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DR-0396-4

UCID-21548

Using the Transportable, Computer-Operated, Liquid-Scintillator Fast-Neutron Spectrometer System

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November 1, 1988

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Using the Transportable, Computer-Operated, Liquid-Scintillator Fast-Neutron Spectrometer System

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DE89 004981

Abstract

When a detailed energy spectrum is needed for radiation-protection measurements from approximately 1 MeV up to several tens of MeV, organic-liquid scintillators make good neutron spectrometers. However, such a spectrometer requires a sophisticated electronics system and a computer to reduce the spectrum from the recorded data. Recently, we added a Nuclear Instrument Module (NIM) multichannel analyzer and a lap-top computer to the NIM electronics we have used for several years. The result is a transportable fast-neutron spectrometer system. The computer was programmed to guide the user through setting up the system, calibrating the spectrometer, measuring the spectrum, and reducing the data. Measurements can be made over three energy ranges, 0.6 to 2 MeV, 1.1 to 8 MeV, or 1.6 to 16 MeV, with the spectrum presented in 0.1-MeV increments. Results can be stored on a disk, presented in a table, and shown in graphical form.

Introduction

Knowledge of the energy distribution (spectrum) of a neutron field has several applications in radiation-protection. Dosimetric quantities or correction factors for other dosimeters can be calculated from the spectrum, and the spectrum can be used as input to, or for verification of, shielding calculations. For the first two applications, the spectrum may not need to be known with much detail; considerable detail may be needed for shielding calculations, however.

Detecting neutrons and measuring their energy distribution by using the recoil protons they produce in an hydrogenous material is a technique that originated with Chadwick's identification of the neutron.¹ A widely used technique to measure a neutron spectrum employing hydrogen recoils uses an organic liquid-scintillator as both the source and the detector of the recoil protons. At the Lawrence Livermore National Laboratory, the Radiation Science Group of the Hazards Control Department has a continuing project to develop spectrometer systems for radiation-protection applications. Our recent work with liquid scintillators is summarized in another report.²

An organic-liquid scintillator is a fairly compact and lightweight detector. It can have reasonable sensitivity, which can be adjusted somewhat by using scintillators of different sizes. The spectrum obtained by reducing the recorded pulse-height data can have considerable detail. We normally reduce the data into bins that are 0.1-MeV wide, though smaller bins are possible.

Every neutron field is accompanied by gamma rays. Thus, electrons as well as protons deposit energy in the scintillator. Fortunately, the light pulses produced by electrons decay more rapidly than those produced by protons, so that an electronic technique called pulse-shape discrimination (PSD) can be used to separate the interactions. However, the PSD process becomes ambiguous below 0.5 MeV, both because electrons produce light more efficiently than recoil protons, and because the light output as a function of the proton energy deposited in the scintillator is a highly nonlinear function of energy.

Provided the energy of the neutron is not much above 10 MeV (i.e., is not relativistic) and scatters only once in the detector, reduction of the proton-recoil data to a neutron spectrum is quite simple, because the hydrogen-scattering cross section is isotropic. However, the nonlinear light output, multiple scattering of neutrons, and neutron interactions with carbon in the detector itself complicate data reduction. Multiple scattering always occurs at low energies, but this can be corrected if it is not

excessive. The problem increases with the size of the detector. Corrections for the neutron interactions with carbon are more difficult.

The pulse-height scale is normally calibrated using the response of the scintillator to gamma rays. This requires a knowledge of light output as a function of energy deposition for both gamma rays and neutrons. Due to the low atomic number of the scintillator material, this calibration is complicated by the fact that gamma rays with energies greater than 100 keV interact predominantly via the Compton-recoil reaction, which produces a continuous distribution rather than a peak. Thus, some feature on the gamma-ray pulse-height distribution must be chosen to use for the calibration.

In addition to one of the 51-mm high by 51-mm diameter NE-213 liquid scintillators described in Ref. 2, our spectrometer consists of a preamplifier and a small powered NIM bin that holds a high-voltage supply, a linear amplifier, a pulse-shape discriminator, and a multichannel buffer. The latter is essentially a multichannel analyzer that requires a computer or terminal to control its operation and display its data. A laptop computer completes the system.

We programmed the computer to guide the user through setting up the detector system, making the gamma-ray calibrations, taking the neutron data, and reducing the spectrum. Neutron data are reduced and displayed periodically as they are acquired. The final results can be stored on a disk and printed out, both in tabular or graphical form.

The bulk of this report will present and discuss the screen displays produced by the program. Although the program is essentially self-explanatory, this report contains extra details that should simplify operation of the system.

Program Description

General

Our program is identified as PNSI (Portable Neutron Spectrometer I) and was written in Microsoft QuickBASIC, version 3, a form of BASIC that can provide a standalone, executable version of the program. Version 4 of QuickBASIC (which is now available) was not used because it produces slower numerical calculations in computers that do not have a math coprocessor, such as the Toshiba 1100+ that we used. The executable file (PNSI.EXE), the operating system (DOS), the DOS utility program GRAPHICS.COM, and an AUTOEXC.BAT file were all loaded on a disk; this enables the computer to automatically boot-up and start PNSI when it is turned on.

Figure 1 is a screen print of the display that occurs when the program starts. The UCID report mentioned is this report. Several items on this screen need to be emphasized. First, the program was compiled to allow responses to error flags, and thus can be stopped at any time by simultaneously pressing the Ctrl and Break keys. Such an action terminates the program—it does not create a pause, thus all data collected to that point will be lost. The program can be restarted from the beginning by typing "PNSI."

Throughout the program, the notation "....." is used at the beginning of most statements that require an input to the computer. (Any absence of this notation is a typographical error that we will correct in later versions of the program.) To proceed from many of the display screens, such as this one, the command, ".....Press any key to continue" is given. Note that due to the keyboard buffer used by DOS, multiple keystrokes in response to this query can result in the program skipping rapidly through several pages.

Spectrometer Setup

In its present form, PNSI is specific to our detector and electronics. Figure 2, the second display screen of the program, is a list of the equipment for which the program was written. The efficiency data included in the program are for a 51-mm diameter by 51-mm high NE-213 liquid scintillator. We have three detectors this size, each designed to operate in a different orientation. Any of these would probably work with this program, because they have similar responses to the gamma rays used for pulse-height calibrations and similar efficiencies. The program could be modified easily to accommodate other apparatus.

The components that need to be connected to ac power are listed on the next display (Fig. 3). Both the computer and the printer that we use can be operated from batteries for a limited time. Also shown in this display are the dc power and computer interconnections.

Signal interconnections are shown in the next display, Fig. 4. We have found that our PSD unit will not function properly with a cable longer than 20 ns between it and the detector anode. It is also important that the gate input on the back of the multichannel buffer be used, because we have modified the unit by adding a pulse shaper on this input. This modification was necessary because the output signals from the PSD unit do not last long enough to open the linear gate.

Once all of the interconnections are made, the computer shows the first two lines of the display as in Fig. 5, which instruct the user to turn on the power to the electronics. This display is typical of several in the program where a reply to a computer query adds additional information to the display. The CPU on the multichannel buffer has to be reset to get its operation coordinated with the computer.

Once communications between the computer and the multichannel buffer have been established, the display changes to that shown in Fig. 6. Dynamic-range limitations of the PSD unit limit the energy range that can be covered by the system in a single measurement. We designed the program to include three ranges that we believe are convenient for most purposes and that can be obtained under field conditions. Somewhat wider ranges are possible with the greater care possible in laboratory measurements. In this display, we entered no energy value to illustrate the response of the program to an incorrect entry, "Bad choice, try again." A correct choice makes the program proceed to the next display.

For the 0.6- to 2-MeV energy range, the display shown in Fig. 7 lists the correct settings for the linear amplifier we use. A graphical representation of the fine-gain control is given to reduce ambiguities about the setting. (Note: The picture is round on the computer display. The difference between the aspect ratio of the computer display and that of the printer used to produce these figures results in the elliptical shape.) The other energy ranges produce similar displays giving the settings for those ranges.

The next set of parameters, Fig. 8, are the settings needed for the pulse-shape discriminator. Most of the settings are made on ten-turn controls, for which we define full scale to represent 1000. This is a different convention than that used with the amplifier fine-gain control. The PSD unit can generate a display on an oscilloscope that is useful while setting up the parameters. Due to a deficiency in the PSD single-channel analyzer circuits, having the display on during data taking can result in signals that fall above the upper-level discriminator, incorrectly producing an output identified as a neutron. Thus, the display switch must be off for proper operation.

Because all of its operating parameters are either preset internally or set remotely from the computer, only one control on the multichannel buffer needs to be set. The gate switch should be set, as shown in Fig. 9, on the COINC setting to provide external gating of the analog-to-digital converter. Figure 10 is the first of several displays associated with setting the high-voltage supply to the proper output. This can be complicated by our use of this same set of apparatus for a transportable multisphere neutron spectrometer, which requires a different polarity for the high voltage. The first display instructs the user to carefully check the output polarity of the high-voltage supply. For this application the polarity should be negative. If it is not, the user should enter lower case 'p,' and the next two displays, Figs. 11 and 12, are given. They provide specific instructions for changing the output polarity of the high-voltage supply we use.

If the output is already negative, or after it has been changed to negative, the display shown in Fig. 13 appears with instructions on how to set the controls of the high-voltage supply for the chosen energy range (0.6-2.0 MeV in this example). Once again, specific instructions about the range of the ten-turn fine control are given. The size of the signals from most photomultiplier tubes will change for a while after the high voltage is first applied. A five-minute wait at this point will minimize further gain adjustments.

Pre-Run Pulse-Height Calibration

The display in Fig. 14 is largely self explanatory. As an illustration, we have entered the "nogam" option to illustrate that a second chance to consider that choice is offered. If any entry other

than "nogam" had been made, the last two lines shown would not have been displayed. Instead, one of the variations of the display in Fig. 15 would have appeared, depending on the energy range chosen.

The gamma-ray sources for which the program contains the parameters needed for gain calibrations are ^{241}Am , ^{22}Na , ^{137}Cs , ^{207}Bi , and PuBe . Those that can be used for calibration when a maximum neutron energy of 2 MeV is chosen are shown in Fig. 15. For this example, we chose none of the sources so that the entire list could be previewed for the figure. Although ^{22}Na emits two gamma rays and ^{207}Bi emits three, only the response to the lowest-energy gamma-ray from each source will be on scale at the high gain needed to cover this low-energy range.

Once the user goes through this list and chooses a minimum of three gamma-ray calibration points, the display changes to the one shown in Fig. 16. The instructions given in this display set up the system so that signals identified by the PSD unit as gamma rays will be used to operate the linear gate of the multichannel buffer. Though not every PSD circuit has this capability, this is what allows us to use the gamma rays produced by a PuBe neutron source.

Figure 17 shows the display that instructs the user to put the ^{241}Am source near the detector. The user is requested to take adequate data because the uncertainties in the final energy assignments of the neutron spectrum depend on the quality of the calibration data. Figure 18 shows the display during the first five seconds before any pulse-height data are presented. Even without data the display shows considerable information. The source being run is shown at the top of the display, as is the elapsed live time. Pulse-height data are displayed as the logarithm of the counts vs the pulse-height bin. The vertical portion of the cross located on the display is at the pulse-height location where the point used for the calibration, in this case a peak, should fall. A horizontal tic indicates the 1000-count level. With this semilogarithmic display, the bottom of the vertical line represent 100 counts and the top 10,000.

As indicated, data taking will stop automatically when 1000 counts have been obtained in the marked channel, or when 600 seconds of live time has been exceeded. Data taking can also be stopped manually by pressing lower case 's.' Regardless of the method used to make it stop, the computer beeps when data taking is complete. This is primarily a convenience to let the user know when an automatic stop has occurred. After the first five seconds have elapsed, the display will look like Fig. 19.

Completion of data taking with ^{241}Am produces a display like that shown in Fig. 20. In this particular case, an automatic stop occurred when the data exceeded the cross mark. Because data are transferred from the multichannel buffer to the computer at fixed 5-s intervals, and because data acquisition is not terminated until the computer confirms that the stop conditions have been met, it is possible to exceed 1000 counts in the marker channel at high count rates. As noted in the line of text immediately below the graphical display, the data for this source can be retaken if a mistake has occurred.

If the data are acceptable, pressing any key except lower-case 'r' will produce the display shown in Fig. 21. The additional vertical marker in this display indicates the peak position calculated by the program. A peak is located by calculating the centroid of the negative values of a smoothed second derivative taken in the vicinity of the original marker. Once it is determined, the peak channel and its corresponding light value are entered into a data set used to calculate a least-squares straight line to the calibration data. The final instruction tells the user to remove the ^{241}Am source from the detector.

Moving from this display would produce the instructions to put up the next source chosen, in this case ^{22}Na . A sample of the data obtained at this gain using this source is shown in Fig. 22. The cross is located at the correct position for the half-height of the upper edge of the Compton recoil-electron distribution. At gain settings where ^{22}Na and ^{207}Bi show more than one edge, the cross is placed at the proper position for the most-energetic electrons. It does not appear to be halfway down the edge because the logarithm of the number of counts in each channel is displayed. Actually, the gain was somewhat high when the data shown in this figure were taken, probably because the photomultiplier had not yet stabilized.

With this source, an additional option is available to stop data taking. Pressing lower-case 'g' will activate a gain check procedure. This option is not used with ^{241}Am because the peak this source produces is too low in pulse height to be a dependable point for checking the gain. If the gain check option is chosen, a display similar to Fig. 23 is obtained. The vertical marker indicates where the

program found the half height. Only the highest-energy Compton edge displayed is used for the gain check. Besides the vertical marker, the correct and calculated positions of the half height are shown on the display.

Gain adjustments need not be made if these two values are within 10%. The instructions given for changing the gain are necessary to insure the correct operation of the PSD unit. Data taking must be restarted after a gain check. Except for the ^{241}Am source, all of the gamma calibrations made prior to the neutron measurements include the option to make a gain check. Once this option has been exercised, calibrations previously taken must be repeated. At present the program must be completely restarted to allow that. Subsequent versions of this program will include changes to improve the gain-checking routine.

To calculate the half height, the program searches the data above the marker for a maximum, and below it for a minimum. Then a pulse-height value is found that is midway between those at the maximum and minimum. Smoothing and interpolation are used.

Final ^{22}Na calibration data for a 2-MeV maximum neutron energy are shown in Fig. 24. The half height identified by the program is shown by the vertical marker. The half height and the corresponding light value are added to the data set for the least-squares calculation.

Figure 25 shows the final display at this energy setting for the ^{207}Bi source, and Fig. 26 gives the comparable ^{137}Cs results.

Figure 27 is analogous to Fig. 15, but lists the gamma-ray sources for which the program has values it can use to calibrate for an 8-MeV full-scale neutron energy: ^{22}Na , ^{207}Bi , and ^{137}Cs . Figures 28, 29, and 30 show typical final displays for these sources at this gain. All of the gamma rays from ^{22}Na and ^{207}Bi are used.

Analogous displays for the case where the maximum neutron energy is 16 MeV are shown in Figs. 31-35. The 4.43-MeV gamma ray from a PuBe neutron source is useful at this gain to decrease the amount of extrapolation needed from the highest calibration energy to the full-scale neutron energy. This gamma ray can only be used if the PSD unit in the system has a gamma-only output.

Neutron Spectrum Measurements

Once the selected pre-run pulse-height calibrations are completed, the program instructs the user to connect the neutron identification signals from the PSD unit to the linear gate of the multichannel buffer. These instructions are shown in Fig. 36. Next, the program calculates an energy calibration using the available gamma-ray data. It also calculates the other parameters it needs to reduce the measured proton-recoil data to a neutron spectrum. A message to this effect occurs on the display while these calculations are underway, as in Fig. 37. Sometimes, as in this case, the calibration will result in an adjustment to the energy range. If so, the new energy range will be displayed.

A number of requests are made on the next display page, which is shown in its entirety in Fig. 38. Normally, subsequent lines appear only after the previous queries have been answered. The first request asks for a total live time for the neutron measurement. If the response to this query is '0' or a carriage return, the program will use a default value of 86400 seconds (one day).

All spectra are normalized to the elapsed time; a second query allows the entry of another normalization, for example a source parameter such as intensity. In this case, the program responds to the entry of a '0' or carriage return with a default value of '1.' Next, the program asks for a title to identify the tabular data and the final graphical display of the spectrum. Finally, the user is instructed to place the detector the desired distance from the source. Pressing any key at this point starts the accumulation of neutron data.

Once neutron data acquisition has begun, the computer display changes to the graphical representation shown in Fig. 39. The top of the display shows the preset live time selected, in this case 300 seconds, and the elapsed live time. During the first 15 s of data acquisition, the message shown in the middle of the graphical area is displayed. Although at low fluences 15 s might not be enough, this delay allows the program to accumulate a minimum amount of data before trying to provide a neutron spectrum. As the message at the bottom of the display indicates, data taking can be halted manually at any time before the preset live time is reached by pressing lower case 's.'

After the first 15 seconds of live time have elapsed, and after each subsequent 15 seconds, the display is updated to a presentation like that shown in Fig. 40, which in this case is the spectrum from a PuBe neutron source measured with 16-MeV full scale. Besides the neutron spectrum, labels to the x and y axis have been added. The normalized fluence is shown vs neutron energy, with the former on a logarithmic scale and the latter on a linear scale. The range of fluences displayed is adjusted automatically from the decade just below the smallest fluence to the decade just above the largest fluence. Tic marks are placed along the y axis at each intermediate decade. The displayed energy range goes from 0 to the chosen maximum energy, although the calibration and the output of the source determine the actual range over which data are obtained. Uncertainties in the energies (1σ) are shown as horizontal ticks centered at each energy. These are primarily due to the uncertainties in the gamma-ray calibration. The vertical lines are the uncertainties in the fluence values, again shown at a 1σ level. These include neutron-data counting statistics and uncertainties in all the parameters, such as efficiency, needed to reduce the data.

Several steps are needed to reduce the recoil-proton spectrum recorded by the multichannel buffer to a neutron spectrum. First, the least-squares fit to the gamma-ray calibration data is used to calculate channel values corresponding to the top and bottom of neutron energy bins that are 0.1-MeV wide, centered every 0.1 MeV. The recoil-proton data are then rebinned into these bins. A first derivative of the resulting distribution is taken by using the differences of adjacent channels. These results are corrected for detector efficiency as a function of energy and then smoothed using a Gaussian weighting function, the width of which varies like the resolution of the detector.

After pressing lower-case 's,' or once the preset live time is reached, a display like that shown in Fig. 41 is obtained. If for any reason the neutron data need to be rerun without a change in the calibration, that can be done by typing lower-case 'r.' Pressing any other key changes the display to that shown in Fig. 42, which indicates that neutron data acquisition is complete.

Post-Run Pulse-Height Calibration

Unless the "nogam" option was chosen, the next display, Fig. 43, asks if the user is going to take post-run gamma-ray calibration data. It is highly recommended that this be done, but in some circumstances this might not be possible. If any input except 'done' (in lower case) is entered, additional lines are added to the display, and the routine for taking gamma-ray calibration data is repeated. The program will only request those sources chosen for the initial calibration.

Figure 44 is an example of one of these calibration runs. Note that the program will no longer allow the gain-adjust option. As a result, data taking can be stopped manually by pressing either lower case 's' or lower case 'g.'

Final Neutron Spectrum and Dosimetric Calculations

After the gamma-ray calibrations are rerun, the program recalculates the energy calibration, as noted in Fig. 45, and uses that result to do a final neutron data reduction, giving the display shown in Fig. 46 while the calculation is in progress. Once that is done, the final neutron spectrum is displayed graphically (Fig. 47). Note that this display shows the title that was previously entered.

At first, the next display (Fig. 48) tells the user that the computer is calculating dosimetric values from the neutron spectrum. When the calculations are complete, the results are added to the display. The fluences to absorbed-dose conversion factors come from the paper of Auxier, Snyder, and Jones, the fluence-to-kerma conversion factors are from ICRU Report 26, and the fluence-to-dose-equivalent factors come from NCRP Report 38.³⁻⁵

Output Options

Next, users are asked if they want to store the spectrum data in a disk file. If that option is chosen, the program asks if there is a disk in the proper drive and asks for a name for the file. The file can be given any name that is compatible with the requirements of the computer operating system. If this option is not chosen, the program moves directly to the next option.

A tabular printout of the neutron spectrum is the next option offered. Naturally, this option is not possible unless the system includes a printer. If chosen, the user is instructed to turn the printer on, and

to determine that the paper is at the top of a page. The computer will then provide a printout like that shown in Fig. 49. The printout has the date and time on the top line, the title, and the tabular data. This set of data was obtained using the 2-MeV full-scale option. The printout is designed to put 4 MeV of data on each page, so two pages are required when the 8-MeV full-scale option is chosen, and four pages are needed for 16-MeV full-scale. The last item on the page is the table of dosimetric values.

Figure 50 appears after the printout option. If the system has an active printer, the program can provide a screen printout such as Fig. 51. (This is the same as Fig. 47, but with no instructions.) This is also the final display produced, after which the program stops.

Summary

We have assembled the equipment and written the software for a computer-controlled, transportable, liquid-scintillator fast-neutron spectrometer. The computer program guides the user through the process of setting up the apparatus and taking the calibration and spectrum data. A printout of the spectrum and dosimetric values calculated from it are available, as are a printer-graphics plot of the results. It is also possible to make a disk file of the spectrum and its uncertainties.

The limitations of the system are primarily those of the detector system. A major limitation for radiation-protection applications is the inability to measure neutrons with energies below 600 keV. This is due to limitations in our ability to reject gamma-ray interactions with the detector. The PSD settings used in this program were selected to allow incorrect identification of only one detected gamma ray in a thousand as a neutron, but some neutron fields allow a gamma-ray-to-neutron ratio that exceeds 1000. The PSD circuits also have a limited pulse-height range, so while this system can be used for energies from 0.6- to 16-MeV, more than one measurement is needed to cover that entire range.

With reasonable care, a user should be able to obtain a neutron spectrum without difficulty. Throughout the program many options allow incorrect data to be repeated. The program itself will undoubtedly evolve as more user experience suggests improvements. Improvements in pulse-shape discrimination circuits could also affect how the data are taken.

Although the instructions given in the program are specific to the apparatus used by this Group, modifications to accommodate other equipment could be made. Such modifications will be needed as work continues to decrease the size, weight, and power consumption of electronic circuits. The ultimate goal is to have a unit that can be carried in a single case that will operate from batteries for at least eight hours. Work on the pulse-shape discriminator to make such a system possible has already begun. Another major simplification under development is to use a stable light pulser to eliminate the need for gamma-ray calibrations.

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Lawrence Livermore National Laboratory
Hazards Control Department
Special Projects Division
Radiation Science Group

Transportable Liquid-Scintillator Neutron Spectrometer System

This system is discussed in more detail in LLNL Report UCRL #000000.

To stop program manually, press 'Ctrl/Break', to start it, type 'PNS1'.

.....Press any key to continue.

Figure 1

In addition to this computer, this program requires the following components:

1) NE-213 liquid-scintillation detector unit #1

NOTE: This detector must be operated either horizontal or pointing up, as indicated by the arrows on the can.

2) Canberra model 2005 preamplifier (serial# 9861155)

3) BNC model AP-3 Portamix power-supply/bin (DOEN 3582280)

The NIM modules listed below are operated in the power-supply/bin.

3.1) ORTEC model 578 linear amplifier (DOEN 3489188)

3.2) Link Systems model 5210 pulse-shape discriminator (DOEN 3869145)

3.3) ORTEC model 917 ADCAM multichannel buffer (DOEN 4739225)

3.4) Bertan model 353 high-voltage supply (DOEN 3987876)

.....After these components are in place - press any key to continue.

Figure 2

Connections to AC power

- 1) Power-supply/bin
- 2) High voltage supply
- 3) Computer AC adapter (if used)
- 4) Printer AC adapter (if used)

Computer and DC power connections

- 1) RS-232 cable from computer to 'null modem' on BACK of multichannel buffer
- 2) Printer cable between the printer and the computer (if a printer is used)
- 3) Preamp-power cable from the preamp to the BACK of the linear amplifier
- 4) High-voltage coaxial cable from the high-voltage output (J1) on the BACK of the high-voltage supply to the detector high-voltage (HV) INPUT

.....After these connections are made - press any key to continue.

Figure 3

Interconnections, continued....

Signal (RG58) coaxial cables (lengths are given in equivalent delay times).

- 1) A 2 ns, or shorter, cable from the detector DYNODE OUTPUT to the preamplifier INPUT (This connection may use rigid adapters.)
- 2) A 20 ns cable from the preamplifier OUTPUT to the linear amplifier FRONT panel INPUT
- 3) A 20 ns cable from the detector ANODE OUTPUT to the pulse-shape discriminator FRONT panel SIGNAL INPUT (This cable, the signal cable from the preamplifier, the high voltage cable, and the preamplifier power cable are usually bundled together.)
- 4) A 2 ns cable from the linear amplifier FRONT panel UNIPOLAR OUTPUT to the multichannel buffer FRONT panel ADC INPUT
- 5) A 5 ns cable to go from the BACK panel GATE input of the multichannel buffer to either the GAMMA output on the BACK panel of the pulse-shape discriminator, or the NEUTRON output on the FRONT panel of the PSD unit

.....After these connections are made - press any key to continue.

Figure 4

Turn on the power to the power-supply/bin.

.....After the power is on - press any key to continue.

The computer is establishing communications with the multichannel buffer.

.....Now press the CPU RESET on the FRONT panel of the multichannel buffer.

Figure 5

This program permits measurements over one of three energy ranges.

0.6 MeV to 2 MeV,

1.1 MeV to 8 MeV,

1.6 MeV to 16 MeV.

Experimental conditions may limit the energy range actually measured.

.....Enter the UPPER energy for the range you wish to measure? █

Bad choice, try again.

Figure 6

Linear amplifier settings for a maximum energy of 2 MeV.

Fine Gain: 9.878

Coarse Gain: 500

Shaping time: 0.5 microseconds

MLR: AUTO

Delay: OUT

POS/NEG: NEG

.....After these settings are made - press any key to continue.

Figure 7

Pulse-shape discriminator settings for a maximum energy of 2 MeV.

NOTE: Full clockwise rotation of the ten-turn controls is defined as 1000.

Separation: 430

Rotation: 260

Lower output limit: 000

Upper output limit: 1000

Threshold: 500

Display: OFF

.....After these settings are made - press any key to continue.

Figure 8

Multichannel buffer setting - GATE COINC

.....After this setting is made - press any key to continue.

Figure 9

!!!! The high voltage supply MUST be set for a NEGATIVE (-) output. !!!!

Set both the coarse and fine voltage adjustments to 0.

Turn on the AC to the high-voltage supply.

If the POSITIVE output voltage indicator is on, press 'p'.

Press any other key if the NEGATIVE output voltage indicator is on.

Figure 10

The output polarity of the high-voltage supply MUST be changed!

- 1) Turn off the high-voltage supply and unplug it from the AC power.
- 2) Disconnect the high-voltage cable from the rear of the supply.
- 3) Take the supply out of the power-supply/bin.
- 4) Remove the five bolts holding on the side with the label referring to reversing the polarity. (This requires a small Phillips screwdriver.)
- 5) Lift off the side plate.
- 6) Grasp the unhinged end of the aluminum clamp holding the polarity reversing plug in place, and rotate it up.
- 7) Remove polarity setting plug. (This is plug just under the 'output' label.)
- 8) Turn the plug end-for-end and reinsert it. The word 'NEGATIVE' should now be faintly visible.
- 9) Rotate the aluminum clamp back down to lock the plug into position.

.....Press any key to continue.

Figure 11

10) Reinstall the side, carefully replacing the five bolts that hold it on.

11) Put the supply back into the power-supply/bin.

12) Reconnect the high voltage cable.

13) Plug the AC cord back in.

14) Make certain the coarse and fine controls are set at zero.

15) Turn the supply on.

The NEGATIVE indicator light on the front panel should now come on.
If it does not, there is something wrong, either with the supply, or with the polarity reversing plug.

.....Press any key to continue.

Figure 12

The high voltage for a maximum energy of 2 MeV is 2040 volts.

Coarse: 1.5 kV

Fine: 540 volts.

NOTE: Full clockwise rotation of the fine control provides 1000 volts.

For better stability, wait five (5) minutes before taking data.

.....After these settings are made - press any key to continue.

Figure 13

Gamma-ray sources are used to provide the calibration needed to convert the pulse-height scale to light units from which neutron energies can be calculated.

However, a LOW QUALITY neutron spectrum may be obtained without a calibration. If you wish to exercise this option, enter 'nogam'? nogam

This option can not compensate for a bad gain adjustment or any detector drift. Are you still willing to exercise this option (y or n)? n

Figure 14

A source may provide multiple calibration points.

To preview which sources can be used to calibrate for a maximum energy of 2 MeV, press any key except 'y' for each of the following queries.

A 'y' response selects a source to be used for this run.

*** A minimum of THREE (3) calibration points is required ***

Am-241 (1 peak) (y to select)?

Na-22 (1 Compton edge) (y to select)?

Bi-210 (1 Compton edge) (y to select)?

Cs-137 (1 Compton edge) (y to select)?

Not enough calibration points

Figure 15

Connect the cable from the GATE input on the BACK of the multichannel buffer to the GAMMA output on the BACK of the pulse-shape discriminator.

.....Press any key to continue.

Figure 16

Place the Am-241 source near the end of the detector.

The quality of the gamma-ray calibrations determines the energy uncertainties

.....When source is in place - press any key to continue

Figure 17

Run stops when the data reach the center of the cross, or live time exceeds 600

.....For a manual stop, press 's'.

Figure 18

Run stops when the data reach the center of the cross, or live time exceeds 600.
For a manual stop, press 's'.

Figure 19

If a mistake has occurred, these data can be redone by typing 'r'.
 Press any other key to continue.

Figure 20

Calibration using Am-241 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 21

Run stops when the data reach the center of the cross, or live time exceeds 600.

.....For a manual stop, press 's' - pressing 'g' performs a gain check.

Figure 22

Run stops when the data reach the center of the cross, or live time exceeds 600.

Correct half height: 245

Measured half height: 258

To raise gain, increase amplifier fine gain; to lower it, decrease high voltage.

.....Press any key to continue.

Figure 23

Calibration using Na-22 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 24

Calibration using Bi-207 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 25

Calibration using Cs-137 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 26

A source may provide multiple calibration points.

To preview which sources can be used to calibrate for a maximum energy of 8 MeV, press any key except 'y' for each of the following queries.

A 'y' response selects a source to be used for this run.

*** A minimum of THREE (3) calibration points is required ***

Na-22 [2 Compton edges]	(y to select)? y
Bi-207 [3 Compton edges]	(y to select)? y
Cs-137 [1 Compton edge]	(y to select)? y

Figure 27

Calibration using Na-22 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 28

Calibration using Bi-207 complete. Remove the source from the detector

.....Press any key to continue.

Figure 29

Calibration using Cs-137 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 30

A source may provide multiple calibration points.

To preview which sources can be used to calibrate for a maximum energy of 16 MeV, press any key except 'y' for each of the following queries.

A 'y' response selects a source to be used for this run.

*** A minimum of THREE (3) calibration points is required ***

Na-22 (2 Compton edges)	(y to select)? y
Bi-207 (3 Compton edges)	(y to select)? y
Co-137 (1 Compton edge)	(y to select)? y
TiBe gamma . . . (1 Compton edge)	(y to select)? u

Figure 31

Calibration using Na-22 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 32

Calibration using Bi-207 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 33

Calibration using Cs-137 complete. Remove the source from the detector.

.....Press any key to continue.

Figure 34

Calibration using PuBe complete. Remove the source from the detector.

.....Press any key to continue.

Figure 35

Connect the cable from the GATE input on the BACK of the multichannel buffer to the NEUTRON output on the FRONT of the pulse-shape discriminator.

.....Press any key to continue.

Figure 36

Calculating the energy calibration, and quantities common to the entire run.

Calibration modified the energy range to 1.9 to 15.9 MeV.

....Press any key to continue.

Figure 37

The run stops automatically when the preset live time is exceeded.

.....Enter the preset live time, in seconds? 300

.....Enter any additional normalization factor (ie. source strength)?

.....Enter a title (up to 50 characters):
PuBe

Set the center of the scintillator, as marked on the detector, the desired distance from the source of neutrons.

.....Press any key to start data taking.

Figure 38

.....Pressing 's' will stop data taking before timeout.

Figure 39

.....Pressing 's' will stop data taking before timeout.

Figure 40

If a mistake has occurred, these data can be redone by typing 'r'.
Press any other key to continue.

Figure 41

Neutron data acquisition is complete.
.....Press any key to continue.

Figure 42

To compensate for any drift that might have occurred during the neutron measurements, the gamma-ray calibrations should now be repeated.

If that cannot be done, enter the word 'done'.

Connect the cable from the GATE input on the BACK of the multichannel buffer to the GATE output on the BACK of the pulse-shape discriminator.

....Press any key to continue.

Figure 43

Run stops when the data reach the center of the cross, or live time exceeds 600.

.....For a manual stop, press 's' or 'g'.

Figure 44

Recalculating the energy calibration.

Calibration modified the energy range to 1.9 to 16 MeV.

.....Press any key to continue.

Figure 45

Recalculating the neutron spectrum.

Figure 46

.....Press any key to continue.

Figure 47

Calculating dosimetric values

Total fluence	2.73E+02 +/- 2.5%
Total absorbed dose	1.45E-06 rads/sec/norm
Total kerma	1.19E-06 rads/sec/norm
Total dose equivalent	1.06E-05 rems/sec/norm

.....Do you want to store the results (y to select)

Be sure there is a disk in Drive B:

.....Enter a name and extension (name.ext) for the file? pube.dat

.....Enter a heading (up to 50 characters):

PuBe in polyethylene

.....Do you want to print the results (y to select)

Is printer on and at the top of the page? █

Figure 48

09-10-1986 11:38:10

Page 1 PuBe

Fluence in the 0.1 MeV bin centered at the neutron energy:

Neutron Energy (MeV)	Neutrons/cmss/time/normalization
0.10	
0.20	
0.30	
0.40	
0.50	
0.60 +/- 0.02	1.95E+00 +/- 12.5%
0.70 +/- 0.02	5.38E+00 +/- 7.9%
0.80 +/- 0.02	6.19E+00 +/- 7.7%
0.90 +/- 0.02	5.90E+00 +/- 7.6%
1.00 +/- 0.03	5.55E+00 +/- 7.7%
1.10 +/- 0.03	5.28E+00 +/- 8.3%
1.20 +/- 0.03	4.69E+00 +/- 8.5%
1.30 +/- 0.03	4.62E+00 +/- 9.1%
1.40 +/- 0.04	4.31E+00 +/- 9.3%
1.50 +/- 0.04	4.33E+00 +/- 9.6%
1.60 +/- 0.04	4.28E+00 +/- 9.7%
1.70 +/- 0.04	4.11E+00 +/- 10.2%
1.80 +/- 0.05	3.65E+00 +/- 11.1%
1.90 +/- 0.05	2.52E+00 +/- 19.4%
2.00	
Total fluence	6.21E+01 +/- 2.8%
Total absorbed dose	1.77E-07 rads/sec/norm
Total kerma	1.50E-07 rads/sec/norm
Total dose equivalent	2.21E-06 rems/sec/norm

Figure 49

If the printer is on, pressing 'd' will print the graph of the spectrum.
Pressing any other key ends the program.

Figure 50

Figure 51