	Integrator	= 1
2nd Differentiator	= out		

PSD TD101/N Discriminator The output from the PSD Ortec 410 Amplifier is the input to this unit. The settings are:

Ungated	INT Mode
ΔE = maximum	E = .430 mv approximately
Width = 4.00 μsec	Delay = none

C104A/N Coincidence The inputs to this unit are the outputs from the two Discriminators. This unit is used in the AND mode to output a gating pulse when a neutron interacts in the detector.

GG 200/N Gate Generator The output from the C104A/N Coincidence unit is input to the LO terminal on this unit. The G output is input to the analyzer Coincidence Input and the $\bar{G}$ output drives the Hammer Scaler. The Width setting is 0.785 μsec.

TMC 4096 Multiparameter Analyzer The inputs to this unit are the linear signal from the Ad-Yu Variable Delay 2011 into the +8 V ADC input, and the coincidence signal from the GG 200/N Gate Generator into the ADC NORMAL COINCIDENCE Input.

10.4 Pulse Height Transformation Code NUDASBIN

APPENDIX

Pulse Height Data Transformation Code

NUDASBIN

NUDASBIN is a raw data shifting and binning code developed and written by James W. Thiesing, Kansas State University, Manhattan, Kansas (16). This code has numerous options, some of which are, (1) gain shifting of raw data using predetermined location of the ^{60}Co tail, (2) gain shifting using an internal least squares fit of ^{60}Co edge data read into the code, (3) background or foreground data normalization using either counting times or foil activation data, (4) background subtraction from foreground data, and (5) several output data formats.

The code is written for the IBM 360 Model 50 computer and requires approximately 0.008 hours of execution time. The following pages detail the input data required.

NUDASBIN (Neutron Data Shifting and Binning)

CARD	FORMAT	
1	1I10	NDS - NUMBER OF DATA SETS TO BE ENTERED
2	1I10	IDTAG - ARBITRARY I.D. NUMBER FOR EACH DATA SET
3	20A4	TITLE - ARBITRARY ALPHAMERIC TITLE CARD IDENTIFYING THE DATA SET.
4	5I10,F10.0,2I10	1. ICØ = IF CO-60 SPECTRUM IS TO BE USED TO DETERMINE 1 COBALT CHANNEL FOR FOREGROUND

ICØ = 0 IF THE ONE COBALT CHANNEL FOR THE FOREGROUND IS TO BE READ IN.

2. ICØBKG = 1 FOR CO-60 FITTING FOR THE BKGD.

ICØBKG = 0 IF ONE COBALT CHANNEL IS TO BE READ IN FOR BKGD.

ICØBKG = 2 IF THE ONE COBALT CHANNEL FOR BKGD IS TO BE ASSUMED THE SAME AS FOR THE FOREGROUND.

3. IØUT = 0 FOR NEUSTEP FORMAT PUNCHED OUTPUT.

IØUT = 1 FOR FERDOR FORMAT PUNCHED OUTPUT.

IØUT = 2 FOR BOTH FERDOR AND NEUSTEP PUNCHED OUTPUT.

IØUT = 5 FOR ONLY 1024 CHANNELS OF SHIFTED NET DATA PUNCHED OUTPUT. (1024 CHANNELS PUNCHED WITH ALL OTHER OUTPUT OPTIONS ALSO.) (NUDASBIN ONLY, NOT AVAILABLE WITH NUDASBIN II.)

4. IBKG = 0 FOR NO BKGD. SUBTRACTION.

IBKG = 1 FOR BKGD SUBTRACTION (IF IBKG = 0, THEN ICØBKG CAN BE ANYTHING).

5. NCHH - NUMBER OF CHANNELS OF NEUTRON DATA (BEGINNING IN CHANNEL 1) TO BE READ IN AND IS THE SAME FOR FGD & BKGD.

6. CØSHFT - CHANNEL TO WHICH THE DATA IS TO BE SHIFTED (NORMALLY BASED ON HIGH GAIN CHANNEL I.E. CH 200).

7. INØRM = 1 FOR BACKGROUND TO FOREGROUND NORMALIZATION USING ACTIVATION DATA.

INØRM = 0 FOR NORMALIZATION USING COUNTING TIMES ONLY.

8. IØFLØ = 0 IF NO CHANNELS OVERFLOWED THE ANALYZER MEMORY. (FOREGROUND).

IØFLØ = 1 IF SOME CHANNELS OVERFLOWED TO 100,000. (FOREGROUND).

IØFLØ = 2 IF SOME CHANNELS OVERFLOWED TO 100,000 AND SOME TO 200,000 ETC. (FOREGROUND).

5	1F10.0	CTF - FOREGROUND COUNTING TIME IN HOURS.
6 deck	6X,12F6.0,2X	Y(I) - FOREGROUND COUNTS PER CHANNEL FOR CHANNELS 1 TO NCHH.
7	16I5	NØFLØ(J), J=1, IØFLØ - NUMBER OF CHANNELS THAT ARE OVERFLOWED TO 100,000, 200,000, ETC. (FOREGROUND)
8	16I5	NCØFLØ(K), K=1, NØFLØ(J), FØR EACH J. CHANNEL CHANNEL NUMBERS OF THOSE CHANNELS OVERFLOWED TO 100,000, 200,000, ETC. (FOREGROUND)
9	5I10	THIS CARD NEEDED ONLY IF ICØ = 1

1. NCØL - LOWEST CHANNEL OF CO-60 DATA TO BE READ IN FOR THE FOREGROUND.

2. NCØH - HIGHEST CHANNEL OF CO-60 DATA TO BE READ IN FOR THE FOREGROUND.

3. NFITLØ - LOWEST CHANNEL TO BE USED IN THE FIT OF THE CO-60 TAIL.

4. NFITHI - HIGHEST CHANNEL TO BE USED IN THE FIT OF THE CO-60 TAIL.

5. NCØDS - ARBITRARY I.D. NUMBER FOR THE CO-60 DATA SET.

10 deck	6x,12F6.0,2x	YCØ(I) - CO-60 SPECTRUM (COUNTS/CHAN.) FROM CH. NCØL TO CH. NCØH FOR THE FOREGROUND. THIS DECK NEEDED ONLY IF ICØ = 1
9,10	1F10.0	CØFIT - CHANNEL IN WHICH ONE COBALT FALLS FOR THE FOREGROUND. THIS CARD REPLACES CARD 9 AND DECK 10 IF ICØ = 0 AND IS USED ONLY IF ICØ = 0
11	1F10.0	CTBKG - BACKGROUND COUNTING TIME IN HOURS. THIS CARD IS NEEDED ONLY IF IBKG = 1
12 deck	6x,12F6.0,2x	BKG(I) - BACKGROUND COUNTS PER CHANNEL FROM CH. 1 TO CH. NCHH THIS DECK NEEDED ONLY IF IBKG = 1
13	5I10	CØL, NCØH, NFITLØ, NFITHI, NCØDS AS FOR CARD 9 (FOR THE BKGD) THIS CARD USED ONLY IF ICØBKG = 1 AND IBKG = 1
14 deck	6x,12F6.0,2x	YCØ(I) - FOR THE BKGD. (AS IN DECK 10) THIS DECK USED ONLY IF ICØBKG = 1 AND IBKG = 1
13,14 (ALTERNATE)	1F10.0	CØBKG - CHANNEL IN WHICH ONE COBALT FALLS FOR THE BACKGROUND. THIS CARD REPLACES CARD 13 AND DECK 14 IF IBKG = 1 AND I¢OBKG = 0.
15	8F10.0	THIS CARD USED ONLY IF INØRM = 1

1,2. CF AND CB ARE THE TOTAL COUNTS FOR THE FOREGROUND AND BACKGROUND NORMALIZATION SAMPLES

3,4. CTSF AND CTSB ARE THE COUNTING TIMES FOR THE FOREGROUND AND BACKGROUND SAMPLES AND MUST BE IN THE SAME UNITS.

5,6. AIRIF AND AIRTB ARE THE IRRAD. TIMES FOR THE FOREGROUND AND BACKGROUND SAMPLES.

7,8. DTF AND DTB ARE THE DECAY TIMES FOR THE FOREGROUND AND BACKGROUND SAMPLES.

(AIRTF, AIRTB, DTF, DTB MUST BE IN THE SAME UNITS)

16 3F10.0 1,2. WF AND WB ARE THE FOREGROUND AND BACKGROUND SAMPLE MASSES AND MUST BE IN THE SAME UNITS.

3. ALAMB - DECAY CONSTANT OF THE SAMPLES IN INVERSE UNITS OF AIRTF, AIRTB, DTF, AND DTB.

THIS CARD USED ONLY IF INØRM = 1

Notes: 1. FOR NUDASBIN II, (TWO GAIN DATA), THE HIGH GAIN DATA IS TREATED AS ONE SET OF DATA WITH CØSHIFT EQUAL TO THE NOMINAL HIGH GAIN ONE COBALT POSITION (CH. 200) AND THE LOW GAIN AS ANOTHER SET WITH CØSHIFT EQUAL TO THE NOMINAL LOW GAIN ONE COBALT POSITION (CH. 40 OR 20). HIGH GAIN DATA SET IS ENTERED FIRST. THEN THE CORRESPONDING LOW GAIN SET, THEN ANOTHER HIGH GAIN SET, ETC. THE MEMORY OVERFLOW OPTIONS ARE NOT AVAILABLE WITH NUDASBIN II.

2. FOR NUDASBIN, AND NUDASBIN II ENTRY 1 (NDS) IS USED ONLY ONCE AND ENTRIES 2-16 ARE USED FOR EACH DATA SET.

```
C******* THIS CODE DEVELOPED AND WRITTEN BY JAMES W. THIESING,
C         DEPT. OF NUCLEAR ENGG., KANSAS STATE UNIV., MANHATTAN, KS. ****
      DIMENSION Y(1024),BKG(1024),YCC(1024)
     1,TITLE(20)
     2,NOFLC(6),NCOFLC(30,6),INET(1024)
  501 FORMAT(20A4)
  502 FORMAT(1I10)
  503 FORMAT(5I10,F10.0,2I10)
  504 FORMAT(1F10.0)
  505 FORMAT(6X,12F6.0,2X)
  506 FORMAT(1H0,42HUNSHIFTED FOREGROUND DATA BEGINNING IN CH1)
  507 FORMAT(1H0)
  508 FORMAT(1H0,24HFOREGROUND COUNTING TIME,F7.4,1X,4HHRS.)
  509 FORMAT(1X,10F7.0)
  510 FORMAT(5I10)
  511 FORMAT(1H0,14HCO-60 DATA SET,I5,5X,21HONE COBALT IN CHANNEL,F7.2)
  512 FORMAT(1H0,42HUNSHIFTED BACKGROUND DATA BEGINNING IN CH1)
  513 FORMAT(1H0,29HSHIFT FOREGROUND DATA FROM CH,F7.2,2X,5HTO CH,F7.2)
  514 FORMAT(1H0,29HSHIFT BACKGROUND DATA FROM CH,F7.2,2X,5HTO CH,F7.2)
  515 FORMAT(1H0,24HBACKGROUND COUNTING TIME,F7.4,1X,4HHRS.)
  516 FORMAT(1H0,40HSHIFTED NET COUNT RATES BEGINNING IN CH1)
      READ(1,502)NDS
C
C  ***** NDS IS THE NUMBER OF DATA SETS TO BE ENTERED ********
C
      DO 100 NSET=1,NDS
      READ(1,502)IDTAG
C
C  ***** IDTAG IS AN ARBITRARY IDENTIFICATION NUMBER WHICH APPEARS IN
C        THE PUNCHED OUTPUT FOR FERDOR OR NEUSTEP *********
C
      READ(1,501)(TITLE(I),I=1,20)
C
C  ***** TITLE IS 80 COLUMNS OF ALPHAMERIC INFORMATION FOR IDENTIFICATI-
C        ON PURPOSES AND IS ARBITRARY ******
C
      READ(1,503)ICO,ICOBKG,IOUT,IPKG,NCHH,COSHFT
     1,INCRM
     2,IOFLC
C
C  ***** ICO=1 IF A CO-60 SPECTRUM IS PROVIDED FOR DETERMINATION OF
C        THE ONE COBALT CHANNEL FOR THE FOREGROUND, ICO=0 IF THE ONE
C        COBALT CHANNEL IS TO BE READ IN DIRECTLY ***********
C
C  ***** ICOBKG=1 IF A CO-60 SPECTRUM IS PROVIDED FOR DETERMINATION
C        OF THE ONE COBALT CHANNEL FOR THE BACKGROUND, ICOBKG=0 IF THE
C        ONE COBALT CHANNEL IS TO BE READ IN DIRECTLY ********
C        ICOBKG=2 IF THE ONE COBALT POSITION FOR THE BACKGROUND IS TO
C        BE ASSUMED THE SAME AS FOR THE FOREGROUND ************
C
C  ***** IOUT=0 FOR NEUSTEP FORMAT PUNCHED OUTPUT, IOUT=1 FOR FERDOR,
C        IOUT=2 FOR BOTH FERDOR AND NEUSTEP OUTPUTS *********
```

```
C
C   ***** IBKG=1 FOR BACKGROUND SUBTRACTION, IBKG=0 FOR NO BACKGROUND
C         SUBTRACTION.  IF IBKG=0 THEN ICOBKG CAN BE ANYTHING *****
C
C   ***** NCHH IS THE NUMBER OF CHANNELS OF NEUTRON DATA TO BE READ IN
C         AND IS THE SAME FOR BOTH FOREGROUND AND BACKGROUND ***********
C
C   ***** CCSHFT IS THE CHANNEL TO WHICH THE DATA IS TO BE SHIFTED *******
C
C *****   INORM=1 FOR BACKGROUND TO FOREGROUND NORMALIZATION USING
C         ACTIVATION DATA, INORM=0 FOR NORMALIZATION USING COUNTING TIMES
C         ONLY
C
      READ(1,504)CTF
C
C   ***** CTF IS THE FOREGROUND COUNTING TIME IN HOURS ******
C
      READ(1,505)(Y(I),I=1,NCHH)
C
C   ***** Y(I) ARE THE FOREGROUND COUNTS FOR CHANNELS 1 TO NCHH *******
C
      IF(IOFLO.LT.1) GO TO 831
      READ(1,473)(NOFLO(I),I=1,IOFLO)
  473 FORMAT(16I5)
      OFLO=100000.
      DO 472 J=1,IOFLO
      NDUM=NOFLO(J)
      READ(1,473)(NCOFLO(I,J),I=1,NDUM)
      DO 474 I=1,NDUM
      NPLUG=NCOFLO(I,J)
  474 Y(NPLUG)=Y(NPLUG)+OFLO
  472 OFLO=OFLO+100000.
  831 CONTINUE
  471 WRITE(3,501)TITLE
      WRITE(3,507)
      WRITE(3,506)
      WRITE(3,508)CTF
      WRITE(3,509)(Y(I),I=1,NCHH)
      IF(ICO.LT.1) GO TO 103
      READ(1,510)NCOL,NCOH,NFITLO,NFITHI,NCODS
C
C   ***** THIS CARD IS CONTROL FOR THE FOREGROUND CO-60 FITTING AND IS
C         NEEDED ONLY IF ICO=1.  NCOL IS THE LOW CHANNEL OF CO-60 DATA TO
C         BE READ IN, NCOH IS THE HIGH CHANNEL.  NFITLO IS THE LOWEST
C         CHANNEL TO BE USED IN THE FIT AND NFITHI IS THE HIGHEST.
C         NCODS IS AN ARBITRARY IDENTIFICATION NUMBER FOR THE CO-60 DATA
C         SET *************
C
      READ(1,505)(YCO(I),I=NCOL,NCOH)
C
C   ***** YCO(I) ARE THE COUNTS PER CHANNEL IN THE CO-60 SPECTRUM *******
C
```

```
      CALL COBFIT(NFITLO,NFITHI,YCO,COFIT)
      WRITE(3,507)
      WRITE(3,511)NCCCS,COFIT
      GO TO 104
  103 READ(1,504)COFIT
C
C  ***** COFIT IS THE CHANNEL IN WHICH ONE COBALT FALLS FOR THE
C         FOREGROUND NEUTRON DATA.  THIS CARD IS NEEDED ONLY IF ICO=0 ***
C
  104 IF(IBKG.LT.1)GO TO 105
      IF(IBKG.EQ.2) GO TO 105
      READ(1,504)CTBKG
C
C  ***** CTBKG IS THE BACKGROUND COUNTING TIME IN HOURS *******
C         THIS CARD IS NEEDED ONLY IF IBKG=1 ******
C
      READ(1,505)(BKG(I),I=1,NCHH)
C
C  ***** BKG(I) ARE THE BACKGROUND COUNTS PER CHANNEL.  THESE CARDS ARE
C         NEEDED ONLY IF IBKG=1 *********
C
      WRITE(3,507)
      WRITE(3,512)
      WRITE(3,515)CTBKG
      WRITE(3,509)(BKG(I),I=1,NCHH)
      IF(ICOBKG.EQ.2)COBKG=COFIT
      IF(ICOBKG.EQ.2)GO TO 756
      IF(ICOBKG.LT.1)GO TO 106
      READ(1,510)NCOL,NCOH,NFITLO,NFITHI,NCODS
C
C  ***** THIS IS THE CONTROL CARD FOR THE CO-60 FITTING FOR THE
C         BACKGROUND.  THE VARIABLES HAVE THE SAME MEANING AS THE CONTROL
C         FOR THE FOREGROUND CO-60 FITTING AND THIS CARD IS READ IN ONLY
C         IF ICOBKG=1 *********
C
      READ(1,505)(YCO(I),I=NCOL,NCOH)
C
C  ***** YCO(I) ARE THE CO-60 SPECTRUM COUNTS PER CHANNEL FOR THE BACK-
C         GROUND AND ARE NEEDED ONLY IF ICOBKG=1 *******
C
      CALL COBFIT(NFITLO,NFITHI,YCO,COBKG)
      WRITE(3,507)
      WRITE(3,511)NCCCS,COBKG
      GO TO 756
  106 READ(1,504)COBKG
C
C  ***** COBKG IS THE CHANNEL IN WHICH ONE COBALT FALLS FOR THE
C         BACKGROUND DATA.  THIS CARD IS NEEDED ONLY IF ICOBKG=0 ******
C
  756 WRITE(3,507)
  105 WRITE(3,513)COFIT,COSHFT
      CALL SHIFT(COFIT,COSHFT,Y,NCHH)
```

```
      WRITE(3,505)( Y(I),I=1,NCHH)
      IF(IBKG.LT.1)GC TO 107
      WRITE(3,507)
      WRITE(3,514)CCBKG,COSHFT
      IF(IBKG.EC.2) GC TO 1500
      CALL SHIFT(COBKG,COSHFT,BKG,NCHH)
 1500 CONTINUE
      WRITE(3,505)(BKG(I),I=1,NCHH)
      IF(INCRM.LT.1)GC TO 841
  964 FCRMAT(8F10.0)
  965 FCRMAT(3F10.0)
      READ(1,964)CF,CB,CTSF,CTSB,AIRTF,AIRTB,CTF,DTB
      READ(1,965)WF,WB,ALAMB
C
C ****** CF AND CB ARE THE TOTAL COUNTS FOR THE FOREGROUND AND
C        BACKGROUND SAMPLES, CTSF AND CTSB ARE THE COUNTING TIMES
C        FOR THE FOREGROUND AND BACKGROUND SAMPLES, AIRTF AND AIRTB
C        ARE THE IRRADIATION TIMES FOR THE FOREGROUND AND BACKGROUND
C        SAMPLES, CTF AND CTB ARE THE DECAY TIMES FOR THE FOREGROUND
C        AND BACKGROUND SAMPLES, WF AND WB ARE THE FOREGROUND AND
C        BACKGROUND SAMPLE WEIGHTS, AND ALAMB IS THE SAMPLE DECAY
C        CONSTANT.  CTSF AND CTSB MUST BE IN THE SAME UNITS OF TIME.
C        AIRTF,AIRTB,CTF,AND DTB MUST BE IN THE SAME UNITS OF TIME
C        AND ALAMB MUST BE IN THE INVERSE OF THESE UNITS.  WF AND WB
C        MUST BE IN THE SAME UNITS OF MASS *************
C
      FLU=CF*EXP(ALAMB*DTF)/(CTSF*WF)
      FLUB=CB*EXP(ALAMB*DTB)/(CTSB*WB)
      FLU=FLU*CTF/AIRTF
      FLUB=FLUB*CTBKG/AIRTB
      DUM=FLU/FLUB
  966 FCRMAT(1X,39HFCREGROUND TO BACKGROUND FLUENCE RATIC=,E14.6)
      WRITE(3,966)DUM
 1001 FORMAT (1X,' FOREGROUND FLUENCE NUMBER =',E14.6)
      WRITE (3,1001) FLU
      GC TC 842
  841 DUM=CTF/CTBKG
  842 DC 200 I=1,NCHH
      Y(I)=Y(I)-DUM*BKG(I)
      IF(Y(I).GT.0.) GO TC 200
      Y(I)=0.
  200 CCNTINUE
      WRITE(3,507)
      WRITE(3,516)
      WRITE(3,509)(Y(I),I=1,NCHH)
  107 CCNTINUE
      DC 475 I=1,NCHH
  475 INET(I)=Y(I)
      WRITE(2,501)(TITLE(I),I=1,20)
      WRITE(2,476)(INET(I),I=1,NCHH)
  476 FCRMAT(12X,10I6)
      IF(ICUT.EC.5)GC TO 100
```

```
      IF(ICUT.GT.0)GO TO 108
      WRITE(3,507)
      WRITE(3,501)(TITLE(I),I=1,20)
      WRITE(2,501)(TITLE(I),I=1,20)
      CALL NEUBIN(Y,ICTAG)
      GO TO 100
  108 IF(ICUT.GT.1) GO TO 110
      WRITE(3,507)
      WRITE(3,501)(TITLE(I),I=1,20)
      WRITE(2,501)(TITLE(I),I=1,20)
      CALL FERBIN(Y,ICTAG)
      GO TO 100
  110 WRITE(3,507)
      WRITE(3,501)(TITLE(I),I=1,20)
      WRITE(2,501)(TITLE(I),I=1,20)
      CALL NEUBIN(Y,ICTAG)
      WRITE(3,501)(TITLE(I),I=1,20)
      WRITE(2,501)(TITLE(I),I=1,20)
      CALL FERBIN(Y,ICTAG)
  244 FORMAT(1H1)
      WRITE(3,244)
  100 CONTINUE
      STOP
      END
      SUBROUTINE COBFIT(NFITLO,NFITHI,Y,COFIT)
      DIMENSION Y(1024),A(2,2),B(2)
      DO 10 I=1,2
      DO 10 J=1,2
   10 A(I,J)=0.
      DO 11 I=1,2
   11 B(I)=0.
      FITLO=NFITLO
      FITHI=NFITHI
      XI=FITLO
      DO 12 I=NFITLO,NFITHI
      A(1,1)=A(1,1)+XI*XI/Y(I)
      A(2,2)=A(2,2)+1./Y(I)
      A(1,2)=A(1,2)+XI/Y(I)
      B(1)=B(1)+XI
      B(2)=B(2)+1.
   12 XI=XI+1.
      A(2,1)=A(1,2)
      AM=A(2,2)*B(1)-A(1,2)*B(2)
      FUD=A(1,1)*A(2,2)-A(2,1)*A(1,2)
      AM=AM/FUD
      BINT=A(1,1)*B(2)-A(2,1)*B(1)
      BINT=BINT/FUD
      COFIT=-BINT/AM
      RETURN
      END
      SUBROUTINE SHIFT(COFIT,COSHFT,Y,NCHH)
      DIMENSION Y(1024),YSHIFT(1024),YSUM(1024)
```

```
      CW=CCFIT/COSHFT
      YDUM=0.
      YSUM(1)=Y(1)
      CC 22 I=2,NCHH
   22 YSUM(I)=YSUM(I-1)+Y(I)
      CC 15 I=1,NCHH
      AN=I
      DUM=AN*CW
      ANCHH=NCHH
      IF(DUM.LT.ANCHH) GO TC 20
      YSHIFT(I)=0.
      GC TO 15
   20 MCDDUM=INT(DUM)
      AMODUM=AINT(DUM)
      IF(MODDUM.GT.0)GO TO 18
      YSHIFT(I)=CW*Y(1)
      GC TC 15
   18 YSHIFT(I)=YSUM(MODDUM)
      YSHIFT(I)=YSHIFT(I)+(DUM-AMODUM)*Y(MODDUM+1)-YDUM
   15 YDUM=YSHIFT(I)+YDUM
      CO 17 I=1,NCHH
   17 Y(I)=YSHIFT(I)
      RETURN
      END
      SUBROUTINE NELBIN(Y,IDTAG)
      DIMENSION Y(1024),YBIN(400)
     1,IBIN(400)
      CC 11 I=1,200
   11 YBIN(I)=Y(I)
      LUP = 207
      LLO = 203
      CO 13 I=201,36C
      YBIN(I)=0.
      DC 12 K=LLO,LUP
   12 YBIN(I)=YBIN(I)+Y(K)
      LUP = LUP+5
   13 LLO = LLO+5
   20 FCRMAT(1X,I4,1HH,I6,10I6,4X,I4)
      DC 40 I=201,36C
   40 YBIN(I)=YBIN(I)/5.
      CC 41 I=1,360
   41 IBIN(I)=YBIN(I)
      CC 14 J=1,20
      LL=10*J-9
      LU=10*J
      WRITE(2,20)IDTAG,LL,(IBIN(I),I=LL,LU),J
   14 WRITE(3,20)IDTAG,LL,(IBIN(I),I=LL,LU),J
   21 FCRMAT(1X,I4,1HL,I6,10I6,4X,I4)
      LL=201
      LU=210
      LCH=41
      CC 15 J=21,36
```

```
      NUD=J-20
      WRITE(3,21)ICTAG,LCH,(IBIN(I),I=LL,LL),NUD
      WRITE(2,21)ICTAG,LCH,(IBIN(I),I=LL,LL),NUD
      LL=LL+10
      LU=LU+10
   15 LCH=LCH+10
      RETURN
      END
      SUBROUTINE FEREIN(Y,ICTAG)
      DIMENSION Y(1024),YBIN(400)
     1,IBIN(400)
      DO 11 I=1,200
   11 YBIN(I)=Y(I)
      DO 101 I=16,40
      IF(YBIN(I).LT.YBIN(I-1))GO TO 102
  101 CONTINUE
  102 CONTINUE
      DUD=(YBIN(I)-YBIN(I+10))/10.
  103 I=I-1
      YBIN(I)=YBIN(I+1)+DUD
      IF(I.GT.1)GO TO 103
      LL=1
      LU=10
   21 FORMAT(1X,3HREH,2X,I6,10I6,I8)
   22 FORMAT(1X,3HREL,2X,I6,10I6,I8)
      DO 12 I=201,300
      YBIN(I)=0.
      DO 13 K=LL,LU
   13 YBIN(I)=YBIN(I)+Y(K)
      LL=LL+10
   12 LU=LU+10
      DUM=YBIN(300)/100.
      DO 14 I=301,400
   14 YBIN(I)=YBIN(I-1)-DUM
      DO 50 I=1,400
      IBIN(I)=YBIN(I)
   50 IF(IBIN(I).GT.999999)IBIN(I)=999999
      LCH=1
      LL=1
      LU=10
   30 FORMAT(1X,20HHIGH GAIN NET COUNTS)
      WRITE(3,30)
      WRITE(2,30)
      DO 15 J=1,20
      WRITE(3,21)LCH,(IBIN(I),I=LL,LU),ICTAG
      WRITE(2,21)LCH,(IBIN(I),I=LL,LU),ICTAG
      LCH=LCH+10
      LL=LL+10
   15 LU=LU+10
      LL=201
      LU=210
      LCH=1
```

```
31 FORMAT(1X,19HLOW GAIN NET COUNTS)
   WRITE(3,31)
   WRITE(2,31)
   DO 16 J=1,20
   WRITE(3,22)LCH,(IBIN(I),I=LL,LU),IDTAG
   WRITE(2,22)LCH,(IBIN(I),I=LL,LU),IDTAG
   LCH=LCH+10
   LL=LL+10
16 LU=LU+10
   RETURN
   END
```

10.5 Unfolding Code DUFOLD

APPENDIX

Unfolding Code DUFOLD

This computer code is a derivative unfolding code developed and written by M. J. Coolbaugh to determine neutron spectra from input pulse height data for the organic scintillator NE-213 (1). The program is written in Fortran IV language for the IBM 360 Model 50 computer and is separated into several subprograms for ease of understanding. The execution time is .006 hours compared to .315 hours for FERDOR. The following list indicates the program division:

DUFOLD . . . . Main Program

ESCALE
PREBIN
EBIN
NORM

. . . . . . Subroutines

DUFOLD Main Program

This main program sequentially fits the pulse height data using a second order least squares fit, and determines new values for the data in each channel and for the associated slope. This is essentially a smoothing routine. The subroutines called from this program in order are PREBIN and ESCALE.

Subroutine PREBIN

This routine groups the raw pulse height data into fewer channels to reduce computation time. A reduction of the number of channels by two reduces the computations by a factor of approximately four. Typically, this routine is used to group 1024 channels of data (with ^{60}Co in channel 200) into 512 channels. The binning factor for this case is 2. This routine calls no other subroutines.

Subroutine ESCALE

This routine sets the energy scale for the NE-213 data by using fitted experimental data for the nonlinear light response of NE-213. This information is used along with the smoothed data and slopes to unfold the data assuming only proton recoil in the scintillator. A calculational scheme is used to obtain values for the cross section of hydrogen. The subroutines called in order from this program are NORM and EBIN.

Subroutine NORM

This routine corrects the spectrum for proton recoil anisotropy and proton leakage, and applies theoretically-determined values of detector efficiencies to obtain the correct spectral shapes. If the detector is absolutely calibrated, this routine also includes the calibration factor. This routine calls no other subroutines.

Subroutine EBIN

This program either uses resolution information to determine bin sizes and locations, or uses bins previously determined. It then bins the neutron spectrum into these bins.

If resolution data are used to determine the bins, these bins are used in the program and are then punched out on cards for inclusion in subsequent unfolding.

This routine calls no other subroutines.

Input Data

The following is a list of the required input cards to DUFOLD.

CARD	FORMAT		OTHER INFORMATION
1*	I5,2F10.0	NCH -	NUMBER OF CHANNELS OF PULSE HEIGHT DATA
		GAMCH -	THE CHANNEL THE ^{60}CO TAIL IS IN.
		TIME -	THE TIME IN MINUTES THAT THE DATA WAS COLLECTED.
2*	20A4	TITLE -	ARBITRARY ALPHAMERIC TITLE CARD IDENTIFYING THE DATA SET.
3*	12x,10F6.0	Y(I) -	PULSE HEIGHT DATA, USUALLY 1024 CHANNELS OUT OF NUDASBIN.
4*	I5	NBIN -	THE BINNING FACTOR USED BY PREBIN TO REDUCE THE AMOUNT OF DATA TO ANALYZE. USUALLY SET = 2 for 1024 CHANNELS OF INITIAL DATA.
5*	I5	NSETS -	NUMBER OF DIFFERENT REGIONS CONSIDERED IN THE LEAST SQUARES FITTING.
6* (deck)	3I5	NCHLO; NCHHI;NPTS -	THE LOW AND HIGH CHANNEL OF EACH CHANNEL OF EACH REGION IN THE LEAST SQUARES FIT AND THE NUMBER OF CHANNELS FITTED IN THE RESPECTIVE REGION. THERE ARE "NSETS" OF THESE CARDS.
7 (deck)		X(I), A(I), B(I), C(I) -	THE "PULSE HEIGHT UNIT" AND THE FITTED DATA PARAMETERS FOR THE NONLINEAR LIGHT RESPONSE AS DESCRIBED IN SECTION 5.1.2.
8*	I5	NM -	DATA REDUCTION FACTOR TO REDUCE THE NUMBER OF SMOOTHED CHANNELS PRINTED OUT. SET = 1 TO PRINT OUT ALL 1024 CHANNELS.
9	I5,3F10.0	NEPTS; ATOT; AVEL; FNORM -	FIRST CARD OF THE DECK: NUMBER OF EFFICIENCY VALUES IN THE REST OF THE DECK; THE AVERAGE CROSS SECTION AREA OF THE DETECTOR; THE AVERAGE PATH LENGTH; LENGTH THE NEUTRONS TRAVEL; THE NORMALIZATION FACTOR (THIS MULTIPLIES THE SPECTRUM FOR ABSOLUTE CALIBRATION AND IS LEFT BLANK UNTIL THE DETECTOR IS CALIBRATED). THIS CARD AND THE REST OF THE DECK IS FROM THE PROGRAM ANGEF.

CARD	FORMAT		OTHER INFORMATION
10	I5	NFIT -	THIS IS = 0 IF ENERGY BINS ARE TO BE READ IN, = 1 IF RESOLUTION DATA IS USED TO OBTAIN THE BINS.
*** FOR NFIT = 0 ***			
11	I5	NUMB -	THE NUMBER OF BIN ENERGIES READ IN.
12 (deck)	8F10.3	EBLO(I) -	THE LOWER ENERGIES OF EACH BIN IN MEV.
*** FOR NFIT = 1 ***			
11	2F10.3	RFRACT; EMAX -	THE FRACTION OF THE RESOLUTION TO INCLUDE IN EACH BIN (USUALLY = 0.2); THE MAXIMUM ENERGY FOR WHICH THERE IS RESOLUTION DATA.
12	I5,F10.3	NRPTS; DELE -	THE NUMBER OF RESOLUTION DATA VALUES; THE ENERGY IN MEV BETWEEN EACH INDEPENDENT ENERGY POINT (NOTE THAT THE RESOLUTION IS A FUNCTION OF ENERGY).
13	8F10.3	R(I) -	THE RESOLUTION (FULL WIDTH AT HALF MAXIMUM) IN MEV AT EACH ENERGY.

OTHER DATA SETS TO BE UNFOLDED - INCLUDE ONLY THOSE CARDS MARKED WITH AN ASTERISK (*).

BLANK CARD - TO TERMINATE THE CODE.

Punched Output

The unfolded neutron spectrum.

ILLEGIBLE

THE FOLLOWING DOCUMENT (S) IS ILLEGIBLE DUE TO THE PRINTING ON THE ORIGINAL BEING CUT OFF

ILLEGIBLE

```
C***********************************************************************
C
C      THIS CODE DEVELOPED BY M. J. COOLBAUGH, 1971.
C
C***********************************************************************
C**** THIS MAIN PROGRAM SEQUENTIALLY FITS THE DATA USING A SECOND ORDER LEAST
C      SQUARES FIT, AND DETERMINES NEW VALUES FOR THE DATA IN EACH CHANNEL AND
C      FOR THE SLOPE AT EACH POINT.  THIS IS A SMOOTHING ROUTINE.
       COMMON FLUXS(1100),FLUX(1100),EP(1100),Y(1100),YP(1100),Z(1100),
      1G(1100),H(1100),ESADT(200),GC(100),GA(100),GB(100),SIGY(1100),
      2SIGYP(1100),SIGYS(1100),ENERGY(200),EFF(200),TIME,TITLE(20)
    10 FORMAT(3I5,F10.0)
    11 FORMAT(12X,10F6.0)
    12 FORMAT(I5,3F10.0)
    13 FORMAT(6X,12F6.0)
    14 FORMAT(20A4)
       ICONT=1
    99 READ(1,12) NCH,GAMCH,TIME
C**** NCH IS THE NUMBER OF DATA POINTS
C**** GAMCH IS THE CHANNEL THAT THE CO-60 TAIL IS IN
C**** TIME IS THE TIME IN MINUTES THAT THE RAW DATA WAS COLLECTED
       IF(NCH.EQ.0) GO TO 98
C**** A BLANK CARD IS USED AT THE END OF THE DATA TO TERMINATE THE
C     UNFOLDING CODE
       READ(1,14) (TITLE(I),I=1,20)
C**** TITLE IS 80 COLUMNS OF ALPHAMERIC INFORMATION FOR IDENTIFICATION
C      PURPOSES AND IS ARBITRARY
       TIME=TIME*60.
C**** NPTS IN THE NUMBER OF DATA POINTS USED FOR THE SECOND ORDER LEAST SQUARES
C      FITTING AND SMOOTHING
       READ(1,11) (Y(I),I=1,NCH)
C**** Y(I) IS THE RAW SPECTRAL DATA
       CALL PREBIN(NCH,NBIN)
C**** PREBIN IS A ROUTINE TO GROUP THE RAW DATA INTO FEWER CHANNELS.
C**** NBIN IS THE REDUCTION FACTOR FOR THE NUMBER OF CHANNELS.
C**** THIS SECTION FINDS THE FIRST CHANNEL OF VALID DATA(I.E., THE
C      PEAK CHANNEL)
       DO 200 I=2,NCH
       NU=I
       IF(Y(I).LT.Y(I-1))  GO TO 201
   200 CONTINUE
   201 NMIN=NU-1
       NG=NMIN-1
C**** SIGY IS THE FRACTIONAL STANDARD DEVIATION OF THE RAW COUNTS
C**** SIGYS IS THE FRACTIONAL STANDARD DEVIATION OF THE SMOOTHED COUNTS
C**** SIGYP IS THE FRACTIONAL STANDARD DEVIATION OF THE COMPUTED SLOPES
       DO 202 I=1,NCH
       SIGY(I)=0.
       SIGYP(I)=0.
       SIGYS(I)=0.
       FLUXS(I)=0.
       YP(I)=0.
```

```
  202 FLUX(I)=0.
      NCONT=1
C**** THIS SECTION SETS UP THE PARAMETERS FOR THE LEAST SQUARES METHOD
      READ(1,10) NSETS
C**** NSETS IS THE NUMBER OF DIFFERENT REGIONS CONSIDERED FOR THE LEAST SQUARES.
  110 READ(1,10) NCHLO,NCHHI,NPTS
C**** NCHLO,NCHHI IS THE LOWER,UPPER CHANNEL NUMBER FOR THE REGION.
C**** NPTS IS THE NUMBER OF POINTS USED IN THE LEAST SQUARES IN THIS REGION.
      DA=0.
      DB=0.
      DC=0.
      DD=0.
      DO 100 I=1,NPTS
      X=FLOAT(I-1)
      DA=DA+X
      DB=DB+X**2
      DC=DC+X**3
  100 DD=DD+X**4
      DET=FLOAT(NPTS)*DB*DD+2.*DA*DB*DC-DB**3-FLOAT(NPTS)*DC**2-DD*DA**2
      AA=(DB*DD-DC**2)/DET
      BA=(DB*DC-DA*DD)/DET
      CA=(DA*DC-DB**2)/DET
      AB=(DB*DC-DA*DD)/DET
      BB=(FLOAT(NPTS)*DD-DB**2)/DET
      CB=(DA*DB-FLOAT(NPTS)*DC)/DET
      AC=(DA*DC-DB**2)/DET
      BC=(DA*DB-FLOAT(NPTS)*DC)/DET
      CC=(FLOAT(NPTS)*DB-DA**2)/DET
      DO 101 I=1,NPTS
      X=FLOAT(I-1)
      GC(I)=AC+BC*X+CC*X**2
      GA(I)=AA+BA*X+CA*X**2
  101 GB(I)=AB+BB*X+CB*X**2
      DA=0.
      DB=0.
      DC=0.
      NLO=(NPTS+1)/2
      IF(NCONT.EQ.0) GO TO 107
      DO 102 I=1,NPTS
      II=I-1+NMIN
      DA=DA+GA(I)*Y(II)
      DB=DB+GB(I)*Y(II)
  102 DC=DC+GC(I)*Y(II)
      NCONT=0
C**** THIS SECTION DETERMINES VALUES AND SLOPES FOR THE FIRST FEW CHANNELS
C**** FLUXS(I) IS THE SMOOTHED DATA.  YP(I) IS THE SLOPE.
      DO 103 I=1,NLO
      X=FLOAT(I-1)
      II=I-1+NMIN
      FLUXS(II)=DA+DB*X+DC*X**2
      YP(II)=DB+2.*DC*X
      DD=0.
```

```
      DE=0.
      DO 130 J=1,NPTS
      NN=J-1+NMIN
      DD=DD+((GA(J)+GB(J)*X+GC(J)*X**2)**2)*Y(NN)
  130 DE=DE+((GB(J)+2.*GC(J)*X)**2)*Y(NN)
      IF(Y(II).EQ.0.) GO TO 300
      SIGY(II)=1./SQRT(Y(II))
  300 IF(FLUXS(II).EQ.0.) GO TO 301
      SIGYS(II)=SQRT(DD)/ABS(FLUXS(II))
  301 IF(YP(II).EQ.0.) GO TO 103
      SIGYP(II)=SQRT(DE)/ABS(YP(II))
  103 CONTINUE
      NSETS=NSETS-1
      NG=NMIN+1
      NHI=NCHHI+1-NLO
      GO TO 109
C**** THIS SECTION DETERMINES THE VALUES AND SLOPES FOR THE MAIN BODY OF DATA
  107 NSETS=NSETS-1
      IF(NSETS.GT.0) GO TO 108
      NHI=NCH-NPTS+1
      NG=NCHLO+1-NLO
      GO TO 109
  108 NG=NCHLO+1-NLO
      NHI=NCHHI+1-NLO
  109 DO 104 I=NG,NHI
      DA=0.
      DB=0.
      DC=0.
      DD=0.
      DE=0.
      NO=I-1+NLO
      X=FLOAT(NLO-1)
      DO 105 J=1,NPTS
      NN=I+J-1
      DD=DD+((GA(J)+GB(J)*X+GC(J)*X**2)**2)*Y(NN)
      DE=DE+((GB(J)+2.*GC(J)*X)**2)*Y(NN)
      DA=DA+GA(J)*Y(NN)
      DB=DB+GB(J)*Y(NN)
  105 DC=DC+GC(J)*Y(NN)
      FLUXS(NO)=DA+DB*X+DC*X**2
      YP(NO)=DB+2.*DC*X
      IF(Y(NO).EQ.0.) GO TO 400
      SIGY(NO)=1./SQRT(Y(NO))
  400 IF(FLUXS(NO).EQ.0.) GO TO 401
      SIGYS(NO)=SQRT(DD)/ABS(FLUXS(NO))
  401 IF(YP(NO).EQ.0.) GO TO 104
      SIGYP(NO)=SQRT(DE)/ABS(YP(NO))
  104 CONTINUE
      IF(NSETS.GT.0) GO TO 110
C**** THIS SECTION DETERMINES VALUES AND SLOPES FOR THE LAST FEW CHANNELS
      NP=NHI+NLO
      DO 106 I=NP,NCH
```

```
      X=FLOAT(NLO)
      YP(I)=CB+2.*CC*X
      FLUXS(I)=CA+CB*X+CC*X**2
      DD=0.
      DE=0.
      DO 140 J=1,NPTS
      NN=J-1+NHI
      DD=DD+((GA(J)+GB(J)*X+GC(J)*X**2)**2)*Y(NN)
  140 DE=DE+((GB(J)+2.*GC(J)*X)**2)*Y(NN)
      IF(Y(I).EQ.0.) GO TO 500
      SIGY(I)=1./SQRT(Y(I))
  500 IF(FLUXS(I).EQ.0.) GO TO 501
      SIGYS(I)=SQRT(DD)/ABS(FLUXS(I))
  501 IF(YP(I).EQ.0.) GO TO 106
      SIGYP(I)=SQRT(DE)/ABS(YP(I))
  106 NLO=NLO+1
      CALL ESCALE(NCH,GAMCH,NBIN,ICONT)
      ICONT=0
      GO TO 99
   98 STOP
      END
      SUBROUTINE ESCALE(NPTS,GAMCH,NBIN,ICONT)
C**** THIS ROUTINE SETS THE ENERGY SCALE UP FOR THE NE-213 DATA BY USING FITTED
C     EXPERIMENTAL DATA FOR THE NONLINEAR LIGHT RESPONSE OF NE-213.  THIS
C     INFORMATION IS UTILIZED ALONG WITH THE SMOOTHED DATA AND SLOPES TO
C     UNFOLD THE DATA ASSUMING ONLY PROTON RECOIL IN THE SCINTILLATOR.  A
C     CALCULATIONAL SCHEME IS USED TO OBTAIN VALUES FOR THE CROSS SECTION OF H
      COMMON Y(1100),FLUX(1100),EF(1100),FLUXS(1100),YP(1100),Z(1100),
     1G(1100),H(1100),ESADT(200),GC(100),GA(100),GB(100),SIGY(1100),
     2SIGYP(1100),SIGYS(1100),ENERGY(200),EFF(200),TIME,TITLE(20)
      DIMENSION X(32),A(30),B(30),C(30)
    1 FORMAT(8F10.6)
    2 FORMAT(5I5)
    3 FORMAT(6F10.4)
    4 FORMAT(20A4,//)
   11 FORMAT('  CHANNEL        RAW DATA      SMOOTHED DATA      DERIVATIVE
     1          CHANNEL        RAW DATA      SMOOTHED DATA      DERIVATIVE'//
     2)
   12 FORMAT(2X,I4,5X,F7.0,'+',F6.4,2X,F7.0,'+',F6.4,2X,F8.2,'+',F6.4,9
     1X,I4,5X,F7.0,'+',F6.4,2X,F7.0,'+',F6.4,2X,F8.2,'+',F6.4)
   13 FORMAT('+',17X,'_',15X,'_',16X,'_',31X,'_',15X,'_',16X,'_')
   14 FORMAT(1X,'NEUTRON',2X,'NEUTRON SPECTRUM',9X,'NEUTRON',2X,'NEUTRON
     1 SPECTRUM',9X,'NEUTRON',2X,'NEUTRON SPECTRUM',9X,'NEUTRON',2X,'NEU
     2TRON SPECTRUM',/2X,'ENERGY',2X,'(#/MEV-SEC-CM**2)',9X,'ENERGY',2X,
     3'(#/MEV-SEC-CM**2)',9X,'ENERGY',2X,'(#/MEV-SEC-CM**2)',9X,'ENERGY'
     4,2X,'(#/MEV-SEC-CM**2)',/2X,'(MEV)',29X,'(MEV)',29X,'(MEV)',29X,'(
     5MEV)'/)
   15 FORMAT(1X,F6.3,1X,F9.4,1X,'+',1X,F6.4,9X,F6.3,1X,F9.4,1X,'+',1X,F6
     1.4,9X,F6.3,1X,F9.4,1X,'+',1X,F6.4,9X,F6.3,1X,F9.4,1X,'+',1X,F6.4)
   16 FORMAT('+',17X,'_',33X,'_',33X,'_',33X,'_')
   17 FORMAT('1')
   18 FORMAT(' ****WARNING****  THIS DETECTOR IS NOT ABSOLUTELY CALIBRAT
```

```
     1ED AND THE FLUXES DETERMINED ARE ONLY APPROXIMATE'//)
  19 FORMAT(///,' THE NEUTRON ENERGIES LISTED REPRESENT THE LOWER ENERG
     1IES OF EACH BIN')
  20 FORMAT(///,' THE DEVIATIONS LISTED ARE FRACTIONAL STANDARD DEVIATI
     1ONS')
      WRITE(3,4) TITLE
      WRITE(3,11)
      IF(ICONT.NE.1) GO TO 99
      READ(1,1) (X(I),I=1,32)
      READ(1,1) (A(I),B(I),C(I),I=1,30)
  99  READ(1,2) NM
C**** NM IS THE DATA REDUCTION FACTOR (I.E., THE NUMBER OF OUTPUT DATA VALUES
C     IS REDUCED BY THIS FACTOR)
C**** X,A,B,C ARE THE FITTED DATA FOR THE NONLINEAR LIGHT RESPONSE
C**** NPTS IS THE NUMBER OF CHANNELS OF DATA
C**** GAMCH IS THE CHANNEL THE CO-60 TAIL IS IN
C**** EP, FLUX ARE RESPECTIVELY THE ENERGY OF THE NEUTRON AND THE NUMBER OF
C     NEUTRONS WITH THIS ENERGY
      AREA=0.
      GAMCH=GAMCH/FLOAT(NBIN)
      CONST=1.064/GAMCH
      DO 100 I=1,NPTS
      EP(I)=0.
      G(I)=0.
      H(I)=0.
 100  Z(I)=CONST*FLOAT(I)
      NPM=NPTS/NM-1
      DO 304 I=1,NPM,2
      K=NM*I
      NP=NM*(I+1)
      L=NBIN*K
      LP=NBIN*NP
      WRITE(3,12) L,FLUXS(K),SIGY(K),Y(K),SIGYS(K),YP(K),SIGYP(K),LP,
     1FLUXS(NP),SIGY(NP),Y(NP),SIGYS(NP),YP(NP),SIGYP(NP)
 304  WRITE(3,13)
      K=1
      I=1
 200  CONTINUE
      IF(Z(I).LE.X(K)) GO TO 300
      K=K+1
      GO TO 200
 300  K=K-1
      IF(K.EQ.0) GO TO 303
      EP(I)=EXP(A(K)*(ALOG(Z(I)))**2+B(K)*ALOG(Z(I))+C(K))
      G(I)=2.*A(K)*ALOG(Z(I))+B(K)
      H(I)=2.*A(K)*(1.-ALOG(Z(I)))-B(K)
      IF(I.GE.NPTS) GO TO 301
 303  I=I+1
      K=K+1
      GO TO 200
 301  CONTINUE
      CALL NORM(ICONT,NPTS,FNORM)
```

```
      DO 302 I=1,NPTS
      SIGY(I)=0.
      IF(EP(I).EQ.0.) GO TO 302
      IF(ESACT(I).EQ.0.) GO TO 302
      FLP=Z(I)/(G(I)*EP(I)*CONST)
      FLPP=-FLP*(1.+H(I)/(G(I)**2))/EP(I)
      FLUX(I)=-(FLPP*Y(I)+(FLP**2)*YP(I))*EP(I)/ESACT(I)
      IF(FLUX(I).EQ.0.) GO TO 302
      SIGY(I)=(SQRT((FLPP*SIGYS(I)*Y(I))**2+(SIGYP(I)*YP(I)*FLP**2)**2))
     1*EP(I)/(ESACT(I)*ABS(FLUX(I)))
  302 CONTINUE
      CALL EBIN(NPTS,ICONT)
      WRITE(3,17)
      WRITE(3,19)
      WRITE (3,20)
      WRITE(3,4) TITLE
      IF(FNORM.EQ.0.) WRITE(3,18)
      WRITE(3,14)
      NF=NPTS/4
      DO 500 I=1,NF
      NA=I
      NB=I+NPTS/4
      NC=I+NPTS/2
      ND=I+3*(NPTS/4)
      WRITE(3,15) EP(NA),FLUX(NA),SIGY(NA),EP(NB),FLUX(NB),SIGY(NB),
     1EP(NC),FLUX(NC),SIGY(NC),EP(ND),FLUX(ND),SIGY(ND)
  500 WRITE(3,16)
      WRITE(3,17)
      WRITE(2,3) (EP(I),FLUX(I),I=1,NPTS)
      RETURN
      END
      SUBROUTINE NORM(ICONT,NPTS,FNORM)
C**** THIS ROUTINE CORRECTS THE SPECTRUM FOR PROTON RECOIL ANISOTROPY,
C     PROTON LEAKAGE, AND APPLIES THEORETICALLY-DETERMINED VALUES
C     OF DETECTOR EFFICIENCIES TO OBTAIN THE CORRECT SPECTRAL SHAPES.
C     IF THE DETECTOR IS ABSOLUTELY CALIBRATED, THIS ROUTINE ALSO
C     INCLUDES THE CALIBRATION FACTOR.
      COMMON Y(1100),FLUX(1100),EP(1100),FLUXS(1100),YP(1100),Z(1100),
     1G(1100),H(1100),ESACT(200),GC(100),GA(100),GB(100),SIGY(1100),
     2SIGYP(1100),SIGYS(1100),ENERGY(200),EFF(200),TIME,TITLE(20)
    1 FORMAT(I5,3F10.0)
    2 FORMAT(10X,6F10.0)
    3 FORMAT(I5,7F10.4)
      IF(ICONT.EQ.0) GO TO 100
      READ(1,1) NEPTS,ATOT,AVEL,FNORM
C**** NEPTS IS THE NUMBER OF EFFICIENCY VALUES TO BE READ IN.  ATOT IS
C     THE AVERAGE AREA IN CM. SEEN BY THE FLUX.  AVEL IS THE AVERAGE
C     PATH LENGTH IN CM. SEEN BY THE FLUX.  FNORM IS THE CALIBRATION
C     FACTOR, AND IS DETERMINED BY COMPARING THE UNFOLDED ABSOLUTE
C     ACTIVITY WITH THE ACTIVITY ACTUALLY PRESENT FROM A STANDARD
C     SOURCE.  THIS FACTOR IS THEN USED AS A MULTIPLIER TO EVERY
C     SPECTRAL VALUE.
```

```
      REAC(1,2) (ENERGY(I),EFF(I),I=1,NEPTS)
C**** ENERGY, EFF ARE THE ENERGIES ANC THE EFFICIENCIES REAC IN.
  1C0 I=1
      K=1
  1C6 IF(EP(I).GT.0.) GC TC 102
      ESADT(I)=0.
      I=I+1
      GC TC 106
  1C2 IF(ENERGY(1).LT.EP(I)) GO TC 109
      ESADT(I)=0.
      I=I+1
      GC TC 102
  1C9 K=K+1
  110 IF(ENERGY(K).GT.EP(I)) GO TC 1C1
      K=K+1
      GC TC 110
  101 ESADT(I)=EFF(K-1)+(EFF(K)-EFF(K-1))*(EP(I)-ENERGY(K-1))/(ENERGY(K)
     1-ENERGY(K-1))
      IF(I.GT.NPTS) GC TO 104
      I=I+1
      GC TO 110
  104 CC 105 I=1,NPTS
      IF(ESADT(I).EC.C.) GO TO 105
      IF(EP(I).EQ.0.) GO TO 105
      AA=(1.+.000247*EP(I)**2)/(1.+.0C00823*EP(I)**2)
C**** AA IS THE CORRECTION FACTCR FCR THE ANISOTRCPY.
      CC=1.-(.00209/AVEL)*EP(I)**1.8
C**** CC IS THE CORRECTION FACTOR FOR PROTCN LEAKAGE.
      ESADT(I)=ESADT(I)*ATOT*AA*DC*TIME
      IF(FNORM.GT.0.) ESADT(I)=ESADT(I)/FNCRM
  1C5 CCNTINUE
      RETURN
      END
      SUBROUTINE PREBIN(NCH,NBIN)
C**** THIS ROUTINE GRCUPS THE RAW DATA INTC FEWER CHANNELS
      COMMON FLUXS(11C0),FLUX(1100),EP(1100),Y(11C0),YP(11C0),Z(1100),
     1G(1100),H(1100),ESADT(200),GC(100),GA(100),GB(1C0),SIGY(11C0),
     2SIGYP(1100),SIGYS(1100),ENERGY(200),EFF(200),TIME,TITLE(20)
C**** NBIN IS THE BINNING FACTOR.
    1 FCRMAT(5I5)
      REAC(1,1) NBIN
      NCH=NCH/NBIN
      DO 1C0 I=1,NCH
      N=NBIN*(I-1)
      CUM=0.
      CC 101 J=1,NBIN
  1C1 CUM=DUM+Y(N+J)
  1C0 Y(I)=CUM
      RETURN
      END
      SUBROUTINE EBIN(NPTS,ICONT)
C**** THIS PROGRAM EITHER USES RESCLUTION INFORMATICN TC CETERMINE BIN
```

```
C      SIZES, OR USES BINS PREVICUSLY CETERMINEC.  IT THEN BINS THE
C      NEUTRON SPECTRUM.
       CCMMON Y(1100),FLUX(1100),EP(1100),FLUXS(110C),YP(11C0),Z(11C0),
      1G(1100),H(1100),ESADT(200),GC(100),GA(100),GB(100),SIGY(1100),
      2SIGYP(1100),SIGYS(1100),ENERGY(2C0),EFF(200),TIME,TITLE(20)
       CIMENSION EBLC(500),R(100)
C**** EBLC ARE THE LCWER ECGES CF THE ENERGY BINS.
     1 FORMAT(8F10.3)
     2 FCRMAT(I5,F10.3)
       IF(ICONT.NE.1) GO TC 105
       REAC(1,2) NFIT
       IF(NFIT.EQ.0) GC TO 104
C**** THIS SECTION FITS THE RESOLUTICN DATA ANC CETERMINES BIN SIZES AND
C      LOCATIONS.
       REAC(1,1) RFRACT,EMAX
       READ(1,2) NRPTS,DELE
       READ(1,1) (R(I),I=1,NRPTS)
       E=0.6
       ECUM=0.
       I=1
       K=2
   1C0 ECUM=ECUM+DELE
       I=I+1
       IF(EDUM.LT.E) GC TO 100
       RCUM=((E-EDUM+DELE)/DELE)*(R(I)-R(I-1))+R(I-1)
       EBLO(1)=E-0.5*RFRACT*RDUM
       EBLO(2)=EBLO(1)+RFRACT*RDUM
   102 CELR=R(I)-R(I-1)
   103 E=(2.*DELE*E+DELE*RFRACT*(RDUM+R(I-1))-RFRACT*(EDUM-DELE)*DELR)
      1/(2.*DELE-RFRACT*DELR)
   111 IF(ECUM.GT.E) GC TO 101
       I=I+1
       EDUM=EDUM+DELE
       GC TO 111
   1C1 RCUM=((E-EDUM+CELE)/DELE)*(R(I)-R(I-1))+R(I-1)
       E=0.5*(EBLO(K)+EBLO(K-1))
       K=K+1
       EBLO(K)=EBLO(K-1)+RFRACT*RDUM
       IF(EBLC(K).LT.EMAX) GO TO 103
       WRITE(3,1) (EBLC(I),I=1,K)
       WRITE(2,2) K
       WRITE(2,1) (EBLO(I),I=1,K)
       NUMB=K
C**** THIS SECTION BINS THE SPECTRUM.
   104 IF(NFIT.NE.0) GC TO 105
       READ(1,2) NUMB
       READ(1,1) (EBLC(I),I=1,NUMB)
   1C5 K=1
       I=1
       DUM=0.
       DUMS=0.
```

```
107 IF(EBLO(K).LT.EP(I)) GO TO 108



    I=I+1
    GO TO 107
108 F=(EP(I)-EBLO(K))/(EBLO(K+1)-EBLO(K))
    DUMF=F*FLUX(I)*(EP(I)-EP(I-1))
    DUM=DUM+DUMF
    DUMS=DUMS+(SIGY(I)*DUMF)**2
    I=I+1
    IF(I.GT.NPTS) GO TO 106
    IF(EP(I).LT.EBLO(K+1)) GO TO 108
    F=(EBLO(K+1)-EP(I-1))/(EP(I)-EP(I-1))
    DUMF=F*FLUX(I)*(EP(I)-EP(I-1))
    DUM=DUM+DUMF
    DUMS=DUMS+(SIGY(I)*DUMF)**2
106 FLUX(K)=DUM/(EBLO(K+1)-EBLO(K))
    IF(FLUX(K).EQ.0.)  GO TO 44
    SIGY(K)=SQRT(DUMS)/(ABS(FLUX(K))*(EBLO(K+1)-EBLO(K)))
 44 CONTINUE
    IF(I.GE.NPTS) GO TO 109
    K=K+1
    DUM=0.
    DUMS=0.
    GO TO 108
109 NPTS=K
    DO 110 I=1,NPTS
110 EP(I)=EBLO(I)
    RETURN
    END
```

Sample DUFOLD Input

```
1024  200.      90.
 FUELED ASSEMBLY RUN, ONE INCH DETECTOR, 3291

 PULSE HEIGHT DATA DECK


   2
   5
   1    50    15
  51    80    25
  81   130    30
 131   220    35
 221   512    50
  .006710   .008860   .012070   .014650   .018380   .024600   .029000   .036500
  .048300   .067800   .091000   .117500   .156200   .238500   .356000   .472500
  .625000   .866000  1.042000  1.327000  1.718000  2.310000  2.950000  3.620000
 4.550000  6.360000  8.830000 10.600000 13.500000 17.700000 20.500000 24.600000
-0.130390 -0.321171 -0.652683 -0.057553  0.346041  0.875606 -0.083551  0.117052
 0.375155 -0.073850  0.197049  0.539838 -0.010776  0.682833  1.473830 -0.137014
-0.232316 -0.184053 -0.109163 -0.041260  0.143512  0.011495  0.723798  1.353609
-0.060767  0.310639  0.765261 -0.029801  0.468444  0.965262  0.017175  0.681611
 1.206289  0.010524  0.654759  1.179150  0.007622  0.644980  1.171209  0.014517
 0.661803  1.181162  0.028951  0.687137  1.192046  0.053469  0.717034  1.200665
-0.015059  0.674966  1.196031 -0.010159  0.675473  1.196002  0.067675  0.650248
 1.196908  0.085907  0.635223  1.199697 -0.015021  0.774317  1.153950  0.017037
 0.712780  1.182982  0.021575  0.702112  1.159316  0.037070  0.658704  1.219464
 0.051507  0.609994  1.259811 -0.019964  0.897701  0.971503  0.023769  0.698720
 1.196920  0.013634  0.749553  1.134266  0.066182  0.450585  1.543388  0.003629
 0.829867  0.987278
   5
  41      5.1393     1.6787   1.43
                 0.1000     0.6221     0.2000     0.5275     0.3000     0.4643
                 0.4000     0.4189     0.5000     0.3846     0.6000     0.3576
                 0.7000     0.3355     0.8000     0.3172     0.9000     0.3015
                 1.0000     0.2880     1.1000     0.2761     1.2000     0.2655
                 1.3000     0.2560     1.5000     0.2396     2.0000     0.2085
                 2.5000     0.1858     3.0000     0.1681     3.5000     0.1535
                 4.0000     0.1419     4.5000     0.1319     5.0000     0.1233
                 5.5000     0.1156     6.0000     0.1089     6.5000     0.1028
                 7.0000     0.0974     7.5000     0.0923     8.0000     0.0879
                 8.5000     0.0839     9.0000     0.0801     9.5000     0.0766
                10.0000     0.0734    10.5000     0.0705    11.0000     0.0677
                11.5000     0.0651    12.0000     0.0627    12.5000     0.0605
                13.0000     0.0584    13.5000     0.0564    14.0000     0.0545
                14.5000     0.0527    15.0000     0.0511
   1
 0.20       15.0
  59     0.250
 0.000      0.140      0.235      0.310      0.370      0.425      0.472      0.515
 0.555      0.590      0.622      0.654      0.682      0.708      0.730      0.754
 0.773      0.792      0.811      0.828      0.844      0.860      0.876      0.892
 0.906      0.921      0.936      0.950      0.965      0.978      0.994      1.008
 1.022      1.039      1.054      1.071      1.089      1.105      1.125      1.147
 1.168      1.190      1.213      1.239      1.266      1.296      1.327      1.362
 1.398      1.438      1.491      1.529      1.579      1.638      1.702      1.780
 1.872      2.100      2.400

 THE FOLLOWING ENERGY BIN SET IS THE RESULT OF THE ABOVE RESOLUTION
 DATA SET AND MAY BE USED IN PLACE OF IT


   0
  84
    0.573      0.626      0.683      0.739      0.799      0.862      0.928      0.997
    1.070      1.145      1.224      1.307      1.392      1.481      1.573      1.669
    1.768      1.870      1.975      2.084      2.196      2.311      2.429      2.551
    2.675      2.803      2.933      3.067      3.203      3.343      3.485      3.630
    3.777      3.927      4.079      4.234      4.391      4.551      4.713      4.877
    5.043      5.211      5.382      5.555      5.730      5.907      6.086      6.267
    6.451      6.636      6.824      7.014      7.206      7.400      7.597      7.796
    7.997      8.200      8.406      8.615      8.826      9.040      9.257      9.476
    9.699      9.926     10.157     10.391     10.630     10.873     11.121     11.374
   11.634     11.900     12.173     12.454     12.744     13.045     13.357     13.663
   14.026     14.391     14.807     15.052
```

10.6 Unfolding Code STUNFO

APPENDIX

Unfolding Code STUNFO

The mathematical expressions and the general purpose of this computer code are found in the main text. Here those details necessary for the actual use of the code are described. The input consists of raw foreground and background (optional) data from a Multi Channel Pulse Height Analyzer. These data must be accompanied by the length of the counting time, the channel number corresponding to the extrapolated Cobalt-60 compton tail and the channel numbers corresponding to the eventual overflows of the counts. The result consists of relative number of neutrons per unit energy corresponding to a discrete number of energy points (which identify the lower end of each bin). A number of comment cards have been inserted in the listing of this code to illustrate the details of the calculations.

10.6.1 Identification

A. Title: UF 213

B. Source Language: FORTRAN IV

C. Installation: Kansas State University Computing Center.

10.6.2 Purpose

This code makes smooth estimates of fast neutron spectra from proton recoil experimental data in form of Multi Channel Pulse Height Analyzer histograms produced through an NE-213 scintillation spectrometer system. The neutron spectra are given as probability density functions of the energy of the neutrons emitted by the source being analyzed.

10.6.3 Restrictions

A. Machine Configuration: IBM System 360/50

B. Programming System Configuration: OS/360

C. Other Routines Required: LIGHT, KORRE and FFT (plus routines for a CALCOMP plotter)

10.6.4 Usage

A. Entry Point: UF 213

B. Space Requirement: 35,000 bytes

C. Data Formats: The following card descriptions are given in the order in which they must appear in the data deck. Standard FORTRAN conventions relating type and name of variable are used.

Each time the code is used, the following set of standard data cards is required. The total number of cards is variable. The following list is made for NPRO = 29, NEF = 21, NFNN = NBNN = 1024 and less than 16 overflows in each foreground and background inputs.

1. FORMAT (5I5, 5F7.3)

columns

1-5 NEF - number of terms in the efficiency data.

6-10 NPE - $\log_2 M$, M being the member of terms in the proton recoil spectrum.

11-15 NPRO - number of terms in the light output data.

16-20 NWN - width of smoothing window

21-25 NOUT - $\log_2 N$, N being the number of terms desired in the unfolded output.

26-32 EMIN - minimum energy (MeV) in output spectrum.

33-39 OCL - lower end of confidence interval.

40-46 VCL - upper end of confidence interval.

47-53 PCI - percent confidence interval.

54-60 BDW - standardized bandwidth.

2-4. FORMAT (10F8.5) Table of energy (MeV) at which the light output of protons is given.

First card:

columns

1-8 EPRO(1) - energy in MeV.

EPRO(1) < EPRO(2)

5-7. FORMAT (10F8.5) Table of proton light output in light units. First card:

columns

1-8 ELPRO(1) - light output

8-10. FORMAT (10F8.5) Table of energy (MeV) at which efficiency is given. Fist card:

columns

1-8 EFE(1) - energy in MeV.

EFE(1) < EFE(2)

11-13. FORMAT (10F8.5) Table of efficiencies. First card:

columns

1-8 EFF(1) - efficiency (absolute)

14. FORMAT (80A1) Identification data.

15. FORMAT (I5, 2F7.3)

columns

1-5	NFNN - number of terms in MCPHA foregound input.
13-19	HRSF - foreground counting time (hours).

16-101. FORMAT (6X, 12F6.0) Foreground input from MCPHA. First card:

columns

7-12	FF(1) - Pulse height.

102. FORMAT (16I5) Overflow data.

columns

1-5	NOVF(1) - multiplicity of overflows.
6-10	NOVF(2) - overflown channel. Channels can follow any order.

There is no limit in the number of overflow data cards. The multiplicity specified in columns 1-5 is intended only for the channels listed in that card.

103. BLANK card to stop overflow correction. If there were no background data the next card would also have to be blank and cards 105-192 would be omitted.

104. FORMAT (I5, 2F7.3) Same as card 15 with data referred to background input here.

105-190. FORMAT (6X, 12F6.0) same as cards 16-101 for background input here.

191. FORMAT (16I5) same as card 102 with overflow data for background here.

192. BLANK card to stop overflow correction.

193. BLANK if the program does not have to calculate another spectrum.

193. Same as card 1 for the new input. Then continue with the same sequence of cards starting with card 14 for the new input.

10.6.5 Operating Instructions

The source deck which includes UF 213, LIGHT, KORRE and FFT and the appropriate OS/360 control cards is followed by the data. The standard input unit is used for reading in the source deck and data and the standard output is used for printing the results. The neutron spectrum is plotted by a CALCOMP plotter on linear scale.

10.6.6 Running Time

The time required to produce an estimate is dependent on the input parameters. When the number of intervals in the proton energy and the unfolded neutron spectrum is around 256 the execution time is approximately equal to 0.84 minutes. Compile time is typically equal to 0.78 minutes. This might indicate that the use of an object deck is unnecessary.

```
C     ************************************************************
C     *------------------ PROGRAM  UF 213 ------------------*
C     *        A CODE TO ESTIMATE FAST NEUTRON ENERGY             *
C     *     SPECTRA FROM PROTON RECOIL EXPERIMENTAL DATA          *
C     *     PRODUCED BY AN NE-213 SCINTILLATION DETECTOR          *
C     *     WRITTEN BY:GIOACCHINO A. MUTONE (MARCH 1972)          *
C     *                DEPARTMENT OF NUCLEAR ENGINEERING          *
C     *                KANSAS STATE UNIVERSITY                    *
C     *                MANHATTAN,KANSAS 66502                     *
C     ************************************************************
C
C
      DIMENSION FF(1150),FB(1150),FFE(1050),FBE(520),EFE(90),
     1EFF(90),EPRO(30),ELPRO(30),IBUF(1000),NOVF(16),
     2EXO(520),DATA(80)
    1 FORMAT (5I5,5F7.3)
C
C     ******************* INPUT VARIABLES ******************
C     *  NEF = NUMBER OF TERMS IN THE EFFICIENCY DATA           *
C     *  NPE = LOGARITHM IN BASE TWO OF THE NUMBER OF TERMS *
C     *           IN THE PROTON RECOIL ENERGY SPECTRUM          *
C     *  NPRO = NUMBER OF TERMS IN THE LIGHT OUTPUT DATA        *
C     *  NWN = WIDTH OF THE SMOOTHING WINDOW                    *
C     *  NOUT = LOGARITHM IN BASE TWO OF THE NUMBER OF          *
C     *           TERMS DESIRED IN THE UNFOLDED OUTPUT          *
C     *  EMIN = LOWER ENERGY END DESIRED IN THE OUTPUT          *
C     *  (OCL,UCL) = CONFIDENCE INTERVAL                        *
C     *  PCI = PERCENT CONFIDENCE INTERVAL                      *
C     *  BWD = STANDARDIZED BANDWIDTH                           *
C     *  EPRO(I) = ENERGIES (MEV) FOR LIGHT OUTPUT DATA         *
C     *  ELPRO(I) = LIGHT OUTPUT DATA                           *
C     *  EFE(I) = ENERGIES (MEV) FOR EFFICIENCY DATA            *
C     *  EFF(I) = EFFICIENCY DATA                               *
C     *  NFNN = NUMBER OF TERMS IN MCPHA FOREGROUND INPUT       *
C     *  NBNN = NUMBER OF TERMS IN MCPHA BACKGROUND INPUT       *
C     *  FCO60 = COBALT-60 EXTRAPOLATED COMPTON TAIL (CHAN- *
C     *           NEL NUMBER) FOR FOREGROUND INPUT              *
C     *  BCO60 = COBALT-60 EXTRAPOLATED COMPTON TAIL (CHAN- *
C     *           NEL NUMBER) FOR BACKGROUND INPUT              *
C     *  HRSF = COUTING TIME (HOURS) FOR FOREGROUND DATA        *
C     *  HRSB = COUTING TIME (HOURS) FOR BACKGROUND DATA        *
C     *  FF(I) = PULSE HEIGHTS, FOREGROUND INPUT                *
C     *  FB(I) = PULSE HEIGHTS, BACKGROUND INPUT                *
C     *  NOVF(I) = OVERFLOW DATA (MCPHA)                        *
C     ************************************************************
C
      READ (5,1) NEF,NPE,NPRO,NWN,NOUT,EMIN,OCL,UCL,PCI,BWD
      N10 = NPRO/10+1
      DO 5 I=1,N10
    5 READ (5,3) (EPRO(10*(I-1)+J),J=1,10)
    3 FORMAT (10F8.5)
      DO 20 I=1,N10
```

```
   20 READ (5,3) (ELPRO(10*(I-1)+J),J=1,10)
      N10 = NEF/10+1
      DO 50 I=1,N10
   50 READ (5,3) (EFE(10*(I-1)+J),J=1,10)
      DO 51 I=1,N10
   51 READ (5,3) (EFF(10*(I-1)+J),J=1,10)
C
C     THE FOLLOWING TWO STATEMENTS INITIALIZE THE PLOTTING
C     ROUTINE FOR A CALCOMP PLOTTER. THEY MUST BE OMITTED
C     IF A PLOT OF THE OUTPUT IS NOT DESIRED
C
      CALL PLOTS(IBUF,1000)
      CALL PLOT(2.0,2.5,-3)
   98 CONTINUE
      NP = 2**NPE
      NI = NPE+1
      NIN = 2*NP
   45 FORMAT (80A1)
      READ 45,DATA
    4 FORMAT (I5,2F7.3)
      READ (5,4) NFNN,FCO60,HRSF
      N12 = NFNN/12+1
    2 FORMAT (6X,12F6.0)
      DO 12 I=1,N12
   12 READ (5,2) (FF(12*(I-1)+J),J=1,12)
   10 FORMAT (16I5)
   11 READ (5,10) (NOVF(J),J=1,16)
C
C*****CORRECTION FOR OVERFLOW, FOREGROUND
C
      IF (NOVF(1).EQ.0) GO TO 17
      II = 2
   13 FF(NOVF(II)) = FF(NOVF(II))+NOVF(1)*100000.
      II = II+1
      IF (II.EQ.17) GO TO 11
      IF (NOVF(II).EQ.0) GO TO 11
C
C     NOVF(1) MUST BE EQUAL TO ZERO TO AVOID OR STOP THE
C     CORRECTION FOR OVERFLOW
C
      GO TO 13
   17 NIND = NFNN/10
   41 FORMAT (1H ,1X,18F7.0)
   42 FORMAT (1H1,'    INPUT DATA,FOREGROUND:')
      WRITE (6,42)
      N18 = NFNN/18+1
C
C*****CALCULATION OF PROTON ENERGY SPECTRUM FOR FOREGROUND
C
      DO 34 I=1,N18
   34 WRITE (6,41) (FF(18*(I-1)+J),J=1,18)
      NINN = NFNN+NIND
```

```
      DO 18 I=1,NIND
   18 FF(NFNN+I) = 0.0
      ELMAX = NINN*1.06/FC060
C
C     ELMAX IS THE LIGHT OUTPUT CORRESPONDING TO THE CHANNEL
C     NUMBER 10% HIGHER THAN THE MAXIMUM INPUT CHANNEL
C
      KKK = 0
   55 K = 1
    6 IF (ELMAX -ELPRO(K)) 8,9,7
    7 K = K+1
      GO TO 6
    8 ENMAX =(ELMAX-ELPRO(K-1))*(EPRO(K)-EPRO(K-1))/(ELPRO(K)
     1-ELPRO(K-1))+EPRO(K-1)
      GO TO 16
    9 ENMAX = EPRO(K)
   16 IF (KKK.EQ.1) GO TO 56
      EMAX = ENMAX
C
C     EMAX IS THE PROTON ENERGY CORRESPONDING TO ELMAX
C
      KKK = 1
      ELMAX = NFNN*1.06/FC060
C
C     ELMAX IS THE LIGHT OUTPUT CORRESPONDING TO THE MAXIMUM
C     INPUT CHANNEL
C
      GO TO 55
   56 EUP = ENMAX
C
C     EUP IS THE PROTON ENERGY CORRESPONDING TO THE LAST
C     ELMAX
C
      DLI = (EMAX-EMIN)/NP
      NP1 = NP+1
      DO 14 I=1,NP1
   14 EXO(I) = EMIN+DLI*(I-1)
      CALL LIGHT (FF,FFE,EXO,EPRO,ELPRO,NP,NINN,NPRO,FC060)
      READ (5,4) NBNN,BC060,HRSB
C
C     NBNN MUST BE EQUAL TO ZERO IF A BACKGROUND DECK DOES
C     NOT EXIST
C
      IF (NBNN.EQ.0) GO TO 36
      DO 23 I=1,N12
   23 READ (5,2) (FB(12*(I-1)+J),J=1,12)
   27 READ (5,10) (NOVF(J),J=1,16)
C
C*****CORRECTION FOR OVERFLOW, BACKGROUND
C
      IF (NOVF(1).EQ.0) GO TO 29
      II = 2
```

```
   28 FB(NOVF(II)) = FB(NOVF(II))+NOVF(1)*100000.
      II = II+1
      IF (II.EQ.17) GO TO 27
      IF (NOVF(II).EQ.0) GO TO 27
      GO TO 28
   29 NINB = NINN*BCO60/FCO60
   58 FORMAT (1H1,'    INPUT DATA,BACKGROUND:')
      WRITE (6,58)
      DO 59 I=1,N18
   59 WRITE (6,41) (FB(18*(I-1)+J),J=1,18)
      IF (NBNN.GT.NINB) GO TO 35
C
C*****CALCULATION OF PROTON ENERGY SPECTRUM FOR BACKGROUND
C
      NIND = NINB-NBNN
      DO 30 I=1,NIND
   30 FB(NBNN+I) = 0.0
   35 CALL LIGHT (FB,FBE,EXO,EPRO,ELPRO,NP,NINB,NPRO,BCO60)
      HRSD = 1.0
      IF (HRSF.NE.HRSB) HRSD = HRSF/HRSB
C
C*****CORRECTION FOR BACKGROUND
C
C
      DO 32 I=1,NP
      FFE(I) = FFE(I)-FBE(I)*HRSD
   32 IF (FFE(I).LE.0.0) FFE(I) = 0.0
   36 NPM1 = NP-1
C
C*****CALCULATION OF THE FIRST DIFFERENCE OF THE RECOIL
C     PROTON SPECTRUM, CORRECTION FOR EFFICIENCY AND
C     CALCULATION OF THE LOGARITHM TRANSFORM
C
      DEMAX = EMAX*DLI
      M = 1
      DO 52 I=1,NPM1
   26 IF (EXO(I)-EFE(M)) 24,24,25
   25 M = M+1
      GO TO 26
   24 XA = EFF(M-1)+(EFF(M)-EFF(M-1))*(EXO(I)-EFE(M-1))/
     1(EFE(M)-EFE(M-1))
      FJ = EXO(I)/(DEMAX*XA)
   52 FFE(I) = (FFE(I)-FFE(I+1))*FJ
C
C     FFE(I) IS THE UNFOLDED NEUTRON SPECTRUM
C
C*****SMOOTHING OF THE UNFOLDED SPECTRUM
C
      DO 37 I=2,NP
   37 FFE(I+NP) = FFE(NP-I+2)
      FFE(NP+1) = 0.0
      CALL FFT(1,FFE,NI,NIN)
```

```
      CALL KORPE(FFE,NIN,NWN)
      IF (NOUT.EQ.NPE) GO TO 64
      NP = 2**NOUT
      NI = NOUT+1
      NIN = 2*NP
      DLI = (EMAX-EMIN)/NP
      DO 33 I=1,NP
   33 EXO(I) = EMIN+DLI*(I-1)
   64 NZZ = NP-NWN
      DO 38 I=1,NZZ
   38 FFE(I+NWN) = 0.0
      DO 39 I=2,NP
   39 FFE(I+NP) = FFE(NP-I+2)
      FFE(NP+1) = 0.0
   22 CALL FFT(1,FFE,NI,NIN)
      BB = SQRT(FFE(NP))
      DO 40 I=1,NP
   40 FFE(I) = SQRT(FFE(I))-BB
      K = NP
   43 IF (EUP.GT.EXO(K)) GO TO 44
      K = K-1
      GO TO 43
   44 MP = K
   46 FORMAT (1H1,1X,80A1)
      PRINT 46,DATA
   60 FORMAT (1H0,'   NUMBER OF POINTS IN P-ENERGY INPUT = ',
     1I2)
   61 FORMAT (1H ,'   WINDOW WIDTH = ',I3)
      WRITE (6,60) NPE
      WRITE (6,61) NWN
   47 FORMAT (1H0,'   NEUTRON',6X,'NEUTRON',5X,F3.0,'% CO',
     1'NFIDENCE INTERVAL')
   48 FORMAT (1H ,'   ENERGY(MEV)',2X,'SPECTRUM',6X,'LOWER',
     18X,'UPPER')
   49 FORMAT (1H ,3X,F7.4,6X,F7.4,6X,F7.4,6X,F7.4)
      WRITE (6,47)  PCI
      WRITE (6,48)
      DO 54 I=1,MP
      OL = FFE(I)*UCL
      HI = FFE(I) *UCL
   54 WRITE (6,49) EXO(I),FFE(I),OL,HI
   53 FORMAT (1H0,'BANDWIDTH =',F7.2,'MEV')
      BANDW = BWD*EMAX*2/NWN
      WRITE (6,53) BANDW
C
C     IF A PLOT IS NOT DESIRED THE NEXT 9 CARDS MUST BE
C     REMOVED
C
      CALL SCALE(FFE,6.0,MP,1)
      CALL AXIS(0.0,0.0,27HRELATIVE NUMBER OF NEUTRONS,27,
     16.0,90.0,FFE(MP+1),FFE(MP+2))
      CALL AXIS(0.0,0.0,20HNEUTRON ENERGY (MEV),-20,6.0,0.0,
```

```
     10.0,2.0)
      EXO(MP+1) = 0.0
      EXO(MP+2) = 2.0
      CALL LINF(EXO,FFE,MP,1,0,0)
      CALL PLOT(8.5,0.0,-3)
      READ (5,1) NEF,NPE,NPRO,NWN,NOUT,EMIN,OCL,UCL,PCI,BWD
      IF (NEF.FQ.21) GC TO 98
C
C     IF A PLOT IS NOT DESIRED THE NEXT CARD MUST BE REMOVED
C
      CALL PLOT(2.0,0.0,999)
   99 CONTINUE
      STOP
      END
```

10.7 Raw Data

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

/2 INCH NE-213 PUBE SPECTRUM

1068.	11696.	12641.	79128.	86300.	88679.	86960.	82411.	79202.	76716.	74958.	72629.
68384.	65520.	64121.	61699.	59244.	59059.	57917.	54134.	50797.	49882.	48891.	46563.
45942.	45418.	44843.	44362.	44367.	43621.	43219.	42604.	42162.	41739.	41310.	40409.
39135.	38534.	37643.	37342.	36933.	35608.	35292.	34125.	33642.	32461.	22589.	30564.
30011.	29651.	29022.	28894.	28424.	27977.	27631.	27117.	26835.	26360.	25813.	25211.
25147.	24158.	24156.	24846.	23746.	23264.	23122.	23936.	23156.	22861.	22589.	22075.
22126.	22015.	21955.	21754.	21833.	21533.	21164.	20985.	21052.	20905.	20515.	20179.
20174.	20066.	19953.	19623.	19333.	19282.	19038.	18840.	18619.	18522.	18323.	18074.
17924.	18014.	17996.	17835.	17584.	17127.	16921.	16644.	16514.	16414.	16203.	16114.
16033.	15947.	18645.	15763.	15692.	15523.	15484.	15453.	15323.	15282.	15171.	14921.
14932.	14812.	14642.	14598.	14293.	14109.	13801.	13945.	13640.	13379.	13280.	13114.
13055.	12915.	12812.	12721.	12630.	12564.	12522.	12411.	12312.	12213.	12111.	12102.
12043.	11913.	11840.	11817.	11783.	11731.	11606.	11591.	11450.	11341.	11406.	11376.
11271.	11103.	11083.	16987.	10829.	10753.	10629.	10530.	10431.	10319.	10201.	10111.
9962.	9950.	9847.	9781.	9766.	9632.	9572.	9544.	9481.	9435.	9371.	9326.
9260.	9151.	9062.	9007.	8943.	8888.	8838.	8781.	8664.	8571.	8539.	8480.
8343.	8251.	8168.	8132.	8052.	7995.	7924.	7881.	7831.	7753.	7689.	7621.
7592.	7563.	7520.	7486.	7431.	7357.	7207.	7132.	7096.	7060.	7025.	6964.
6901.	6889.	6823.	6793.	6795.	6774.	6674.	6633.	6585.	6522.	6496.	6480.
6437.	6384.	6321.	6293.	6259.	6208.	6123.	6098.	6089.	6049.	5971.	5905.
5869.	5828.	5796.	5744.	5685.	5654.	5631.	5583.	5515.	5491.	5461.	5424.
5383.	5325.	5264.	5232.	5164.	5109.	5070.	5049.	5011.	4980.	4962.	4923.
4887.	4832.	4817.	4789.	4740.	4725.	4692.	4686.	4658.	4642.	4627.	4598.
4586.	4565.	4511.	4485.	4427.	4370.	4358.	4331.	4280.	4259.	4228.	4206.
4171.	4159.	4113.	4066.	4022.	3988.	3959.	3913.	3898.	3844.	3857.	3791.
3765.	3736.	3706.	3677.	3615.	3591.	3559.	3521.	3486.	3456.	3427.	3407.
3408.	3397.	3388.	3361.	3346.	3329.	3308.	3277.	3241.	3224.	3202.	3184.
3177.	3154.	3128.	3105.	3094.	3070.	3051.	3031.	3015.	2986.	2959.	2922.
2880.	2869.	2851.	2841.	2829.	2812.	2791.	2778.	2766.	2759.	2725.	2708.
2683.	2657.	2644.	2625.	2601.	2586.	2552.	2531.	2507.	2478.	2450.	2437.
2405.	2381.	2341.	2311.	2291.	2272.	2254.	2243.	2221.	2209.	2203.	2196.
2171.	2154.	2136.	2112.	2092.	2085.	2073.	2063.	2049.	2034.	2015.	1996.
1971.	1950.	1941.	1920.	1903.	1892.	1874.	1863.	1851.	1849.	1838.	1822.
1817.	1807.	1793.	1791.	1784.	1774.	1760.	1747.	1739.	1721.	1716.	1708.
1691.	1680.	1681.	1679.	1664.	1651.	1635.	1630.	1626.	1616.	1612.	1609.
1609.	1598.	1593.	1585.	1582.	1575.	1576.	1564.	1560.	1559.	1556.	1543.
1539.	1532.	1529.	1515.	1508.	1487.	1471.	1462.	1458.	1456.	1449.	1449.
1432.	1436.	1429.	1414.	1413.	1401.	1396.	1384.	1371.	1371.	1366.	1351.
1346.	1333.	1326.	1329.	1313.	1312.	1306.	1303.	1293.	1292.	1281.	1274.
1268.	1269.	1257.	1256.	1243.	1240.	1237.	1236.	1221.	1212.	1213.	1201.
1200.	1189.	1172.	1170.	1162.	1160.	1150.	1153.	1140.	1140.	1130.	1132.
1130.	1128.	1124.	1112.	1103.	1100.	1098.	1093.	1087.	1076.	1071.	1064.
1053.	1050.	1044.	1037.	1033.	1025.	1015.	1010.	1000.	999.	993.	991.
988.	986.	982.	978.	975.	971.	969.	963.	962.	957.	952.	950.
944.	934.	926.	915.	906.	903.	897.	894.	891.	898.	863.	873.
876.	875.	860.	855.	843.	841.	839.	832.	828.	813.	805.	803.
796.	792.	785.	783.	773.	770.	762.	755.	753.	743.	741.	732.
731.	728.	722.	719.	715.	710.	707.	703.	700.	699.	698.	692.
687.	685.	683.	677.	672.	668.	666.	664.	658.	656.	652.	650.
648.	642.	636.	630.	629.	628.	622.	617.	615.	605.	602.	596.

591.	586.	587.	598.	578.	566.	555.	546.	542.	530.	531.	529.
524.	522.	516.	511.	506.	500.	497.	491.	487.	483.	478.	473.
470.	469.	465.	462.	459.	455.	449.	443.	440.	439.	436.	432.
426.	423.	420.	419.	416.	404.	401.	396.	392.	388.	385.	381.
379.	378.	378.	376.	372.	369.	369.	362.	350.	346.	343.	340.
330.	325.	320.	321.	316.	314.	312.	320.	307.	305.	306.	301.
300.	296.	293.	290.	285.	280.	275.	273.	270.	267.	265.	263.
259.	260.	255.	252.	245.	242.	240.	236.	230.	228.	226.	222.
220.	217.	215.	216.	214.	212.	210.	207.	206.	207.	204.	200.
199.	198.	198.	196.	195.	197.	194.	193.	190.	187.	186.	186.
184.	186.	180.	179.	176.	172.	173.	171.	169.	169.	167.	166.
163.	160.	160.	149.	149.	153.	155.	149.	150.	159.	151.	150.
148.	146.	145.	144.	143.	143.	142.	141.	140.	143.	140.	138.
135.	137.	135.	133.	132.	131.	133.	130.	128.	125.	128.	125.
122.	121.	120.	117.	117.	116.	116.	111.	114.	112.	112.	114.
113.	110.	107.	105.	107.	106.	106.	105.	104.	104.	105.	102.
103.	102.	107.	101.	107.	101.	104.	105.	106.	105.	97.	98.
95.	94.	97.	95.	94.	93.	96.	95.	94.	92.	89.	88.
88.	76.	94.	92.	83.	81.	80.	78.	79.	75.	74.	74.
73.	72.	76.	73.	71.	72.	68.	71.	70.	68.	69.	62.
58.	56.	60.	59.	49.	54.	50.	46.	49.	49.	46.	48.
49.	46.	45.	49.	45.	38.	34.	40.	27.	32.	25.	20.
26.	25.	31.	29.	24.	22.	23.	23.	20.	21.	17.	16.
15.	13.	20.	23.	14.	6.	2.	13.	9.	6.	4.	14.
10.	8.	0.	9.	5.	8.	3.	10.	4.	10.	2.	0.
0.	6.	2.	3.	2.	0.	4.	1.	8.	6.	0.	2.
4.	2.	0.	3.	3.	2.	0.	5.	1.	3.	2.	0.
1.	0.	0.	3.	.	2.	1.	0.	0.	1.	0.	3.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
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UBE 1 INCH NE-213

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.	.	10263.	36941.	88923.	1?4648?.1?191?6642?14?2??8367?46?3996??						
93190.	90413.	87412.	84281.	81224.	79515.	76255.	76371.	73112.	71590.	68000.	60220.
65158.	62353.	61017.	58563.	56534.	54301.	54017.	52105.	50836.	48797.	48664.	48142.
46369.	45918.	44612.	44382.	43907.	42820.	42110.	40136.	40170.	39989.	39645.	39008.
37187.	36688.	36246.	35976.	35238.	35073.	34326.	33914.	33610.	33363.	33123.	33058.
32998.	32403.	32240.	31813.	30654.	30531.	30242.	29729.	29696.	29265.	29174.	28311.
27514.	27658.	27396.	27880.	27227.	27661.	26757.	27129.	26317.	26138.	26014.	25142.
25914.	25386.	25012.	25169.	24821.	24990.	24063.	24137.	24139.	23980.	23648.	23066.
22857.	22063.	22150.	21591.	21515.	21425.	21204.	21090.	20929.	20848.	20329.	21036.
20201.	20420.	20275.	20152.	20094.	19233.	19342.	19244.	19021.	19157.	19172.	18916.
18835.	18941.	18808.	18866.	18621.	18339.	18179.	17917.	17180.	17238.	17389.	17205.
16911.	16859.	16767.	16762.	16698.	16931.	16873.	16647.	16232.	16144.	16124.	16026.
15965.	15583.	15685.	15716.	15745.	15096.	15107.	15094.	15087.	14983.	14908.	14859.
14653.	14472.	14241.	14220.	14006.	13909.	13831.	13424.	13417.	13210.	13352.	13257.
12861.	12758.	12272.	12349.	12058.	12229.	12044.	12061.	11910.	11852.	11873.	11736.
11681.	11433.	11395.	11226.	11039.	11031.	10927.	10614.	10641.	10568.	10470.	10361.
10371.	10218.	10200.	10181.	10092.	9991.	9935.	9824.	9761.	9790.	9671.	9681.
9510.	9499.	9421.	9328.	9227.	9214.	9108.	9145.	9026.	8945.	8935.	8817.
8734.	8682.	8616.	8516.	8524.	8407.	8492.	8336.	8218.	8121.	8122.	8118.
7931.	7810.	7732.	7647.	7555.	7511.	7426.	7433.	7436.	7312.	7325.	7317.
7249.	7237.	7218.	7113.	7144.	7124.	7041.	7106.	7086.	6923.	6924.	6984.
6851.	6848.	6753.	6701.	6662.	6584.	6555.	6502.	6457.	6403.	6461.	6357.
6358.	6344.	6204.	6266.	6177.	6105.	6043.	6049.	5986.	5918.	5996.	5895.
5714.	5731.	5646.	5679.	5699.	5500.	5501.	5586.	5414.	5426.	5438.	5396.
5337.	5385.	5254.	5225.	5215.	5102.	5116.	5066.	5017.	5065.	4927.	4931.
4878.	4898.	4781.	4732.	4747.	4687.	4680.	4670.	4513.	4539.	4469.	4430.
4368.	4329.	4224.	4267.	4155.	4122.	4103.	4028.	4018.	4064.	3932.	3939.
3977.	3945.	3897.	3816.	3871.	3733.	3748.	3740.	3742.	3781.	3688.	3636.
3649.	3623.	3540.	3596.	3521.	3456.	3427.	3494.	3429.	3363.	3320.	3328.
3276.	3225.	3244.	3172.	3112.	3117.	3141.	3034.	3054.	3089.	3083.	2935.
2922.	2953.	2958.	2995.	2907.	2857.	2805.	2828.	2821.	2762.	2754.	2733.
2775.	2711.	2633.	2673.	2642.	2629.	2518.	2590.	2535.	2550.	2421.	2434.
2484.	2455.	2408.	2422.	2443.	2358.	2306.	2322.	2322.	2261.	2235.	2236.
2210.	2232.	2274.	2143.	2292.	2118.	2293.	2119.	2109.	2120.	2136.	2115.
2094.	2146.	2024.	2043.	2049.	2059.	2051.	2060.	2089.	2030.	2037.	2007.
2001.	1990.	1988.	1981.	1971.	1960.	1958.	1942.	1947.	1938.	1929.	1929.
1919.	1910.	1904.	1891.	1889.	1876.	1865.	1859.	1858.	1842.	1830.	1831.
1791.	1789.	1772.	1769.	1750.	1748.	1732.	1721.	1717.	1713.	1700.	1694.
1690.	1688.	1680.	1671.	1662.	1658.	1645.	1637.	1622.	1612.	1606.	1591.
1580.	1561.	1552.	1548.	1533.	1511.	1517.	1506.	1492.	1482.	1475.	1466.
1454.	1448.	1437.	1431.	1425.	1413.	1403.	1406.	1396.	1393.	1381.	1372.
1351.	1342.	1331.	1338.	1324.	1323.	1314.	1314.	1303.	1293.	1289.	1280.
1279.	1267.	1252.	1254.	1243.	1235.	1234.	1223.	1225.	1214.	1217.	1206.
1200.	1199.	1193.	1185.	1161.	1172.	1174.	1165.	1162.	1153.	1144.	1132.
1135.	1123.	1126.	1114.	1106.	1093.	1095.	1081.	1086.	1075.	1065.	1054.
1045.	1037.	1025.	1024.	1016.	1017.	1016.	1007.	1006.	994.	995.	998.
982.	986.	985.	979.	973.	962.	956.	950.	954.	945.	937.	931.
921.	920.	911.	912.	907.	902.	898.	896.	893.	883.	878.	877.
863.	855.	849.	845.	835.	834.	820.	816.	803.	791.	785.	785.
723.	766.	752.	741.	740.	730.	737.	739.	728.	718.	705.	698.

697.	689.	680.	676.	67[illegible].	664.	659.	642.	644.	63[illegible].	635.	620.
621.	612.	616.	601.	607.	590.	589.	582.	588.	579.	57[illegible].	567.
568.	556.	554.	540.	545.	534.	521.	510.	516.	512.	492.	495.
483.	487.	484.	475.	475.	478.	460.	460.	469.	451.	442.	44[illegible].
430.	433.	424.	426.	42[illegible].	421.	412.	407.	403.	398.	399.	39[illegible].
387.	374.	372.	370.	366.	365.	365.	356.	354.	347.	345.	349.
338.	338.	333.	322.	329.	319.	311.	310.	310.	308.	301.	302.
291.	295.	293.	282.	285.	284.	273.	274.	269.	265.	265.	266.
260.	256.	257.	257.	25[illegible].	248.	249.	248.	24[illegible].	239.	230.	235.
234.	238.	227.	224.	225.	223.	213.	217.	216.	212.	214.	207.
209.	207.	200.	198.	19[illegible].	191.	195.	195.	192.	190.	194.	19[illegible].
187.	188.	186.	185.	185.	184.	182.	175.	175.	177.	173.	176.
174.	173.	179.	179.	16[illegible].	168.	168.	163.	163.	167.	161.	158.
156.	151.	153.	156.	148.	157.	148.	147.	146.	143.	145.	147.
144.	134.	140.	133.	134.	143.	132.	137.	136.	138.	138.	137.
138.	137.	132.	139.	123.	129.	130.	120.	125.	131.	128.	120.
121.	122.	127.	123.	131.	126.	122.	125.	124.	127.	119.	122.
118.	120.	129.	120.	11[illegible].	111.	118.	117.	117.	112.	116.	115.
114.	114.	113.	103.	115.	102.	104.	116.	108.	100.	111.	106.
99.	10[illegible].	99.	99.	78.	97.	96.	94.	93.	92.	90.	89.
88.	86.	84.	82.	81.	80.	78.	76.	75.	73.	72.	71.
70.	69.	68.	66.	67.	65.	62.	61.	6[illegible].	60.	59.	56.
55.	54.	52.	51.	49.	48.	47.	45.	46.	44.	43.	41.
39.	36.	34.	35.	3[illegible].	28.	27.	25.	24.	23.	22.	21.
19.	18.	18.	17.	1[illegible].	15.	15.	13.	12.	12.	11.	10.
11.	9.	9.	8.	7.	7.	6.	6.	5.	.	4.	2.
.	5.	3.	4.	.	1.	3.	.	2.	6.	1.	4.
1.	.	.	2.	1.	.	.	1.	.	.	1.	.
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-252 IN WATER WITH 1 INCH NE-213

0.	0.	7.	0.	6.	0.	0.	3.	1.	2.	57.	131.
200.	437.	1585.	6952.	18731.	29783.	40224.	48773.	57087.	63144.	68085.	71123.
73070.	73769.	73980.	72998.	72289.	70544.	69113.	66923.	64526.	62627.	60581.	58257.
56671.	54662.	53162.	51535.	49346.	48408.	47040.	45872.	44339.	43671.	42580.	41561.
40414.	39663.	38095.	36815.	35922.	34558.	33689.	32369.	30988.	30285.	29238.	28367.
27278.	26461.	26158.	25346.	24492.	24047.	23531.	23313.	22876.	22110.	21948.	21315.
20958.	20692.	20278.	19843.	19465.	19145.	18875.	18360.	18219.	17866.	17424.	16965.
16477.	16260.	15588.	15487.	15255.	14510.	14383.	13906.	13514.	13098.	12964.	12484.
12354.	12142.	11692.	11336.	11176.	10578.	10409.	9927.	9708.	9329.	8996.	8701.
8512.	8019.	8043.	7504.	7507.	6947.	6820.	6540.	6383.	6056.	5895.	5829.
5467.	5343.	5030.	4892.	4605.	4301.	4227.	4022.	3952.	3752.	3657.	3444.
3169.	3062.	2921.	2761.	2707.	2581.	2376.	2312.	2225.	2096.	1953.	1824.
1756.	1761.	1532.	1506.	1350.	1329.	1218.	1201.	1093.	1039.	1002.	893.
906.	781.	797.	741.	699.	652.	592.	550.	528.	496.	471.	453.
434.	407.	340.	374.	306.	295.	292.	279.	223.	247.	216.	215.
188.	212.	195.	154.	148.	162.	138.	141.	135.	131.	136.	115.
131.	106.	91.	85.	92.	88.	72.	82.	80.	70.	64.	58.
55.	74.	55.	49.	59.	58.	47.	46.	48.	45.	52.	37.
49.	43.	45.	39.	25.	36.	39.	33.	45.	36.	24.	38.
32.	38.	20.	33.	61.	22.	31.	34.	39.	23.	24.	25.
28.	26.	24.	31.	24.	18.	27.	12.	18.	17.	34.	23.
20.	22.	22.	12.	24.	25.	20.	22.	28.	37.	33.	20.
25.	27.	19.	16.	19.	21.	19.	21.	15.	14.	20.	26.
22.	22.	23.	9.	21.	11.	22.	15.	13.	14.	18.	19.
23.	17.	15.	15.	18.	18.	12.	9.	11.	17.	19.	15.
13.	11.	16.	13.	17.	25.	11.	20.	15.	14.	15.	9.
11.	10.	15.	13.	12.	11.	10.	10.	10.	16.	14.	11.
10.	13.	7.	12.	13.	15.	10.	12.	9.	8.	14.	10.
7.	13.	12.	10.	6.	12.	12.	7.	5.	15.	11.	9.
15.	6.	12.	8.	5.	15.	8.	12.	14.	14.	9.	4.
7.	10.	6.	12.	8.	13.	8.	14.	9.	9.	5.	6.
10.	5.	5.	6.	5.	9.	6.	9.	9.	7.	6.	5.
7.	10.	7.	5.	5.	7.	7.	5.	8.	5.	7.	11.
2.	5.	8.	7.	2.	3.	7.	5.	3.	3.	7.	4.
6.	11.	3.	9.	8.	2.	5.	3.	7.	4.	8.	5.
6.	6.	9.	3.	9.	7.	5.	7.	9.	8.	5.	5.
8.	3.	9.	1.	6.	10.	8.	1.	4.	5.	10.	3.
5.	5.	6.	8.	9.	5.	4.	6.	4.	3.	5.	4.
6.	4.	5.	5.	8.	5.	5.	6.	5.	1.	3.	2.
8.	4.	5.	3.	5.	4.	4.	3.	7.	3.	4.	3.
2.	2.	1.	9.	5.	3.	4.	3.	6.	3.	5.	3.
4.	2.	3.	5.	6.	5.	5.	4.	6.	1.	4.	1.
5.	4.	1.	3.	5.	2.	5.	9.	3.	5.	1.	2.
9.	0.	3.	0.	2.	7.	7.	3.	4.	3.	4.	4.
3.	6.	6.	2.	5.	2.	0.	4.	1.	0.	3.	5.
3.	3.	5.	5.	2.	1.	4.	5.	2.	0.	1.	3.
8.	4.	0.	4.	5.	2.	5.	1.	3.	1.	4.	2.
2.	4.	4.	2.	4.	1.	3.	4.	1.	0.	2.	2.
4.	2.	3.	1.	4.	3.	0.	1.	1.	4.	7.	3.
2.	1.	3.	3.	2.	5.	3.	3.	3.	5.	4.	1.
5.	2.	1.	1.	6.	1.	4.	1.	2.	3.	2.	2.

2.	1.	2.	2.	1.	1.	1.	2.	2.	2.	0.	2.
2.	0.	3.	0.	2.	0.	3.	1.	1.	1.	2.	0.
2.	0.	5.	2.	2.	2.	0.	2.	1.	2.	[illegible]	1.
2.	0.	1.	0.	2.	3.	0.	1.	[illegible]	[illegible]	[illegible]	[illegible]
2.	0.	0.	3.	[illegible]	1.	1.	4.	1.	4.	1.	0.
0.	3.	0.	1.	[illegible]	2.	3.	1.	0.	3.	2.	1.
1.	5.	1.	0.	[illegible]	0.	5.	3.	3.	0.	1.	2.
1.	1.	1.	2.	1.	2.	2.	1.	1.	1.	2.	1.
1.	1.	1.	0.	1.	0.	2.	0.	2.	1.	[illegible]	3.
2.	1.	0.	0.	1.	1.	1.	1.	0.	1.	3.	1.
1.	2.	[illegible]	1.	[illegible]	0.	0.	1.	1.	0.	1.	2.
0.	2.	1.	0.	[illegible]	2.	0.	0.	0.	0.	2.	2.
1.	1.	0.	0.	[illegible]	1.	2.	2.	1.	0.	1.	1.
2.	0.	0.	1.	[illegible]	1.	0.	1.	1.	2.	[illegible]	1.
1.	1.	1.	0.	[illegible]	0.	0.	1.	2.	1.	[illegible]	3.
1.	0.	3.	0.	1.	1.	0.	0.	0.	0.	1.	1.
1.	1.	0.	0.	[illegible]	0.	0.	0.	0.	1.	[illegible]	0.
0.	0.	0.	0.	[illegible]	0.	1.	0.	0.	2.	[illegible]	0.
0.	2.	0.	0.	[illegible]	0.	0.	1.	0.	0.	[illegible]	[illegible]
0.	0.	0.	0.	[illegible]	2.	1.	0.	0.	0.	[illegible]	[illegible]
0.	0.	0.	0.	[illegible]	0.	0.	1.	0.	0.	[illegible]	1.
0.	0.	0.	0.	1.	1.	0.	0.	1.	1.	[illegible]	[illegible]
0.	0.	0.	0.	[illegible]	1.	0.	1.	0.	0.	[illegible]	[illegible]
0.	0.	0.	0.	[illegible]	0.	1.	0.	1.	0.	[illegible]	0.
0.	0.	0.	0.	[illegible]	0.	0.	0.	1.	2.	[illegible]	[illegible]
0.	0.	0.	0.	[illegible]	0.	1.	0.	0.	0.	[illegible]	[illegible]
0.	0.	1.	0.	[illegible]	0.	1.	1.	0.	2.	[illegible]	[illegible]
0.	0.	0.	1.	[illegible]	2.	0.	0.	0.	[illegible]	[illegible]	[illegible]
0.	0.	0.	0.	[illegible]	0.	0.	0.	[illegible]	[illegible]	[illegible]	[illegible]
0.	[illegible]	0.	0.	[illegible]	0.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.	0.	[illegible]	1.	[illegible]	0.	[illegible]	0.	[illegible]	1.	[illegible]	0.
0.	[illegible]	0.	0.	[illegible]	0.	0.	0.	[illegible]	[illegible]	[illegible]	[illegible]
1.	0.	1.	0.	[illegible]	0.	[illegible]	[illegible]	[illegible]	[illegible]	1.	[illegible]
0.	1.	0.	1.	[illegible]	0.	0.	0.	[illegible]	[illegible]	[illegible]	[illegible]
0.	0.	[illegible]	0.								

CF-252 IN WATER 1/2 INCH NE-213 DETECTOR

.	.	.	.	.	.	.	.	.	.	23064.	30723.
32524.	33961.	35092.	34270.	33534.	32592.	31832.	29226.	28339.	26946.	25248.	24391.
23361.	22428.	22048.	21226.	20467.	19738.	19019.	18648.	17402.	17056.	16013.	15284.
14963.	14231.	13894.	13278.	13019.	12686.	12203.	11816.	11432.	11222.	10891.	10660.
10292.	9925.	9644.	9340.	9099.	8783.	8598.	8167.	8052.	7772.	7586.	7375.
7251.	7064.	6833.	6706.	6517.	6457.	6290.	6142.	6038.	5941.	5819.	5621.
5482.	5311.	5197.	5026.	4881.	4808.	4667.	4538.	4472.	4315.	4193.	4179.
4081.	4030.	3991.	3992.	3882.	3794.	3723.	3693.	3624.	3595.	3495.	3426.
3340.	3295.	3216.	3132.	3092.	3009.	2981.	2910.	2874.	2826.	2794.	2760.
2729.	2685.	2622.	2596.	2524.	2511.	2492.	2452.	2411.	2398.	2351.	2307.
2268.	2223.	2205.	2180.	2124.	2103.	2084.	2008.	1983.	1937.	1906.	1897.
1885.	1855.	1828.	1807.	1793.	1789.	1748.	1728.	1700.	1689.	1659.	1610.
1601.	1584.	1576.	1540.	1529.	1509.	1495.	1486.	1465.	1447.	1406.	1394.
1366.	1327.	1304.	1287.	1248.	1223.	1218.	1199.	1180.	1120.	1111.	1085.
1086.	1107.	1081.	1064.	1048.	1026.	1010.	1009.	991.	972.	969.	946.
928.	903.	907.	882.	874.	869.	846.	843.	825.	817.	806.	798.
782.	761.	741.	744.	730.	720.	715.	706.	699.	687.	681.	682.
671.	661.	656.	642.	640.	632.	624.	614.	602.	594.	592.	584.
580.	576.	562.	558.	549.	546.	541.	532.	521.	513.	502.	492.
482.	478.	462.	460.	457.	441.	438.	423.	420.	418.	403.	397.
391.	387.	380.	342.	327.	309.	280.	263.	259.	249.	233.	218.
248.	221.	197.	206.	207.	204.	184.	179.	193.	158.	184.	169.
192.	187.	161.	164.	155.	154.	126.	153.	147.	152.	126.	150.
116.	128.	139.	105.	112.	108.	104.	98.	114.	102.	114.	116.
100.	117.	110.	111.	99.	104.	97.	64.	88.	[illegible]	99.	104.
85.	89.	79.	87.	85.	90.	90.	72.	82.	89.	82.	76.
57.	83.	68.	81.	62.	73.	90.	64.	75.	70.	56.	71.
70.	81.	61.	62.	55.	61.	76.	59.	67.	51.	65.	54.
49.	53.	62.	61.	67.	57.	54.	53.	64.	42.	47.	34.
52.	64.	49.	47.	53.	50.	56.	42.	44.	47.	53.	56.
54.	42.	59.	58.	39.	30.	40.	46.	37.	52.	34.	34.
48.	39.	46.	29.	35.	50.	39.	38.	39.	38.	38.	47.
27.	44.	31.	34.	33.	43.	42.	41.	35.	39.	32.	38.
38.	28.	34.	35.	31.	46.	25.	22.	32.	37.	33.	34.
31.	30.	37.	33.	37.	32.	22.	34.	39.	30.	26.	38.
31.	34.	29.	24.	26.	29.	29.	35.	28.	36.	29.	33.
37.	26.	27.	27.	26.	25.	29.	21.	28.	31.	32.	33.
24.	34.	30.	25.	20.	21.	27.	27.	23.	15.	29.	22.
18.	29.	22.	20.	25.	17.	21.	28.	22.	17.	16.	22.
17.	16.	21.	21.	21.	23.	20.	22.	15.	16.	22.	23.
18.	23.	16.	20.	24.	23.	23.	20.	25.	20.	17.	19.
25.	13.	13.	15.	16.	17.	22.	17.	13.	12.	12.	19.
16.	15.	15.	14.	17.	12.	14.	14.	14.	11.	8.	18.
16.	17.	17.	10.	19.	6.	15.	11.	16.	12.	20.	13.
15.	15.	14.	11.	16.	13.	12.	12.	17.	9.	14.	7.
12.	10.	8.	12.	6.	9.	8.	13.	6.	11.	14.	11.
10.	10.	7.	12.	14.	9.	9.	11.	10.	9.	9.	9.
14.	17.	9.	11.	3.	12.	9.	3.	7.	11.	10.	12.
7.	10.	8.	14.	7.	10.	12.	7.	4.	6.	10.	10.
10.	2.	11.	8.	3.	7.	3.	8.	6.	9.	5.	9.
2.	8.	7.	6.	5.	3.	4.	4.	7.	9.	8.	7.

3.	9.	9.	4.	2.	6.	5.	5.	7.	3.	0.	1.
1.	8.	5.	8.	2.	3.	4.	8.	3.	8.	1.	4.
9.	6.	3.	2.	3.	5.	5.	3.	8.	4.	4.	0.
1.	5.	3.	5.	7.	5.	0.	5.	2.	3.	4.	0.
6.	3.	4.	3.	3.	1.	7.	3.	6.	4.	0.	4.
2.	3.	5.	2.	3.	2.	1.	3.	3.	2.	1.	4.
2.	3.	1.	2.	4.	2.	3.	5.	2.	5.	1.	4.
3.	1.	0.	2.	4.	2.	2.	4.	2.	1.	2.	5.
4.	2.	1.	4.	1.	2.	2.	1.	4.	1.	2.	2.
3.	1.	1.	3.	3.	2.	0.	2.	4.	5.	4.	1.
0.	2.	3.	1.	2.	2.	0.	2.	1.	0.	2.	1.
3.	2.	1.	2.	1.	2.	3.	1.	1.	1.	7.	2.
5.	2.	1.	4.	0.	0.	1.	1.	3.	1.	0.	1.
1.	1.	0.	2.	3.	1.	1.	2.	1.	2.	2.	2.
1.	3.	0.	2.	0.	1.	2.	1.	2.	1.	5.	2.
3.	2.	1.	0.	1.	1.	0.	0.	0.	0.	1.	1.
1.	1.	4.	4.	0.	2.	2.	0.	0.	0.	2.	1.
0.	0.	0.	1.	0.	2.	2.	0.	2.	2.	2.	0.
0.	3.	2.	3.	1.	1.	1.	0.	4.	1.	1.	3.
1.	0.	0.	0.	0.	3.	0.	0.	0.	1.	1.	0.
1.	2.	1.	1.	0.	1.	2.	0.	2.	0.	1.	1.
0.	0.	0.	0.	1.	0.	0.	3.	1.	0.	2.	1.
0.	1.	2.	2.	0.	1.	0.	0.	1.	1.	1.	2.
0.	4.	0.	0.	0.	0.	1.	0.	0.	0.	2.	2.
0.	2.	1.	0.	0.	0.	0.	2.	0.	1.	1.	1.
1.	1.	0.	1.	1.	1.	0.	0.	1.	1.	1.	1.
1.	0.	0.	0.	2.	0.	1.	0.	1.	1.	1.	0.
2.	0.	1.	0.	0.	0.	0.	0.	1.	0.	1.	1.
1.	0.	2.	0.	0.	0.	0.	0.	0.	1.	1.	1.
0.	0.	0.	1.	0.	0.	1.	2.	1.	1.	1.	1.
1.	0.	0.	0.	1.	0.	0.	0.	1.	0.	0.	0.
0.	1.	0.	0.	0.	1.	0.	1.	0.	0.	1.	1.
0.	0.	0.	1.	0.	0.	0.	0.	0.	1.	1.	1.
.	.	.	.	.	.	.	.	.	.	.	.
0.	0.	0.	0.								

CF-252 IN WATER   1/2 INCH NE-213 DETECTOR   LEAD SHIELD

.	.	.	.	.	.	.	.	.	10236.	11424.	12232.
16386.	16018.	15871.	16222.	15006.	14736.	13951.	13292.	12949.	12133.	11963.	11618.
11149.	10873.	10334.	9919.	9777.	9363.	9086.	8891.	8655.	844[illegible]	8213.	8[illegible]4.
7834.	7615.	7425.	7376.	7024.	6833.	6682.	6542.	6326.	6115.	5998.	5806.
5664.	5587.	5454.	5220.	5071.	4923.	4832.	4763.	4631.	4549.	4456.	435[illegible]
4257.	4189.	4068.	4006.	3928.	3865.	3802.	3727.	3629.	3526.	3447.	3429.
3313.	3268.	3221.	3180.	31[illegible]	3059.	3008.	[illegible]599.	2804.	2827.	2798.	272[illegible]
2698.	2624.	2597.	2512.	2478.	2433.	2391.	2320.	2[illegible]37.	223[illegible]	2202.	2186.
2124.	2103.	2052.	2037.	20[illegible]	1985.	1926.	1914.	1895.	1887.	1846.	1796.
1785.	1726.	1706.	1689.	164[illegible]	1716.	1581.	1555.	1528.	1514.	1495.	1472.
1456.	1418.	1395.	1377.	1359.	1419.	1406.	1395.	1371.	1344.	129[illegible]	1243.
1202.	1182.	1151.	1142.	1212.	1103.	1099.	1083.	1075.	7054.	1[illegible]16.	1[illegible]33.
1010.	991.	985.	974.	962.	942.	936.	913.	903.	887.	861.	854.
832.	825.	817.	804.	791.	786.	767.	740.	723.	718.	709.	69[illegible]
686.	679.	664.	656.	648.	633.	624.	619.	614.	606.	596.	583.
578.	574.	566.	551.	549.	544.	538.	531.	523.	519.	514.	508.
505.	497.	480.	475.	473.	465.	456.	452.	449.	444.	440.	436.
431.	430.	427.	423.	411.	406.	401.	397.	393.	388.	385.	381.
378.	373.	368.	361.	357.	353.	351.	346.	341.	343.	341.	346.
343.	342.	339.	335.	320.	311.	299.	298.	290.	286.	283.	281.
177.	174.	266.	261.	257.	253.	246.	243.	241.	239.	235.	228.
272.	302.	263.	255.	252.	248.	245.	236.	272.	235.	227.	215.
222.	214.	194.	193.	202.	192.	188.	196.	172.	178.	160.	165.
155.	158.	151.	155.	164.	148.	146.	145.	157.	154.	132.	127.
126.	155.	139.	131.	16[illegible]	133.	121.	127.	121.	130.	123.	149.
122.	107.	121.	120.	107.	107.	101.	96.	117.	95.	114.	88.
106.	95.	106.	111.	95.	119.	110.	106.	9[illegible]	83.	113.	97.
99.	100.	95.	79.	97.	99.	86.	90.	73.	86.	88.	91.
107.	83.	91.	100.	102.	80.	80.	90.	95.	7[illegible]	84.	81.
84.	63.	72.	69.	76.	90.	68.	66.	74.	71.	77.	78.
68.	79.	67.	68.	82.	74.	79.	69.	61.	72.	64.	6[illegible]
83.	65.	56.	59.	54.	65.	60.	60.	56.	64.	47.	71.
64.	61.	56.	58.	46.	49.	57.	53.	68.	57.	67.	5[illegible]
43.	58.	61.	47.	59.	49.	47.	58.	55.	63.	67.	53.
48.	53.	64.	54.	38.	59.	61.	48.	39.	52.	41.	44.
42.	49.	58.	46.	47.	50.	43.	55.	44.	35.	44.	52.
41.	45.	44.	46.	43.	38.	45.	56.	58.	37.	53.	49.
43.	33.	49.	50.	43.	44.	51.	35.	46.	45.	41.	37.
33.	39.	46.	38.	37.	33.	32.	32.	[illegible]	32.	28.	35.
33.	25.	35.	27.	26.	27.	24.	31.	27.	4[illegible]	37.	30.
30.	28.	31.	32.	31.	36.	28.	29.	26.	28.	[illegible]	26.
42.	34.	20.	26.	21.	27.	24.	31.	26.	29.	30.	36.
26.	19.	25.	25.	18.	26.	29.	20.	19.	16.	19.	21.
17.	16.	27.	24.	19.	28.	29.	22.	24.	17.	18.	18.
23.	32.	17.	24.	16.	19.	21.	20.	21.	18.	20.	19.
19.	22.	15.	19.	20.	18.	19.	15.	11.	15.	14.	16.
19.	18.	12.	15.	11.	12.	12.	9.	12.	13.	14.	7.
12.	18.	12.	18.	18.	11.	13.	13.	11.	12.	6.	13.
7.	12.	15.	10.	8.	7.	8.	9.	14.	9.	6.	11.
9.	8.	7.	10.	12.	8.	10.	11.	11.	8.	12.	10.
10.	10.	7.	6.	12.	9.	8.	10.	9.	7.	6.	9.

7.	6.	12.	6.	6.	6.	4.	10.	4.	5.	13.	10.
5.	6.	4.	5.	6.	6.	13.	6.	4.	10.	10.	3.
7.	4.	3.	4.	7.	4.	3.	6.	5.	5.	4.	5.
7.	3.	7.	9.	8.	2.	2.	4.	7.	9.	6.	5.
10.	8.	3.	5.	4.	9.	4.	10.	3.	2.	5.	2.
3.	6.	7.	6.	2.	3.	2.	2.	5.	3.	6.	3.
4.	3.	6.	6.	3.	6.	4.	6.	4.	2.	4.	1.
1.	4.	5.	5.	2.	2.	2.	1.	3.	5.	2.	6.
5.	7.	3.	3.	2.	2.	3.	2.	2.	2.	1.	1.
5.	2.	4.	2.	3.	1.	3.	1.	3.	1.	3.	3.
3.	3.	4.	4.	2.	1.	3.	1.	1.	2.	3.	2.
2.	5.	2.	1.	1.	0.	2.	0.	1.	2.	3.	1.
1.	2.	0.	2.	2.	3.	2.	0.	3.	4.	1.	2.
0.	1.	2.	1.	2.	6.	5.	3.	4.	3.	5.	3.
3.	1.	1.	0.	1.	1.	3.	1.	0.	3.	2.	2.
1.	1.	3.	2.	3.	2.	1.	2.	2.	2.	3.	1.
2.	1.	0.	3.	4.	3.	3.	0.	2.	0.	2.	1.
3.	3.	1.	2.	0.	1.	3.	1.	1.	1.	1.	2.
2.	1.	0.	1.	1.	2.	1.	2.	1.	0.	0.	3.
2.	1.	0.	2.	4.	0.	0.	3.	2.	0.	1.	1.
1.	2.	0.	2.	3.	0.	0.	2.	1.	3.	1.	0.
1.	1.	0.	1.	1.	1.	1.	2.	1.	0.	0.	4.
0.	0.	0.	0.	0.	0.	0.	1.	2.	0.	1.	0.
1.	0.	0.	2.	1.	1.	0.	1.	0.	1.	1.	1.
1.	0.	0.	0.	0.	1.	0.	0.	0.	1.	1.	0.
1.	0.	3.	0.	0.	0.	0.	1.	1.	1.	0.	0.
0.	0.	0.	1.	0.	0.	1.	0.	0.	1.	0.	1.
0.	0.	0.	2.	0.	2.	0.	0.	1.	1.	0.	0.
0.	1.	2.	0.	0.	0.	0.	0.	0.	0.	1.	0.
0.	0.	0.	0.	0.	1.	1.	2.	0.	0.	2.	1.
0.	0.	0.	1.	0.	1.	0.	0.	0.	0.	0.	0.
1.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.
1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.
0.	0.	0.	1.	0.	0.	0.	0.	0.	0.	1.	1.
0.	0.	0.	0.								

DIRECT BEAM 1/2 INCH NE-213 DETECTOR

0.	0.	[illegible]	0.	[illegible]	0.	[illegible]	[illegible]	5.	4.	[illegible]	[illegible]
21.	45.	279.	2109.	6367.	13647.	23914.	30613.	51608.	65962.	78454.	87168.
93008.	96353.	97500.	96956.	95529.	93703.	90819.	88676.	85607.	82417.	79777.	75671.
74100.	71259.	69326.	66326.	64227.	62172.	60281.	57834.	56278.	54743.	52813.	51458.
49925.	48375.	47325.	45415.	44526.	43270.	41666.	40722.	39463.	38510.	37531.	36317.
35413.	34542.	33716.	32913.	31709.	30759.	30357.	29466.	28594.	27791.	27438.	26473.
25985.	25496.	25007.	24203.	23504.	23023.	22666.	22032.	21471.	21093.	20405.	20069.
19277.	18919.	18764.	18351.	17904.	11314.	17295.	16711.	16517.	16401.	15821.	15693.
15311.	14959.	14456.	14295.	14126.	13833.	13475.	13339.	13057.	12749.	12687.	12273.
12094.	11986.	11755.	11562.	11249.	11228.	10911.	10567.	10663.	10321.	10194.	10023.
9912.	9778.	9621.	9328.	9184.	9066.	9053.	8643.	8487.	8402.	8375.	8225.
7996.	8043.	7827.	7552.	7554.	7487.	7403.	7205.	7100.	7099.	6927.	6758.
6617.	6709.	6566.	6480.	6343.	6260.	6205.	6167.	5916.	5999.	5907.	5870.
5702.	5684.	5552.	5460.	5456.	5345.	5319.	5254.	5174.	5025.	5133.	4834.
4909.	4831.	4890.	4748.	4665.	4574.	4532.	4424.	4370.	4233.	4313.	4255.
4117.	4119.	4107.	3953.	3995.	3856.	3965.	3825.	3858.	3699.	3762.	3629.
3645.	3579.	3463.	3414.	3388.	3394.	3352.	3430.	3258.	3229.	3243.	3264.
3104.	3083.	3069.	2992.	2996.	3000.	2915.	2923.	2911.	2871.	2776.	2767.
2871.	2718.	2726.	2618.	2715.	2681.	2663.	2518.	2566.	2603.	2516.	2482.
2441.	2487.	2464.	2352.	2338.	2293.	2329.	2269.	2214.	2158.	2276.	2233.
2188.	2211.	2162.	2153.	2093.	2058.	2028.	2043.	2028.	2043.	1979.	1985.
2087.	1972.	1942.	1902.	1871.	1923.	1902.	1841.	1801.	1790.	1790.	1805.
1733.	1758.	1691.	1738.	1678.	1738.	1650.	1648.	1610.	1651.	1619.	1594.
1554.	1557.	1535.	1511.	1525.	1557.	1494.	1463.	1406.	1410.	1449.	1462.
1419.	1424.	1353.	1340.	1357.	1350.	1305.	1294.	1276.	1316.	1287.	1329.
1228.	1242.	1243.	1140.	1188.	1179.	1182.	1147.	1149.	1141.	1159.	1095.
1143.	1119.	1136.	1075.	1135.	1060.	1024.	1066.	1020.	1082.	1051.	992.
983.	1028.	1014.	981.	971.	932.	940.	920.	975.	933.	955.	944.
913.	874.	857.	872.	877.	896.	832.	831.	841.	839.	854.	834.
796.	818.	810.	825.	811.	813.	737.	758.	752.	726.	771.	727.
748.	749.	694.	713.	713.	678.	683.	678.	675.	672.	684.	649.
677.	634.	637.	630.	658.	602.	603.	624.	637.	587.	627.	603.
581.	576.	579.	572.	578.	565.	558.	565.	579.	583.	564.	552.
541.	520.	526.	518.	518.	532.	489.	507.	495.	519.	486.	496.
488.	469.	461.	481.	455.	458.	479.	461.	461.	447.	462.	446.
424.	404.	424.	383.	435.	401.	390.	426.	415.	398.	378.	383.
419.	424.	370.	381.	363.	384.	350.	359.	375.	367.	341.	355.
368.	344.	363.	355.	335.	343.	320.	336.	355.	343.	321.	336.
330.	324.	320.	304.	298.	318.	336.	297.	299.	267.	269.	287.
283.	262.	287.	288.	275.	281.	251.	272.	288.	295.	262.	234.
264.	257.	256.	240.	267.	247.	244.	244.	269.	249.	228.	249.
222.	240.	226.	195.	227.	230.	234.	242.	194.	206.	218.	210.
207.	192.	208.	198.	204.	186.	190.	221.	188.	201.	202.	190.
179.	196.	190.	192.	213.	181.	195.	195.	161.	170.	178.	164.
183.	175.	175.	172.	166.	158.	189.	141.	159.	147.	153.	188.
161.	166.	144.	138.	161.	151.	161.	145.	133.	138.	138.	147.
130.	129.	145.	135.	131.	150.	145.	130.	[illegible]	132.	129.	139.
133.	123.	126.	118.	124.	113.	110.	116.	121.	119.	116.	132.
113.	127.	109.	107.	102.	112.	117.	116.	[illegible]	98.	92.	102.
93.	96.	105.	98.	93.	109.	101.	107.	59.	109.	91.	105.
90.	84.	93.	93.	84.	87.	92.	86.	65.	[illegible]	89.	82.

74.	84.	85.	82.	81.	80.	90.	87.	65.	75.	76.	78.
72.	79.	64.	68.	72.	73.	71.	64.	79.	76.	77.	71.
70.	58.	69.	73.	65.	69.	73.	60.	64.	56.	62.	73.
60.	60.	63.	72.	64.	63.	64.	53.	60.	58.	54.	55.
53.	58.	56.	56.	56.	55.	58.	60.	52.	58.	50.	55.
45.	56.	44.	55.	44.	47.	38.	54.	45.	41.	39.	55.
53.	58.	47.	50.	52.	41.	43.	41.	49.	44.	43.	53.
44.	37.	38.	42.	38.	38.	45.	42.	43.	44.	47.	40.
34.	48.	42.	42.	47.	32.	44.	28.	42.	33.	35.	33.
35.	33.	48.	37.	35.	35.	30.	41.	36.	35.	32.	34.
39.	33.	30.	24.	34.	37.	41.	36.	21.	25.	30.	21.
32.	30.	27.	28.	25.	28.	25.	27.	32.	23.	24.	26.
22.	24.	23.	25.	24.	25.	25.	27.	23.	19.	28.	25.
29.	23.	18.	27.	19.	22.	25.	24.	15.	18.	22.	22.
24.	17.	24.	21.	20.	21.	21.	19.	16.	21.	28.	19.
19.	18.	21.	18.	19.	18.	22.	18.	22.	25.	13.	22.
18.	15.	22.	19.	20.	19.	18.	21.	20.	21.	13.	17.
17.	19.	12.	27.	17.	15.	13.	21.	17.	15.	13.	20.
18.	18.	11.	10.	12.	15.	19.	15.	13.	11.	13.	13.
14.	10.	12.	11.	12.	12.	11.	15.	18.	17.	10.	19.
15.	12.	10.	12.	13.	7.	13.	15.	12.	13.	10.	13.
9.	10.	11.	9.	7.	13.	16.	7.	7.	8.	12.	7.
10.	12.	5.	11.	8.	10.	8.	10.	7.	8.	12.	12.
7.	9.	7.	12.	7.	8.	9.	6.	7.	12.	7.	16.
10.	11.	8.	10.	9.	8.	7.	5.	8.	7.	6.	10.
10.	8.	8.	3.	8.	7.	6.	7.	11.	9.	9.	8.
5.	4.	9.	4.	4.	7.	5.	7.	4.	8.	4.	8.
7.	4.	7.	5.	6.	6.	9.	4.	9.	8.	3.	7.
7.	4.	9.	4.	7.	5.	4.	2.	3.	6.	6.	4.
8.	11.	5.	7.	4.	4.	3.	4.	6.	5.	4.	5.
6.	5.	7.	5.	4.	6.	4.	7.	5.	4.	4.	4.
4.	7.	8.	7.	8.	4.	5.	4.	2.	2.	2.	5.
4.	4.	4.	5.	4.	4.	7.	2.	4.	2.	2.	4.
4.	3.	5.	3.	5.	2.	4.	4.	2.	4.	2.	4.
3.	4.	3.	2.								

OXYGEN PENETRATION 1/2 INCH NE-213

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	42894.	39885.	36241.	33754.	[illegible]	31173.	29651.	28332.	[illegible]
26500.	25442.	24926.	[illegible]	23640.	23312.	22906.	22399.	21999.	21556.	21409.	[illegible]
20625.	20340.	19863.	19393.	19057.	18599.	18065.	17667.	[illegible]	16728.	[illegible]	[illegible]
15546.	15332.	15234.	14754.	14564.	14516.	14350.	14040.	14023.	13908.	13699.	[illegible]
13675.	13640.	13471.	13411.	13433.	13391.	13300.	13280.	13165.	[illegible]	13098.	12912.
12868.	12912.	12893.	12732.	12715.	12724.	12452.	12415.	12279.	[illegible]	12077.	[illegible]
11896.	11903.	11690.	11548.	11544.	11386.	11235.	11129.	11098.	[illegible]	10856.	10836.
10664.	10728.	10530.	10357.	10355.	10271.	10228.	[illegible]	9842.	9647.	9566.	[illegible]
9295.	[illegible]	8830.	8594.	8457.	8259.	7892.	7749.	7520.	7191.	6970.	6692.
6443.	6261.	5990.	5659.	5572.	5275.	5217.	5038.	4845.	4785.	4662.	4543.
4461.	4431.	4272.	4219.	4193.	4149.	4098.	3951.	3971.	3961.	3873.	3900.
3807.	3748.	3759.	3756.	3758.	3751.	3709.	3665.	3656.	3648.	3567.	3621.
3529.	3560.	3459.	3463.	3438.	3428.	3443.	3414.	3390.	3391.	3373.	3309.
3239.	3225.	3274.	3292.	3268.	3231.	3244.	3227.	3168.	3135.	3162.	3133.
3146.	3143.	3194.	3101.	3170.	3095.	3112.	3086.	3059.	3059.	3050.	2988.
3044.	2954.	2956.	2991.	2927.	2911.	2895.	2924.	2879.	2888.	2849.	2869.
2895.	2856.	2875.	2781.	2865.	2855.	2831.	2763.	2793.	2740.	2755.	2773.
2726.	2751.	2722.	2709.	2743.	2741.	2703.	2745.	2657.	[illegible]	2652.	2707.
2699.	2635.	2629.	2620.	2581.	2576.	2577.	2525.	2559.	2522.	2553.	2565.
2498.	2544.	2483.	2502.	2511.	2490.	2469.	2483.	2482.	2470.	2443.	2417.
2444.	2371.	2408.	2399.	2387.	2358.	2395.	2383.	2357.	2368.	2353.	2316.
2310.	2284.	2273.	2279.	2288.	2269.	2247.	2197.	2190.	2193.	2165.	2211.
2238.	2211.	2191.	2193.	2190.	2167.	2188.	2154.	2135.	2130.	2150.	2115.
2113.	2086.	2092.	2076.	2107.	2026.	2055.	2054.	2007.	2029.	1996.	1976.
2052.	1966.	2015.	1968.	1915.	1949.	1917.	1950.	1966.	1919.	1915.	1883.
1907.	1900.	1881.	1852.	1878.	1839.	1841.	1792.	1775.	1802.	1729.	1720.
1717.	1704.	1650.	1625.	1640.	1636.	1647.	1579.	1566.	1575.	1565.	1567.
1516.	1558.	1509.	1576.	1498.	1492.	1485.	1457.	1441.	1442.	1443.	1378.
1431.	1422.	1416.	1415.	1399.	1358.	1405.	1367.	1407.	1355.	1318.	1315.
1374.	1334.	1328.	1343.	1350.	1263.	1307.	1301.	1244.	1227.	1257.	1302.
1226.	1245.	1259.	1257.	1221.	1211.	1247.	1176.	1238.	1209.	1202.	1185.
1193.	1198.	1118.	1188.	1145.	1287.	1164.	1122.	1106.	1108.	1124.	1132.
1101.	1092.	1091.	1094.	1094.	1085.	1089.	1063.	1052.	1078.	1099.	1088.
1025.	1077.	1003.	1042.	1005.	1047.	1006.	999.	[illegible]	963.	[illegible]	991.
986.	967.	947.	952.	944.	924.	971.	935.	932.	916.	933.	884.
915.	893.	913.	924.	873.	881.	899.	888.	877.	872.	849.	861.
849.	823.	832.	832.	841.	811.	819.	844.	827.	813.	805.	[illegible]
799.	788.	764.	787.	783.	790.	736.	748.	773.	744.	743.	726.
770.	714.	721.	725.	736.	705.	750.	742.	736.	719.	684.	684.
700.	704.	683.	633.	696.	691.	673.	668.	649.	655.	646.	651.
630.	657.	673.	655.	635.	631.	625.	629.	617.	614.	598.	597.
592.	620.	578.	585.	600.	600.	569.	555.	573.	545.	555.	569.
555.	550.	553.	543.	564.	518.	536.	523.	533.	510.	513.	513.
505.	499.	487.	493.	510.	491.	477.	495.	481.	494.	477.	473.
448.	471.	465.	448.	447.	450.	443.	429.	438.	419.	440.	416.
411.	423.	420.	402.	405.	395.	404.	419.	385.	418.	387.	380.
383.	391.	411.	391.	386.	350.	368.	358.	359.	368.	370.	359.
334.	342.	336.	331.	340.	329.	325.	317.	319.	320.	307.	320.
334.	300.	306.	316.	298.	297.	310.	274.	310.	278.	287.	279.

287.	286.	275.	278.	266.	266.	272.	278.	255.	269.	256.	247.
247.	246.	258.	263.	255.	241.	236.	228.	228.	230.	236.	227.
215.	228.	226.	212.	209.	217.	228.	213.	216.	202.	215.	201.
217.	196.	204.	194.	190.	194.	185.	192.	182.	195.	194.	182.
177.	179.	164.	171.	170.	164.	163.	175.	171.	150.	174.	171.
155.	155.	164.	159.	154.	148.	150.	148.	149.	157.	161.	147.
133.	148.	135.	134.	127.	128.	127.	136.	129.	132.	114.	112.
127.	133.	124.	135.	115.	118.	114.	127.	117.	115.	112.	113.
124.	110.	118.	99.	112.	105.	97.	106.	97.	109.	100.	97.
104.	95.	98.	112.	90.	90.	95.	101.	86.	97.	89.	97.
76.	85.	92.	88.	76.	95.	79.	76.	72.	84.	68.	76.
84.	82.	84.	72.	71.	70.	81.	69.	74.	73.	66.	79.
65.	62.	69.	63.	69.	78.	68.	71.	66.	68.	62.	70.
64.	62.	58.	60.	59.	59.	73.	77.	53.	57.	56.	58.
48.	54.	58.	56.	47.	51.	45.	49.	51.	50.	52.	45.
45.	49.	53.	48.	50.	42.	54.	44.	44.	41.	41.	45.
45.	41.	48.	43.	48.	37.	35.	42.	45.	41.	39.	38.
42.	41.	29.	45.	40.	43.	43.	32.	38.	38.	38.	40.
31.	33.	29.	37.	33.	37.	32.	37.	37.	36.	38.	28.
29.	30.	29.	30.	30.	32.	27.	27.	30.	32.	26.	27.
28.	26.	23.	29.	36.	29.	30.	31.	28.	29.	27.	28.
22.	25.	21.	30.	25.	27.	24.	23.	24.	20.	21.	23.
27.	23.	26.	22.	26.	19.	19.	22.	22.	26.	21.	21.
21.	23.	18.	19.	18.	18.	17.	21.	19.	19.	15.	22.
19.	16.	20.	15.	19.	16.	17.	19.	21.	17.	19.	18.
14.	21.	19.	14.	17.	15.	20.	17.	14.	13.	12.	16.
15.	15.	14.	13.	19.	15.	18.	13.	9.	14.	12.	14.
9.	12.	17.	15.	13.	11.	11.	14.	14.	11.	12.	9.
12.	11.	12.	9.	10.	10.	11.	13.	10.	9.	9.	14.
9.	9.	11.	11.	13.	13.	11.	9.	8.	7.	7.	9.
15.	7.	11.	9.	9.	12.	9.	11.	8.	14.	11.	15.
15.	7.	10.	9.	9.	12.	9.	11.	8.	14.	11.	15.
8.	10.	8.	8.	4.	12.	5.	4.	1.	1.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.								
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	33963.	30099.	27138.	24520.	22370.	20670.	19271.	18022.	16910.
16080.	15404.	14807.	14164.	13755.	13349.	12980.	12705.	12406.	12191.	11809.	11529.
11366.	10909.	10507.	10002.	9679.	9196.	8839.	8274.	7925.	7297.	6918.	6576.
6379.	6049.	5883.	5633.	5409.	5300.	5030.	4976.	4858.	4731.	4654.	4594.
4505.	4458.	4457.	4363.	4302.	4331.	4196.	4158.	4113.	4003.	4023.	3912.
4036.	3895.	3917.	3869.	3857.	3855.	3779.	3716.	3766.	3606.	3650.	3644.
3590.	3498.	3479.	3454.	3434.	3441.	3366.	3259.	3322.	3251.	3252.	3175.
3159.	3156.	3151.	3098.	3066.	3035.	2999.	3000.	2951.	2943.	2936.	2951.
2902.	2881.	2861.	2807.	2862.	2850.	2802.	2769.	2766.	2756.	2786.	2680.
2697.	2688.	2681.	2643.	2628.	2663.	2643.	2617.	2561.	2605.	2545.	2587.
2524.	2500.	2518.	2502.	2437.	2494.	2441.	2423.	2423.	2393.	2427.	2434.
2344.	2356.	2342.	2277.	2298.	2190.	2242.	2217.	2204.	2259.	2227.	2215.
2198.	2221.	2150.	2126.	2144.	2110.	2104.	2030.	2080.	2047.	2012.	2031.
1994.	2026.	2016.	1974.	1977.	1975.	1969.	1929.	1963.	1931.	1915.	1896.
1907.	1934.	1878.	1836.	1862.	1843.	1878.	1820.	1913.	1841.	1810.	1842.

1780.	1835.	1730.	1766.	1805.	1777.	1738.	1714.	1707.	1716.	1720.	1717.
1680.	1670.	1688.	1727.	1707.	1649.	1658.	1656.	1634.	1606.	1666.	1602.
1630.	1605.	1637.	1608.	1543.	1612.	1610.	1590.	1579.	1364.	1505.	1536.
1526.	1522.	1522.	1506.	1478.	1469.	1511.	1490.	1470.	1458.	1444.	1466.
1477.	1399.	1442.	1402.	1451.	1426.	1387.	1397.	1356.	1415.	1421.	1364.
1342.	1363.	1357.	1345.	1334.	1336.	1305.	1317.	1311.	1309.	1293.	1295.
1295.	1271.	1314.	1269.	1267.	1273.	1250.	1266.	1230.	1243.	1249.	1233.
1222.	1192.	1208.	1227.	1235.	1193.	1173.	1198.	1199.	1173.	1183.	1196.
1204.	1139.	1154.	1133.	1184.	1170.	1171.	1157.	1113.	1103.	1107.	1117.
1099.	1091.	1095.	1066.	1046.	1089.	1075.	1050.	1037.	1014.	1056.	1049.
999.	987.	986.	971.	940.	963.	949.	939.	946.	916.	916.	896.
889.	902.	888.	882.	847.	830.	840.	781.	844.	828.	766.	788.
802.	796.	785.	769.	751.	781.	762.	730.	754.	718.	703.	757.
722.	697.	707.	707.	695.	718.	720.	688.	720.	672.	657.	671.
660.	673.	668.	683.	672.	683.	694.	644.	654.	643.	653.	656.
660.	630.	658.	636.	629.	624.	610.	637.	626.	632.	593.	638.
604.	599.	614.	582.	613.	581.	590.	589.	578.	560.	580.	564.
606.	565.	564.	575.	553.	564.	593.	534.	534.	562.	534.	527.
531.	547.	538.	527.	518.	523.	512.	502.	549.	527.	512.	489.
506.	496.	486.	505.	492.	488.	455.	480.	490.	474.	500.	466.
476.	452.	486.	467.	458.	464.	460.	448.	473.	442.	446.	431.
440.	441.	431.	438.	443.	437.	439.	419.	431.	401.	413.	399.
412.	427.	417.	421.	406.	403.	406.	399.	383.	379.	407.	375.
381.	381.	388.	375.	374.	364.	378.	387.	375.	356.	370.	376.
348.	349.	365.	367.	362.	350.	367.	347.	344.	340.	346.	346.
341.	349.	336.	339.	330.	300.	271.	311.	309.	296.	309.	300.
303.	303.	293.	284.	302.	286.	290.	276.	292.	275.	267.	283.
283.	294.	257.	285.	270.	264.	260.	265.	245.	254.	249.	228.
248.	228.	226.	227.	217.	214.	215.	222.	218.	211.	220.	218.
206.	210.	203.	195.	211.	208.	206.	200.	180.	201.	192.	195.
196.	193.	196.	180.	180.	195.	181.	179.	181.	183.	180.	181.
183.	163.	166.	160.	174.	176.	161.	171.	169.	162.	151.	156.
154.	151.	159.	135.	153.	150.	151.	162.	157.	164.	150.	155.
140.	143.	140.	143.	142.	138.	132.	133.	123.	134.	125.	133.
143.	123.	132.	136.	125.	124.	117.	118.	120.	122.	128.	107.
116.	121.	116.	111.	109.	122.	104.	114.	109.	89.	111.	103.
109.	107.	114.	96.	112.	93.	100.	95.	94.	96.	110.	98.
91.	85.	88.	95.	94.	90.	88.	78.	88.	85.	101.	68.
75.	86.	89.	85.	86.	78.	76.	76.	78.	80.	82.	71.
72.	70.	83.	76.	72.	75.	72.	76.	77.	69.	95.	69.
60.	68.	67.	64.	61.	58.	57.	54.	67.	61.	58.	61.
56.	51.	69.	55.	53.	56.	58.	55.	61.	55.	58.	52.
56.	54.	53.	46.	55.	53.	53.	53.	56.	50.	43.	38.
46.	48.	57.	40.	44.	47.	48.	46.	42.	48.	44.	38.
43.	38.	40.	45.	38.	41.	44.	44.	48.	41.	39.	32.
37.	41.	38.	32.	38.	39.	35.	30.	33.	36.	36.	41.
33.	31.	33.	27.	35.	25.	32.	35.	25.	32.	34.	38.
29.	33.	35.	26.	26.	29.	24.	28.	31.	27.	29.	30.
36.	22.	26.	21.	31.	23.	25.	27.	25.	23.	20.	21.
25.	28.	22.	27.	21.	22.	24.	21.	24.	21.	22.	19.
19.	22.	24.	21.	19.	20.	21.	17.	16.	22.	21.	19.
19.	21.	20.	21.	15.	19.	22.	15.	20.	16.	16.	14.

15.	19.	13.	16.	17.	13.	18.	18.	18.	16.	21.	2[illegible].
19.	15.	19.	15.	16.	10.	1[illegible].	18.	12.	14.	17.	13.
14.	15.	1[illegible].	14.	16.	14.	16.	15.	1[illegible].	12.	14.	13.
11.	15.	13.	15.	13.	11.	13.	13.	11.	10.	15.	13.
9.	12.	9.	8.	7.	7.	10.	11.	10.	11.	9.	8.
10.	12.	9.	8.	9.	6.	6.	5.	8.	9.	5.	7.
7.	7.	9.	7.	7.	8.	6.	7.	8.	6.	8.	7.
9.	9.	7.	9.	6.	7.	4.	9.	7.	8.	6.	8.
7.	7.	6.	7.	9.	8.	7.	8.	5.	9.	4.	6.
8.	3.	8.	6.	3.	9.	8.	7.	7.	8.	7.	7.
8.	3.	8.	6.	3.	9.	8.	7.	7.	8.	7.	7.
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10.8 DUFOLD Results

THE NEUTRON ENERGIES LISTED REPRESENT THE LOWER ENERGIES OF EACH BIN

THE DEVIATIONS LISTED ARE FRACTIONAL STANDARD DEVIATIONS
1/2 INCH NE-213 PUBE SPECTRUM

****WARNING**** THIS DETECTOR IS NOT ABSOLUTELY CALIBRATED AND THE FLUXES DETERMINED ARE ONLY APPROXIMATE

NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)
0.573	0.0 ± 0.0	1.975	466.5439 ± 0.0115	4.391	578.7991 ± 0.0051	7.597	256.9900 ± 0.0070
0.626	0.0 ± 0.0	2.084	504.9507 ± 0.0081	4.551	556.6006 ± 0.0051	7.796	268.0808 ± 0.0066
0.683	525.8286 ± 0.0136	2.196	526.5376 ± 0.0052	4.713	467.4155 ± 0.0060	7.997	266.1277 ± 0.0063
0.739	676.5381 ± 0.0090	2.311	465.9109 ± 0.0061	4.877	415.5723 ± 0.0066	8.200	243.9219 ± 0.0065
0.799	766.9045 ± 0.0065	2.429	447.2693 ± 0.0067	5.043	426.7212 ± 0.0068	8.406	215.4167 ± 0.0071
0.862	904.1521 ± 0.0059	2.551	476.5359 ± 0.0067	5.211	440.5833 ± 0.0065	8.615	171.2543 ± 0.0084
0.928	829.6206 ± 0.0040	2.675	471.8381 ± 0.0070	5.382	415.9883 ± 0.0070	8.826	129.5797 ± 0.0104
0.997	846.0425 ± 0.0032	2.803	392.6155 ± 0.0090	5.555	338.6233 ± 0.0085	9.040	102.4585 ± 0.0124
1.070	783.9939 ± 0.0038	2.933	439.5659 ± 0.0068	5.730	262.5503 ± 0.0109	9.257	84.0878 ± 0.0144
1.145	644.7253 ± 0.0048	3.067	489.3889 ± 0.0061	5.907	236.7095 ± 0.0110	9.476	87.7201 ± 0.0131
1.224	591.2310 ± 0.0055	3.203	601.9446 ± 0.0052	6.086	237.0954 ± 0.0075	9.699	109.7549 ± 0.0091
1.307	654.9229 ± 0.0060	3.343	753.8303 ± 0.0045	6.267	236.0185 ± 0.0076	9.926	127.0479 ± 0.0070
1.392	749.4941 ± 0.0050	3.485	676.1987 ± 0.0052	6.451	237.7857 ± 0.0077	10.157	96.4849 ± 0.0078
1.481	837.5493 ± 0.0047	3.630	639.3838 ± 0.0054	6.636	233.5282 ± 0.0080	10.391	43.8980 ± 0.0115
1.573	735.0322 ± 0.0057	3.777	607.5117 ± 0.0058	6.824	242.0316 ± 0.0077	10.630	11.2950 ± 0.0222
1.669	533.8772 ± 0.0083	3.927	627.1057 ± 0.0057	7.014	247.9103 ± 0.0074	10.873	2.9312 ± 0.0423
1.768	496.9753 ± 0.0105	4.079	607.9053 ± 0.0047	7.206	249.2919 ± 0.0074	11.121	-0.2945 ± 0.1929
1.870	387.0642 ± 0.0129	4.234	589.7449 ± 0.0048	7.400	257.1099 ± 0.0072	11.374	********* ± 0.1173

THE NEUTRON ENERGIES LISTED REPRESFNT THE LOWER ENERGIES OF EACH BIN

THE DEVIATIONS LISTED ARE FRACTIONFL STANDARD DEVIATIONS
PUBE 1 INCH NE-213

****WARNING**** THIS DETECTOR IS NOT ABSOLUTELY CALIBRATED AND THE FLUXES DETERMINED ARE ONLY APPROXIMATE

NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)
0.573	0.0 ± 0.0	1.975	300.0586 ± 0.0100	4.391	361.0278 ± 0.0046	7.597	167.4225 ± 0.0056
0.626	0.0 ± 0.0	2.084	336.5784 ± 0.0068	4.551	369.1353 ± 0.0042	7.796	167.3454 ± 0.0054
0.683	0.0 ± 0.0	2.196	348.8530 ± 0.0044	4.713	318.8159 ± 0.0048	7.997	153.1611 ± 0.0056
0.739	397.2764 ± 0.0100	2.311	291.4514 ± 0.0055	4.877	296.6741 ± 0.0051	8.200	137.0523 ± 0.0059
0.799	492.8235 ± 0.0068	2.429	250.2188 ± 0.0067	5.043	272.5632 ± 0.0058	8.406	116.1894 ± 0.0066
0.862	610.3777 ± 0.0061	2.551	223.1369 ± 0.0080	5.211	262.1919 ± 0.0059	8.615	90.5747 ± 0.0080
0.928	606.1748 ± 0.0040	2.675	234.5867 ± 0.0079	5.382	245.0252 ± 0.0064	8.826	68.5042 ± 0.0099
0.997	674.0305 ± 0.0027	2.803	273.0835 ± 0.0072	5.555	205.1953 ± 0.0076	9.040	50.8968 ± 0.0125
1.070	696.1616 ± 0.0025	2.933	331.8860 ± 0.0050	5.730	155.2993 ± 0.0100	9.257	39.1688 ± 0.0157
1.145	633.6848 ± 0.0028	3.067	388.1772 ± 0.0043	5.907	136.6988 ± 0.0103	9.476	37.1523 ± 0.0158
1.224	604.2493 ± 0.0031	3.203	416.6973 ± 0.0042	6.086	145.4589 ± 0.0066	9.699	48.4076 ± 0.0109
1.307	573.0112 ± 0.0040	3.343	467.2239 ± 0.0040	6.267	153.7032 ± 0.0062	9.926	65.8576 ± 0.0072
1.392	456.6287 ± 0.0046	3.485	420.4983 ± 0.0046	6.451	156.7010 ± 0.0062	10.157	62.6904 ± 0.0065
1.481	393.3904 ± 0.0056	3.630	396.4834 ± 0.0048	6.636	150.1331 ± 0.0066	10.391	39.4079 ± 0.0081
1.573	343.3945 ± 0.0068	3.777	377.8950 ± 0.0051	6.824	138.4953 ± 0.0071	10.630	12.3435 ± 0.0144
1.669	333.3750 ± 0.0075	3.927	359.0952 ± 0.0056	7.014	133.7231 ± 0.0073	10.873	1.6278 ± 0.0366
1.768	305.1245 ± 0.0095	4.079	339.3191 ± 0.0046	7.206	144.3723 ± 0.0067	11.121	-0.1740 ± 0.1393
1.870	296.9036 ± 0.0095	4.234	333.4121 ± 0.0047	7.400	156.2957 ± 0.0061	11.374	********* ± 0.1191

THE NEUTRON ENERGIES LISTED REPRESENT THE LOWER ENERGIES OF EACH BIN

THE DEVIATIONS LISTED ARE FRACTIONAL STANDARD DEVIATIONS
OXYGEN PENETRATION 1/2 INCH NE-213

****WARNING**** THIS DETECTOR IS NOT ABSOLUTELY CALIBRATED AND THE FLUXES DETERMINED ARE ONLY APPROXIMATE

NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)
0.573	0.0 ± 0.0	1.975	206.6047 ± 0.0198	4.391	156.5337 ± 0.0133	7.597	152.6986 ± 0.0084
0.626	0.0 ± 0.0	2.084	292.1089 ± 0.0107	4.551	187.7982 ± 0.0107	7.796	140.4987 ± 0.0088
0.683	0.0 ± 0.0	2.196	440.2146 ± 0.0046	4.713	203.1904 ± 0.0099	7.997	128.2268 ± 0.0091
0.739	0.0 ± 0.0	2.311	581.3056 ± 0.0035	4.877	215.8653 ± 0.0093	8.200	113.3222 ± 0.0098
0.799	0.0 ± 0.0	2.429	719.4702 ± 0.0029	5.043	212.7721 ± 0.0101	8.406	98.9490 ± 0.0107
0.862	0.0 ± 0.0	2.551	787.0779 ± 0.0028	5.211	170.2997 ± 0.0125	8.615	82.7245 ± 0.0121
0.928	291.3125 ± 0.0152	2.675	654.2644 ± 0.0033	5.382	147.9202 ± 0.0148	8.826	69.4280 ± 0.0135
0.997	649.5835 ± 0.0090	2.803	384.0505 ± 0.0056	5.555	148.4886 ± 0.0148	9.040	59.0141 ± 0.0147
1.070	670.3247 ± 0.0076	2.933	211.1719 ± 0.0083	5.730	153.1098 ± 0.0144	9.257	48.7871 ± 0.0168
1.145	626.2341 ± 0.0057	3.067	115.1015 ± 0.0149	5.907	162.6740 ± 0.0125	9.476	40.2483 ± 0.0195
1.224	530.0371 ± 0.0047	3.203	90.4407 ± 0.0198	6.086	165.0007 ± 0.0084	9.699	31.4210 ± 0.0224
1.307	453.0669 ± 0.0065	3.343	112.9357 ± 0.0175	6.267	160.9591 ± 0.0086	9.926	27.6983 ± 0.0240
1.392	415.4050 ± 0.0066	3.485	108.7041 ± 0.0195	6.451	160.7609 ± 0.0086	10.157	23.2806 ± 0.0266
1.481	413.7104 ± 0.0070	3.630	110.5358 ± 0.0194	6.636	162.6958 ± 0.0087	10.391	20.2747 ± 0.0285
1.573	318.8853 ± 0.0096	3.777	109.3908 ± 0.0203	6.824	166.8775 ± 0.0083	10.630	13.8979 ± 0.0394
1.669	179.7247 ± 0.0183	3.927	129.1407 ± 0.0182	7.014	171.5092 ± 0.0080	10.873	20.1467 ± 0.0202
1.768	84.7402 ± 0.0456	4.079	139.0424 ± 0.0136	7.206	169.4310 ± 0.0079	11.121	13.8872 ± 0.0241
1.870	94.2469 ± 0.0399	4.234	145.3684 ± 0.0134	7.400	163.1732 ± 0.0081	11.374	0.0 ± 0.0068

THE NEUTRON ENERGIES LISTED REPRESENT THE LOWER ENERGIES OF EACH BIN

THE DEVIATIONS LISTED ARE FRACTIONAL STANDARD DEVIATIONS
DIRECT BEAM 1/2 INCH NE-213 DETECTOR

****WARNING**** THIS DETECTOR IS NOT ABSOLUTELY CALIBRATED AND THE FLUXES DETERMINED ARE ONLY APPROXIMATE

NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)
0.573	0.0 ± 0.0	1.975	1071.6301 ± 0.0045	4.391	228.6501 ± 0.0072	7.597	43.5121 ± 0.0162
0.626	0.0 ± 0.0	2.084	923.3357 ± 0.0039	4.551	206.2001 ± 0.0076	7.796	38.0461 ± 0.0179
0.683	0.0 ± 0.0	2.196	846.9019 ± 0.0027	4.713	165.9783 ± 0.0091	7.997	33.1527 ± 0.0197
0.739	0.0 ± 0.0	2.311	728.2371 ± 0.0032	4.877	150.5901 ± 0.0097	8.200	28.4548 ± 0.0221
0.799	0.0 ± 0.0	2.429	632.5266 ± 0.0037	5.043	144.4116 ± 0.0106	8.406	26.1371 ± 0.0235
0.862	0.0 ± 0.0	2.551	577.8943 ± 0.0041	5.211	132.4617 ± 0.0113	8.615	24.9617 ± 0.0234
0.928	1135.5425 ± 0.0082	2.675	519.5210 ± 0.0046	5.382	123.2358 ± 0.0122	8.826	23.3906 ± 0.0242
0.997	1376.8779 ± 0.0159	2.803	471.3979 ± 0.0052	5.555	116.4228 ± 0.0126	9.040	18.6255 ± 0.0292
1.079	1569.7737 ± 0.0043	2.933	450.1904 ± 0.0045	5.730	110.7632 ± 0.0131	9.257	13.8067 ± 0.0365
1.145	1683.0674 ± 0.0027	3.067	420.6563 ± 0.0047	5.907	105.3232 ± 0.0123	9.476	12.7679 ± 0.0384
1.224	1804.0654 ± 0.0022	3.203	392.3552 ± 0.0051	6.086	98.7502 ± 0.0088	9.699	14.0559 ± 0.0327
1.307	1835.4468 ± 0.0026	3.343	403.5632 ± 0.0053	6.267	89.7048 ± 0.0094	9.926	11.4783 ± 0.0383
1.392	1624.7961 ± 0.0026	3.485	360.8447 ± 0.0060	6.451	82.8182 ± 0.0100	10.157	9.3464 ± 0.0445
1.481	1558.8760 ± 0.0028	3.630	315.0969 ± 0.0067	6.636	73.7237 ± 0.0111	10.391	6.9205 ± 0.0557
1.573	1453.4204 ± 0.0031	3.777	284.8718 ± 0.0073	6.824	67.3344 ± 0.0118	10.630	5.8773 ± 0.0637
1.669	1395.4692 ± 0.0033	3.927	271.5046 ± 0.0078	7.014	60.6881 ± 0.0126	10.873	5.1144 ± 0.0656
1.768	1382.5886 ± 0.0027	4.079	255.7374 ± 0.0064	7.206	55.8722 ± 0.0133	11.121	3.2000 ± 0.1000
1.870	1186.9282 ± 0.0040	4.234	246.8220 ± 0.0065	7.400	49.4123 ± 0.0147	11.374	0.0 ± 0.0096

THE NEUTRON ENERGIES LISTED REPRESENT THE LOWER ENERGIES OF EACH BIN

THE DEVIATIONS LISTED ARE FRACTIONAL STANDARD DEVIATIONS
CF-252 IN WATER WITH 1 INCH NE-213

****WARNING**** THIS DETECTOR IS NOT ABSOLUTELY CALIBRATED AND THE FLUXES DETERMINED ARE ONLY APPROXIMATE

NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)
0.573	0.0 ± 0.0	1.975	444.3674 ± 0.0040	4.391	1.6109 ± 0.0558	7.597	0.5466 ± 0.0886
0.626	0.0 ± 0.0	2.084	362.3215 ± 0.0028	4.551	1.2326 ± 0.0669	7.796	0.5223 ± 0.1001
0.683	0.0 ± 0.0	2.196	352.3662 ± 0.0018	4.713	0.8414 ± 0.0962	7.997	0.0977 ± 0.4954
0.739	0.0 ± 0.0	2.311	345.4299 ± 0.0019	4.877	0.7077 ± 0.1105	8.200	0.0695 ± 0.6472
0.799	0.0 ± 0.0	2.429	336.7791 ± 0.0020	5.043	0.7426 ± 0.1089	8.406	0.1642 ± 0.2583
0.862	0.0 ± 0.0	2.551	317.2249 ± 0.0021	5.211	0.9049 ± 0.0867	8.615	0.3927 ± 0.1228
0.928	375.0020 ± 0.0109	2.675	303.3806 ± 0.0023	5.382	0.9019 ± 0.0920	8.826	0.2378 ± 0.2028
0.997	458.5840 ± 0.0077	2.803	224.1597 ± 0.0028	5.555	0.3348 ± 0.2420	9.040	0.2174 ± 0.1846
1.070	527.1704 ± 0.0056	2.933	156.8978 ± 0.0030	5.730	0.1255 ± 0.6399	9.257	0.3158 ± 0.1167
1.145	569.4834 ± 0.0035	3.067	93.5155 ± 0.0039	5.907	0.2343 ± 0.3035	9.476	0.4132 ± 0.0947
1.224	624.6201 ± 0.0028	3.203	51.1820 ± 0.0054	6.086	0.4482 ± 0.1111	9.699	0.2176 ± 0.1574
1.307	671.6770 ± 0.0031	3.343	27.1294 ± 0.0082	6.267	0.5149 ± 0.1012	9.926	0.0521 ± 0.5428
1.392	640.2856 ± 0.0029	3.485	13.2561 ± 0.0134	6.451	0.4139 ± 0.1258	10.157	-0.0544 ± 0.5489
1.481	637.8372 ± 0.0030	3.630	6.5045 ± 0.0215	6.636	0.2854 ± 0.1796	10.391	0.0548 ± 0.4656
1.573	559.3857 ± 0.0036	3.777	3.2866 ± 0.0378	6.824	0.3687 ± 0.1376	10.630	0.1368 ± 0.1807
1.669	468.7607 ± 0.0044	3.927	2.2040 ± 0.0538	7.014	0.3265 ± 0.1619	10.873	0.0735 ± 0.4265
1.768	471.1934 ± 0.0052	4.079	1.7738 ± 0.0499	7.206	0.4166 ± 0.1246	11.121	-0.0757 ± 0.2829
1.870	463.6167 ± 0.0046	4.234	1.4474 ± 0.0589	7.400	0.4735 ± 0.1058	11.374	0.0 ± 0.0049

THE NEUTRON ENERGIES LISTED REPRESENT THE LOWER ENERGIES OF EACH BIN

THE DEVIATIONS LISTED ARE FRACTIONAL STANDARD DEVIATIONS
CF-252 IN WATER 1/2 INCH NE-213 DETECTOR

****WARNING**** THIS DETECTOR IS NOT ABSOLUTELY CALIBRATED AND THE FLUXES DETERMINED ARE ONLY APPROXIMATE

NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)
0.573	0.0 ± 0.0	1.975	134.0995 ± 0.0112	4.391	20.1176 ± 0.0158	7.597	2.4937 ± 0.0517
0.626	49.4864 ± 0.0451	2.084	125.4769 ± 0.0089	4.551	13.4489 ± 0.0207	7.796	1.8643 ± 0.0638
0.683	157.1970 ± 0.0164	2.196	116.9868 ± 0.0062	4.713	9.7888 ± 0.0272	7.997	1.8276 ± 0.0613
0.739	192.5549 ± 0.0112	2.311	97.8462 ± 0.0075	4.877	7.9162 ± 0.0319	8.200	1.8281 ± 0.0598
0.799	222.0515 ± 0.0077	2.429	83.3528 ± 0.0089	5.043	6.7303 ± 0.0388	8.406	1.4646 ± 0.0713
0.862	268.1807 ± 0.0065	2.551	79.8051 ± 0.0096	5.211	5.6166 ± 0.0451	8.615	0.9803 ± 0.0977
0.928	256.7729 ± 0.0042	2.675	79.6956 ± 0.0096	5.382	4.6544 ± 0.0556	8.826	0.6758 ± 0.1379
0.997	279.3005 ± 0.0037	2.803	80.2999 ± 0.0098	5.555	3.2579 ± 0.0779	9.040	0.7031 ± 0.1252
1.070	272.8691 ± 0.0041	2.933	81.3513 ± 0.0081	5.730	3.2600 ± 0.0776	9.257	0.3988 ± 0.2194
1.145	261.0151 ± 0.0044	3.067	77.5641 ± 0.0082	5.907	4.0878 ± 0.0552	9.476	0.5344 ± 0.1590
1.224	255.2308 ± 0.0047	3.203	67.5878 ± 0.0093	6.086	4.2604 ± 0.0364	9.699	0.4187 ± 0.1833
1.307	243.6546 ± 0.0058	3.343	68.7543 ± 0.0096	6.267	4.5124 ± 0.0339	9.926	0.5201 ± 0.1568
1.392	215.9102 ± 0.0060	3.485	64.3577 ± 0.0102	6.451	3.9035 ± 0.0383	10.157	0.3052 ± 0.2334
1.481	205.6629 ± 0.0064	3.630	62.0825 ± 0.0084	6.636	3.6178 ± 0.0410	10.391	0.3907 ± 0.1873
1.573	188.9827 ± 0.0071	3.777	60.8777 ± 0.0071	6.824	3.5240 ± 0.0419	10.630	0.3967 ± 0.1693
1.669	182.3372 ± 0.0076	3.927	57.5908 ± 0.0072	7.014	2.8324 ± 0.0481	10.873	0.5235 ± 0.0968
1.768	170.6950 ± 0.0092	4.079	55.9695 ± 0.0071	7.206	3.1255 ± 0.0433	11.121	0.3372 ± 0.1320
1.870	145.0556 ± 0.0101	4.234	31.6109 ± 0.0106	7.400	2.5426 ± 0.0511	11.374	********* ± 0.2926

THE NEUTRON ENERGIES LISTED REPRESENT THE LOWER ENERGIES OF EACH BIN

THE DEVIATIONS LISTED ARE FRACTIONAL STANDARD DEVIATIONS
CF-252 IN WATER 1/2 INCH NE-213 DETECTOR LEAD SHIELD

****WARNING**** THIS DETECTOR IS NOT ABSOLUTELY CALIBRATED AND THE FLUXES DETERMINED ARE ONLY APPROXIMATE

NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)	NEUTRON ENERGY (MEV)	NEUTRON SPECTRUM (#/MEV-SEC-CM**2)
0.573	0.8773 ± 1.5671	1.975	81.3071 ± 0.0148	4.391	12.1367 ± 0.0157	7.597	2.2278 ± 0.0454
0.626	11.8909 ± 0.1169	2.084	76.8829 ± 0.0117	4.551	11.6315 ± 0.0225	7.796	1.5582 ± 0.0538
0.683	54.3226 ± 0.0286	2.196	71.7933 ± 0.0081	4.713	10.6197 ± 0.0297	7.997	1.2457 ± 0.0575
0.739	68.5049 ± 0.0184	2.311	67.8552 ± 0.0164	4.877	8.9088 ± 0.0373	8.200	1.0187 ± 0.0600
0.799	78.8559 ± 0.0121	2.429	56.6318 ± 0.0235	5.043	7.8024 ± 0.0363	8.406	1.1316 ± 0.0566
0.862	94.3095 ± 0.0100	2.551	49.5594 ± 0.0156	5.211	7.1099 ± 0.0393	8.615	1.0290 ± 0.0674
0.928	90.9043 ± 0.0075	2.675	44.2174 ± 0.0102	5.382	6.3138 ± 0.0511	8.826	0.9012 ± 0.1213
0.997	97.5273 ± 0.0073	2.803	37.2357 ± 0.0076	5.555	5.2826 ± 0.0603	9.040	0.3590 ± 0.2834
1.070	96.8153 ± 0.0082	2.933	35.8194 ± 0.0061	5.730	4.0991 ± 0.0784	9.257	0.3816 ± 0.2430
1.145	95.6911 ± 0.0085	3.067	33.6439 ± 0.0102	5.907	4.8223 ± 0.0458	9.476	1.0067 ± 0.1054
1.224	98.8988 ± 0.0087	3.203	29.8964 ± 0.0126	6.086	4.7957 ± 0.0289	9.699	1.0017 ± 0.0919
1.307	106.7806 ± 0.0098	3.343	27.9258 ± 0.0135	6.267	3.2205 ± 0.0267	9.926	0.9361 ± 0.0892
1.392	109.5133 ± 0.0097	3.485	24.2762 ± 0.0142	6.451	3.9597 ± 0.0279	10.157	0.8378 ± 0.0974
1.481	116.4721 ± 0.0104	3.630	22.6124 ± 0.0147	6.636	3.6377 ± 0.0319	10.391	0.3247 ± 0.2126
1.573	109.5620 ± 0.0115	3.777	20.7147 ± 0.0164	6.824	3.4628 ± 0.0277	10.630	0.2676 ± 0.2201
1.669	99.5792 ± 0.0121	3.927	15.4553 ± 0.0158	7.014	3.0859 ± 0.0279	10.873	0.3396 ± 0.1626
1.768	89.2674 ± 0.0138	4.079	14.0246 ± 0.0127	7.206	2.6939 ± 0.0293	11.121	0.1992 ± 0.2748
1.870	83.2487 ± 0.0138	4.234	13.0423 ± 0.0124	7.400	2.3427 ± 0.0358	11.374	4950.0625 ± 0.5608

NEUTRON SPECTRA MEASUREMENTS WITH MINIATURE NE-213 SPECTROMETERS

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

Miniature NE-213 liquid scintillators are incorporated in a fast neutron spectroscopy system for neutron spectra determinations. Improvements are made to an existing 1 inch detector system. Additional work includes the design and assembly of a ½ inch NE-213 detector system. The expansion tube portions of the ½ and 1 inch detectors are recognized for the first time as a problem area. The interactions of neutrons and gamma-rays in the expansion tube are shown to cause spectra distortion. An attempt is made to minimize these distortions.

With detector efficiency for both gamma-rays and neutrons being proportional to detector volume, a smaller detector permits neutron spectrum measurements to be made in areas of higher gamma-ray flux. This is demonstrated in water with a fueled assembly and the KSU ^{252}Cf Facility. Only with the ½ inch detector is it possible to gather an undistorted fission spectrum with the ^{252}Cf sources.

PuBe spectra from the 2 inch, 1 inch, and ½ inch NE-213 detectors show increasing resolution with decreasing detector size. With decreasing detector size, the amount of multiple scattering decreases while the effect of edge distortions increases. Thus, the spectra indicate that the lessening of multiple interactions results in increased resolution, while the edge distortion effects are relatively unimportant.