**VOLUME 3: EXPERIMENTAL APPLICATIONS
FOR THE MARK-1 AND MARK-1A PULSED
IONIZING RADIATION DETECTION SYSTEMS**

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Volume 3: Experimental Applications
for the
MARK-1 and MARK-1A Pulsed Ionizing Radiation Detection Systems

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ABSTRACT

This report is the third volume in a three volume set describing the MARK series of pulsed ionizing radiation detection systems. This volume describes the MARK-1A detection system, compares it with the MARK-1 system, and describes the experimental testing of the detection systems. Volume 1 of this set presents the technical specifications for the MARK-1 detection system. Volume 2 is an operations manual specifically for the MARK-1 system, but it generally applies to the MARK-1A system as well.

These detection systems operate remotely and detect photon radiation from a single or a multiple pulsed source. They contain multiple detectors (eight in the MARK-1 and ten in the MARK-1A) for determination of dose and incident photon effective energy. The multiple detector arrangement, having different detector sizes and shield thicknesses, provides the capability of determining the effective photon energy of the radiation spectrum. Dose measurements using these units are consistent with TLD measurements. The detection range is from 3 nanorads to 90 microrads per source burst; the response is linear over that range. Three units were built and are ready for field deployment.

MARK-1 AND MARK-1A: RADIATION DETECTION SYSTEMS EXPERIMENTAL APPLICATIONS

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1. EXECUTIVE SUMMARY

This report covers experimental and computational studies of the MARK-1 and MARK-1A detection systems. Because the MARK-1A detection system was completed after the publication of the MARK-1 detection system specifications manual (reference 2); this report also covers the general description of the MARK-1A detection system and compares it with the MARK-1 design.

The MARK series detection units and their forerunners were tested at several irradiation facilities, but only those tests which involved the MARK-1 or the MARK-1A are discussed in this report. The performance tests have demonstrated that the units are linear in response with respect to dose and have a detection range of 3 nanorads to 90 microrads per radiation burst. In side-by-side comparisons, the MARK-1 and MARK-1A detection units show consistent operation to within 10 % over the detection range and are consistent with TLD measurements under approximately the same exposure conditions.

Experiments and calculational studies designed to define the energy differentiation capability of the MARK-1 detection unit have shown that it is capable of differentiating between low energy (~ 6 MeV electron energy), medium energy (~ 15 MeV electron energy) and high energy (> 20 MeV electron energy) radiation cone sources. The detection unit can provide useful information about the beam energy of the source even when the source is obscured by shielding or other obstacles.

These detection units have potential commercial applications as realtime dose monitors for pulsed ionizing radiation sources, such as are used in X-ray radiography and in radiation therapy. The capability to measure the intensity of each radiation burst provides a definite

advantage over integrating dosimeters, such as TLD's or ion chambers. A straight-forward technical challenge in adapting this technology for this purpose is matching the detection range to the intensity of the fields to be measured. A second key factor is the development of a calibration protocol using conventional radiation source standards such as ^{60}Co or ^{137}Cs . This will require incorporating the capability to measure constant intensity sources and pulsed sources with the same instrument. A suitable source of funding for this development will be sought in the private sector.

2. INTRODUCTION

This report is the third in a three volume set which describes the MARK-1 and MARK-1A detection systems and provides data concerning their performance under typical field applications. Volume 1 of the set contains the specifications and detailed design of the MARK-1 detection system. Volume 2 is a field operator's manual for the MARK-1 system. This volume contains a description of the MARK-1A detection system and presents experimental results for both the MARK-1 and the MARK-1A detection systems. In the description of the MARK-1A system, only those design features which differ from the MARK-1 design are covered.

The MARK-1 and MARK-1A detection systems were primarily designed to fill the U.S. Department of Energy Department of Research and Development/Office of Intelligence and National Security need to detect and identify highly-intense, pulsed-ionizing photon sources. The specifications for the radiation detection system to monitor such sources are:

1. The detection system must be capable of detecting high-energy photons from bremsstrahlung or fissioning sources.
2. It must be able to detect each individual burst from a pulsed source and store the intensity of the burst and its time of occurrence.
3. It must be able to determine the effective photon energy of each burst or average of several bursts.
4. It must be able to differentiate between pulsed source operation and random background noise.
5. It must have a self-activating ("triggering") capability.

6. It must have a dynamic range of sensitivity able to detect and characterize bursts over five orders of magnitude of photon intensity.
7. It must be able to operate remotely and unattended for several hours with no external power source.
8. The time required to service the unit in the field and retrieve stored burst data must be less than 2 minutes.
9. The detection unit must be portable by one person (weigh less than 23 kg).

Development of the detection device commenced at the Idaho National Engineering Laboratory (INEL) in 1987; and a proof-of-principle detection system was constructed from standard, "off-the-shelf" detectors and nuclear electronics. This system was powered by a small gasoline-powered portable generator and required a small van to transport. It was successfully tested at Lawrence Livermore National Laboratory (LLNL) in the spring of 1988. These tests demonstrated the feasibility of the basic concept of the multiple detector system and provided the basis for a more detailed set of specifications for the follow-on detection systems.

The proof-of-principle detection system was followed by a battery-powered prototype system which was contained in a 36 cm x 36 cm x 53 cm metal box and was effectively two person portable. This system was tested at Oak Ridge Electron Accelerator (ORELA) (Section 3.7), MIT BATES Accelerator Laboratory (Section 3.7) and the PHERMEX test facility at Los Alamos National Laboratory (Section 3.2). The basic design of the MARK-1 detection system was based on the results of these tests.

The MARK-1 detection system is contained in a 17 cm x 33 cm x 53 cm aluminum suitcase and weighs 20 kg. A description of the MARK-1 is given in Section 2 of this report

and also in references 2 and 3. The first detection unit of the MARK-1 design was tested at the EG&G Santa Barbara Electron Accelerator (see Section 3.3) and at the electron accelerator at the TITAN BETA facility (see Section 3.4). A second unit of the MARK-1 design was constructed; and the two MARK-1 units were tested using the electron accelerators at High Energy Services Corp (HESCO) (See Section 3.5) and at LANL/M-4 (see Section 3.6).

A variation of the MARK-1 design, called the MARK-1A, has been developed more recently. The new design incorporates different detectors which do not require high voltage power supplies or as much lead shielding in the detection box, enabling reduction of the weight of the MARK-1A to less than 16 kg. In addition, the MARK-1A design incorporates two sets of fixed gain detectors; one set operates in the low intensity range (3 nanorad - 690 nanorad per burst) and the other set operates in the high intensity range (300 nanorad - 88 microrad per burst). The MARK-1A design is particularly useful for detecting and characterizing single burst sources.

Both MARK-1A and the two MARK-1 detection units were tested at the M-4 facilities at LANL. These tests are described in Section 3.6, and the results are described in Section 6.

The rest of this report is organized as follows: Section 3 provides general descriptions of the MARK-1 and MARK-1A detection systems and highlights the differences between the two systems. Details of the MARK-1 design are given in references 2 and 3; and details of the MARK-1A design and its analysis routines are given in the appendices. Brief descriptions of the performance tests of these systems are presented in Section 4. In Section 5, the calculational model for the detection system and calculated results of electron/photon transport calculations are presented. Section 6 presents the results of the tests and gives a

discussion of the results of the measurements and the calculations. The appendices of this report present those particular design specifications of the MARK-1A that are different from the corresponding design specifications for the MARK-1.

3. MARK-1 AND MARK-1A GENERAL SYSTEM DESCRIPTIONS

A MARK-1 or MARK-1A Radiation Detection System (see Figure 3.1) consists of two portable, suitcase-sized units: the detection unit and the support unit. Views of opened detection units for the MARK-1 and MARK-1A are shown in Figures 3.2 and 3.3, respectively. The detection unit for either the MARK-1 or the MARK-1A is a battery-powered system that requires no external power for a period up to 18 hr and it can acquire radiation data at a burst repetition rate up to 60 Hz. Inside the detection unit are multiple radiation detectors, dc power supplies, analog circuits, system microcontroller, and removable data memory card. The suitcase enclosure is 53 cm (21") long, 33 cm (13") tall, and 17.5 cm (6.7") wide. The complete unit weighs approximately 20 kg (45 lb) for the MARK-1 and 16 kg (35 lb) for the MARK-1A.

The support unit suitcase is the same for either the MARK-1 or the MARK-1A detection unit. It contains a laptop computer, a memory card reader, a printer, remote off/on controls and battery chargers. It is used for initial detection system setup and data analysis. After initialization the computer can be disconnected from the detection unit and that unit can be left to acquire burst data in stand alone mode. The support unit suitcase enclosure is 53 cm (21") long, 43 cm (17") tall, and 18 cm (7") wide and weighs approximately 16 kg (35 lb).

A MARK-1 or MARK-1A detection unit determines the intensity of a radiation burst by measuring the integrated total energy deposited in each scintillation crystal in the multi-detector array in the detection unit. The system is self-activated or triggered by coincident detection pulses in two or more of detectors in the array. Since the background noise intensity is generally orders of magnitude less than the

Figure 3.1. The MARK series pulsed ionizing radiation detection system. The system consists of two suitcases; the smaller case is the field-deployable detection unit and the larger case contains the support equipment needed to read and process the collected data.

Figure 3.2. MARK-1 detection unit with suitcase lid open.

Figure 3.3. MARK-1A detection unit with suitcase lid open.

"source generated" intensity, the probability of simultaneous events occurring from a random background is quite low. During initialization of the detection unit, the operator selects which detectors will be used in the coincidence network to trigger the system.

Upon detection of a coincidence event, the system microcontroller reads each detector's pulse peak value and stores this value in memory. In addition, the date and time of the event (to the nearest millisecond) are read and stored in the same data record with the peak intensity data. The MARK-1 system also measures and stores in the data record two temperature readings, and amplifier gain information for use in post-processing analyses. All data are stored in a removable, "credit card" size memory cartridge. After data acquisition is complete, the memory cartridge is removed from the detection unit and read using the memory card reader and the laptop computer. Removal of the memory card and replacing it with another requires less than one minute to perform. After removal, the memory card can be taken to another location and the contents transferred to permanent memory or to a floppy disk. The time for transferring data from a memory card and analyzing the data is approximately 10 minutes.

The detector response versus detector size and shield thickness allow the analyst to determine the effective photon energy in a single burst or an average of several radiation bursts. The absolute intensity data is used to determine energy deposited and dose per radiation burst for a single burst or average energy deposited and average dose per radiation burst for multiple bursts. Analyses of the stored pulsed data provide the total energy deposited per pulse, dose per pulse, dose rate over the collection time, source pulse rate, and source stability.

The MARK-1A is a modification of the MARK-1 with the following changes: (1) the photomultiplier-based detectors are replaced with photodiode detectors which eliminates the high voltage module, (2) the use of photodiode detectors reduces the amount of lead shielding that is required, (3) the system power requirement with photodiode detectors is less, (4) the automatic gain control is eliminated in favor of two sets of detectors operating at two different fixed gains permitting single pulse analyses, and (5) the software required for the MARK-1A data acquisition is simplified which speeds up both acquisition and analysis.

Shown in Figures 3.4 and 3.5 are simplified hardware block diagrams of the MARK-1 and MARK-1A systems, respectively. The differences between the two systems are listed in Table 3.1. The most obvious hardware differences between the two MARK versions are: (1) the elimination of the high voltage module and associated automatic gain control components (digital-to-analog converted and automatic gain latch) from the MARK-1 system, and (2) the addition of the low voltage power distribution and bias voltage module in the MARK-1A.

Additional hardware difference occur in the analog circuit systems. Figures 3.6 and 3.7 are block diagrams of the MARK-1 and MARK-1A analog circuits, respectively. The primary differences between the MARK-1 and MARK-1A analog circuits are: (1) physical location of

Figure 3.4. Simplified block diagram for MARK-1 detection unit.

Figure 3.5. Simplified block diagram for MARK-1A detection unit.

Table 3.1

COMPARISON OF MARK-1 AND MARK-1A GENERAL FEATURES

	MARK-1	MARK-1A
1. Detectors	Bismuth-Germinate crystals coupled to photomultiplier tubes. Output is fed to external preamplifiers	Cesium-Iodide crystals coupled to silicon photodiodes with built-in integral preamplifiers
2. Detector Bias	High-voltage module (1500 Vdc capability) fed to photomultiplier tubes	18 Vdc reverse bias to photodiodes from two series-connected 9 volt alkaline batteries.
3. Preamplifier	(1) Preamplifier external to detector -- first stage on analog circuit board. (2) Circuit gain adjust via high-voltage applied to photomultiplier tube. Amplifier circuit board has fixed gain.	(1) Preamplifier integral with CsI/photodiode assembly. (2) Circuit gain adjust via wide-band variable gain, signal/amplifier. (CsI/photodiode/preamp assembly has fixed gain.)
4. Dynamic Range	(1) 61 keV (ADC least significant bit) to 32 GeV full scale. (2) One set of eight detectors is controlled with automatic gain control system in the high voltage circuit to generate eight gain settings as a function of signal amplitude. Successive gain settings	(1) 61 keV (ADC least significant bit) to 25 GeV full scale. (1) Two sets of five detectors each (total = 10 detectors) are set at different gain settings. High-gain set yields full-scale energy of 250 MeV. Low-gain set yields full-scale energy of 25 GeV. The-

Table 3.1 (Cont'd)

COMPARISON OF MARK-1 AND MARK-1A GENERAL FEATURES

	MARK-1	MARK-1A
	double preceding full-scale energy starting at 250 MeV full-scale to 32 GeV full-scale.	two sets yield total range of 61 KeV to 25 GeV, where range of 12 MeV to 250 MeV overlaps on two sets.
5. Temperature Sensors	Two temperature sensors measure the temperature inside the suitcase and the temperature inside the thickest lead shield.	No temperature sensors.
6. Data Analysis	Data analyses are obtained from data for one set of eight detectors (four unshielded with different crystal sizes and four with same crystal size but different lead shield thicknesses). Analyses include ratio plots, pulse height analysis and amplitude versus record (shot) number. Normalization of data is required because of possibility of data being taken at different gain settings.	Data analyses are obtained from data for two sets of five detectors. Each set consists of three unshielded detectors with different sized crystals and two shielded detectors with the same size crystal as the largest unshielded detector but with different thicknesses of lead shielding. For ratio analysis, the three unshielded detectors are included together. The ratio analysis for the shielded detectors uses the data from the largest unshielded detector

Table 3.1 (Cont'd)

COMPARISON OF MARK-1 AND MARK-1A GENERAL FEATURES

<u>MARK-1</u>	<u>MARK-1A</u>
	as a detector with zero shield thickness. The second set of five detectors is the same except for the full-scale energy. Analyses are the same as the MARK-1 (ratio plots, pulse height, amplitude versus shot number).

the preamplifier, (2) high voltage module (MARK-1) versus low voltage bias batteries (MARK-1A), and (3) gain control via high voltage (MARK-1) versus a variable gain broadband buffer amplifier (MARK-1A).

The physical configuration of the MARK detector assemblies are shown in simplified form in Figures 3.8, 3.9 and 3.10. In the MARK-1 design the lead shielding for the shielded detectors is around the complete scintillator/photomultiplier assembly shown in Figure 3.8. In Figure 3.10, the lead shielding for the MARK-1A design is just around the scintillator. This change greatly reduced amount of lead required in the MARK-1A detection unit and consequently reduced its weight. Figures 3.11 and 3.12 show the detector configuration within the MARK-1 and MARK-1A detection unit suitcases.

Detailed operation of the MARK-1 system can be found in "Volume 1: Technical Specifications Manual for the MARK-1 Pulsed Ionizing Radiation Detection System," (Reference 2). Detailed component description of the MARK-1A system is

Figure 3.6. MARK-1 analog circuit block diagram.

Figure 3.7. MARK-1A analog circuit block diagram.

Figure 3.8. BGO detector assembly for MARK-1 detection unit.

Figure 3.9. CsI unshielded detector assembly for MARK-1A detection unit.

Figure 3.10. CsI shielded detector assembly for MARK-1A detection unit.

Figure 3.11. Detector placement in MARK-1 detection unit.

Figure 3.12. Detector placement in MARK-1A detection unit.

included in Appendix A of this manual. Only the circuits which are different between the MARK-1 and MARK-1A are included in Appendix A of this manual. The remaining circuits are described in Reference 2.

4. PERFORMANCE TESTS DESCRIPTIONS

Over the years, there have been a series of performance tests which have characterized the MARK series and forerunner designs.

4.1 Proof-of-Principle Test

This test was performed using the proof-of-principle detection system at the Advanced Test Accelerator (ATA) at LLNL. The detection system in this case was composed of eight sodium iodide scintillation detectors. The supporting electronics were basically conventional nuclear electronics. The complete system was powered from a portable gasoline powered electric generator and was transported by a small van. The accelerator test consisted of operating the ATA with the electron beam traveling through the open air. The detection system was placed at various positions on the hills surrounding the ATA, and in one case it was placed approximately 2 miles (3 km) away at a location not in direct line of sight of the ATA. The results of these tests clearly demonstrated the utility of this technique to detect the operation of such a pulsed source even when the detector and source are not in direct line of sight and separated by distances of 3 km. The details of these tests are presented in reference 1.

4.2 1989 PHERMEX Test

A test was performed at the PHERMEX facility at LANL using the prototype detection system. Since it involved only the prototype detection system, the results will not be included in this report. However, experience with the prototype system led to the refinements which were incorporated in the MARK-1 design. The major refinement was

automatic gain adjustment via changing the high voltage bias to the photomultiplier tubes. This adjustment was needed to keep the detector responses within range of the analysis electronics. The transition time of the high voltage circuit in the prototype detection system was too long to record all data from source bursts occurring during the gain change process. In the MARK-1 design, a faster responding high voltage circuit was used.

4.3 EG&G Santa Barbara Test

This was an operations check of the newly completed MARK-1 detection system. This test was performed concurrently at the EG&G Linear Electron Accelerator Facility located near Santa Barbara, California with another test program. The main objective was to observe whether the new system performed as designed (i.e., fast gain change, etc). It was determined that the system performed as designated, but because the conditions were dictated by the other experiment, the conditions were not amenable for quantitative assessment of the MARK-1 performance, therefore no performance data from that test is presented in this report.

4.4 TITAN Test

The TITAN Test was performed using 3 - 13 MeV electron accelerator being developed by TITAN-SPECTRON Corp. for use in land mine detection. In this test series only the MARK-1 detection systems were used and the most interesting data from this series was the measure of the system response as a function of electron energy. These tests provided the first opportunity for the INEL program to observe the detector response under controlled

conditions where only the electron energy was varied. A marked change in the attenuation in the lead shielded detectors was observed, even though the detector was at approximately 90° with respect to the axis of the radiation cone and behind shielding.

4.5 HESCO Tests

This test series was performed at the High Energy Services Corp. (HESCO) test facility located near Palo Alto, CA. In these tests two detector units of the MARK-1 design were used. One of the objectives was to perform side-by-side comparisons of the performance of the two detector units. Like in the TITAN test, parts of the HESCO test series were performed using a 2 - 13 MeV energy electron accelerator purchased for the INEL Gamma-Neutron Threshold arms control and nonproliferation program. The HESCO test cell is an underground room in the side of a hill. It is surrounded by regular soil on all sides except one. The exposed side of the cell is a 60 cm thick wall of normal density concrete and faces a driveway apron. The access door to the cell is also on this side of the cell. The service building and control room are located on the grade above the test cell.

The detector location during the response versus electron energy measurement series was just outside the test cell next to the exposed wall on the driveway apron at approximately 90° with respect to the electron beam direction.

Another test series was performed with one of HESCO's 6-MeV electron accelerators situated outside the test cell on the driveway apron. The objective here was to measure the detector responses inside the radiation cone in direct line-of-sight of the source, outside the radiation cone in line-of-sight of the source, and outside radiation cone but not in line-of-sight of the source. The latter measurements were performed at locations on and over the

hill above the driveway apron where the accelerator is located. The major source of radiation at these locations should be photons from the accelerator source which are scattered off the atmosphere (i.e., skyshine).

4.6 1993 LANL Test

The most recent test series was performed in May 1993 at the M-4 Group test facilities at LANL. The tests involving the INEL detector units, were performed at the invitation of the M-4 group, because they are interested in using detector units of MARK-1 or MARK-1A design to monitor the radiation fields at their facilities. The two MARK-1 units and the MARK-1A unit were tested. An initial objective was to compare the performance of the new MARK-1A unit with that of the MARK-1. The three radiation sources used during these tests are listed in Table 4.1.

Table 4.1

LANL M-4 IRRADIATION TEST FACILITIES

<u>Facility</u>	<u>Electron Energy</u>	<u>Beam Current</u>	<u>Dose @ 1 meter</u>
PHERMEX	25-30 MeV	500 A	~ 100 R
New Gun	300 - 500 keV	900 A	< < 1 R
ITS	5.5 MeV	3 kA	~ 25 R

Three tests were performed at PHERMEX. They were: (1) side-by-side comparison of all three detection units at approximately 80° with respect to the electron beam at approximately 45 meters from the source, (2) response versus electron beam intensity at the former location, and (3) response versus distance from source along the radiation cone axis and in line-of-sight of the accelerator.

The New Gun facility was used to compare detector dose response versus TLD dose readings and to determine the radiation field that a worker was exposed to in a recent LANL test at that facility. The New Gun is a replacement electron injector for PHERMEX and is currently being tested as a stand alone system prior to installation on PHERMEX.

The Integrated Test Stand (ITS) is a new accelerator facility which will be used to test new accelerator concepts for flash radiography applications. During the time that the INEL detectors were being tested, the LANL group were testing the basic operation of the ITS with a graphite target. This produced more diffuse radiation field than that normally associated radiography tests at PHERMEX. In the first set of measurements, all MARK-1 and MARK-1A detection units were tested side by side at 45° with respect to the electron beam, in line-of-sight of and approximately 80 meters from the graphite convertor photon source. For the second set of measurements all three detectors were side by side approximately on axis of the accelerator and approximately 400 meters from the graphite convertor source. For the third set of measurements, detection units were set at locations corresponding to the approximate locations of TLD's from the last survey performed by the LANL Health and Safety Group. For the fourth set of measurements, the detectors were at different locations inside the ITS building in the service area adjacent to and on the outside of the shielding surrounding the ITS accelerator. Since there is no shielding over the top of the accelerator, the primary radiation is expected to be skyshine.

4.7 Other Tests

In addition to the tests described above there were also tests involving the prototype detection unit at the Oak Ridge Electron Accelerator (ORELA), MIT-Bates Accelerator, and at Nevada Test Site. Since all of these tests did not use the MARK-1 units, their results will not be presented in this report.

5. CALCULATIONS

Electron/photon transport Monte Carlo calculations were performed to aid in the evaluation of the performance of the MARK-1 detection system.

5.1 Calculational Model

These calculations were completed in three phases, to reduce the computer running time. First, calculations of the relative photon spectra were performed with a mini-scale geometry model. It is based on an energetic beam of electrons incident on a 0.1778 cm copper/0.127 cm tungsten convertor indicative of a commercial type, high-energy X-ray source, for example the HESCO source as explained in Section 4.5. In the calculation, the photon flux spectra were tallied in two regions with dimensions commensurate with the overall dimensions of a MARK-1 detection unit. The first region was located centered on the beam axis and 10 cm from the convertor. The second detector region was also located 10 cm from the convertor but normal to the electron beam axis. To simulate photon attenuation in air, a 1-cm thick region with an atomic composition of high density air (2.7 g/cm^3) was placed around the convertor such that all photons created in the convertor would have to pass through the air region to reach the detector regions. Photon spectra were calculated for 4, 6, 9, and 25-MeV electron energies.

The second phase of the calculations involved modeling the MARK-1 detection system precisely and calculating the detection system response for a monoenergetic and mono-directional photon beam incident on the detection system. Calculations were performed for different angles of incidence representing different orientations of the detection system relative to the incoming photon flux. The first detector orientation was with the plane (mid-

plane through handle) of the detection unit normal to the direction of the photon beam. This orientation represents the detection unit oriented such that the handle is upward with the suitcase lid facing the source. The second orientation was with the plane of the detection unit parallel to the photon beam with the top edge (handle edge) facing the source. This orientation represents the detection unit laying flat with its top edge facing the source. The third orientation was the same as the second except that the bottom edge faces the source. The fourth orientation is with the plane of the detection unit (mid-plane through handle) at 45° with respect to the photon beam and with the photon beam entering through the front face and top of the unit. This orientation represents a detection unit located at a non-line-of-sight position with the primary photon flux coming from skyshine rather than directly from the source. The monoenergetic photon energies selected were: 0.2, 0.3, 0.5, 1.0, 2.0, 4.0, 8.0, 12.0, 16.0, 20.0 MeV.

The third phase involved folding (integrating) the detector responses from the monoenergetic photon flux calculations (second phase) with the relative photon source spectra (first phase). The results contain the individual detector responses for the MARK-1 system for different electron energies, two detector positions and four detector orientations. The multiple detectors in the MARK-1 system are used for the purpose of obtaining energy information about the incoming photon spectrum. The photon spectrum can then be used to discern energy characteristics of the photon source. The effective photon energy can be obtained by determining (1) the effective attenuation coefficient through lead using the shielded detectors (#'s 5 - 8, in Figure 3.11 and #'s 4,5,9,10 in Figure 3.12) or (2) effective attenuation coefficient for BGO (MARK-1) or CsI (MARK-1A) unshielded detectors (#'s 1 - 4 in Figure 3.11 and #'s 1,2,3,6,7,8 in Figure 3.12). (For the theory behind this approach the reader is referred to reference 2.)

5.2 Calculated Detector Response versus Electron Energy

Figures 5.1 and 5.2 present the detector intensity responses for a photon source produced by an electron beam with an energy of 6 MeV. The detection unit is located directly in front of the source and centered on the beam axis. Figure 5.1 presents the response versus detector diameter for the unshielded detectors (#'s 1 - 4) for three detector orientations relative to the incident beam, while Figure 5.2 presents the detector response versus shield thickness for the shielded detectors (#'s 5 - 8). Similar behavior is observed for other electron energies and the off-axis (90°) detector position. It is apparent that the detector orientation relative to the source has a noticeable effect on the detector responses. For the unshielded detectors, the 90° detector orientation shows the shadowing effect from the shielded detectors located in the suitcase. If the self-shielding in detectors 1 - 4 was low, the response of the unshielded detectors would follow a d^2 dependence where d is the diameter of the detector. With significant self-shielding, the responses will be less than the d^2 dependence and evidence for that is shown in the response curve for the detector normal orientation. As seen in Figure 5.2 for the shielded detectors, detector orientation has a pronounced effect. In this case, the 45° orientation represents the maximum path length through the lead shield, and detector response decreases faster with shield thickness than for any other angular orientation.

A parameter that is determined from the unshielded detector responses is the "dose slope" which is defined as the slope of the dose response versus detector diameter. It is used to determine the effective attenuation coefficient in BGO for the incident flux spectrum. In Figure 5.3, this slope is plotted versus electron energy for four detector position/orientation configurations. The data in this figure show that the slope approaches zero as the energy increases.

---■--- Detector Normal ---+--- Det. 90 Degrees ---*--- Det. 45 Degrees

Figure 5.1. Detector response versus detector diameter for unshielded detectors.

Figure 5.2. Detector response versus detector shield thickness for shielded detectors.

---■--- On Axis/Nor ---+--- Off Axis/Nor ---*--- On Axis/45 ---□--- Off Axis/45

Figure 5.3. "Dose Slope" for unshielded detectors versus electron energy.

A second parameter, called "log slope" is the slope of the logarithm of the dose versus lead shield thickness. This parameter is used to determine the effective attenuation coefficient in lead for the incident photon spectrum. In Figures 5.4 and 5.5 the "log slope" versus electron energy is presented for on-axis and off-axis detector locations, respectively. In each figure curves for three detector orientations are presented. As is the case for the unshielded detectors in Figure 5.3, the "log slopes" in Figures 5.4 and 5.5 are more negative at lower electron energies and reach an asymptotic value somewhere near 25 MeV.

---■--- Normal to Detector ---+--- Top 90 degrees —*— Top 45 degrees

Figure 5.4. "Log Slope" for shielded detectors versus electron energy for detector on-axis.

---■--- Normal to Detector ---+--- Top 90 degrees ---*--- Top 45 degrees

Figure 5.5. "Log Slope" for shielded detectors versus electron energy for detector off-axis

6. EXPERIMENTAL RESULTS

Presented in this section are the data accumulated over the various experimental tests which have been performed with MARK series systems.

6.1 Detector-to-Detector Comparisons

Side-by-side comparisons were made at the 1993 LANL Test (Section 4.6) of the two MARK-1 units and the MARK-1A unit. The results of these tests are given in Table 6.1. From this table it is evident that the two MARK-1 units are reading the same and all the units (MARK-1 and MARK-1A) are in agreement to better than 20%. This is a reasonable agreement and is within expectations for the current calibration methods.

Table 6.1

DETECTOR RESPONSE COMPARISONS

(Detector responses are listed in $\mu\text{rad}/\text{accelerator pulse.}$)

<u>Accelerator</u>	<u>Detector Position^a</u>	<u>MARK-1 #1</u>	<u>MARK-1 #2</u>	<u>MARK-1A</u>
PERMEX	$r = 45\text{m}, \theta = 80^\circ$	17.5	17.0	20.5
ITS	$r = 64\text{m}, \theta = 45^\circ$	63	70	---
ITS	$r = 550\text{m}, \theta = 0^\circ$	8.9	8.7	9.6

^a Detector positions are given in polar coordinates, with the polar axis along the electron beam direction.

6.2 Detector Sensitivity

Detector Response vs. Source Intensity - At PHERMEX, a test of the MARK-1A detector response versus the intensity of the electron/photon source was performed. The source intensity was measured by a Compton diode directly behind the electron-to-photon convertor. These data are shown in Figure 6.1. A linear fit was made to the detector response versus source intensity. The correlation factor for that fit was 0.995. These data show that the response of the MARK-1A unit is linear with respect to the source intensity.

Detector Response vs. Distance From Source - Also at PHERMEX, a test of the MARK-1 response versus distance from the source was performed. In this test the two MARK-1 units were used and this test shows a response consistency in the units under different levels of dose intensity. For a point source, the dose should decrease as $1/r^2$ where r is the distance from the source to the detector. The data from these tests are given in Table 6.2 and shown in Figure 6.2. The consistency of the detector units with the $1/r^2$ dependence is better than 10%.

Detection Range - The detection range of either the MARK-1 or the MARK-1A units is from 3 nanorads to 90 microrads per source burst. The lower limit is the dose which can be measured above the "background noise" by the least sensitive detector in the unit. The upper limit is the highest dose which can be measured without saturating the most sensitive detector in the unit.

Figure 6.1. Detector response versus source intensity.

Figure 6.2. Detector response versus distance from source.

Table 6.2
RESPONSE VERSUS DISTANCE FROM SOURCE^a
(Detector responses are listed in $\mu\text{rad}/\text{accelerator pulse}$.)

<u>Detector Position^b</u>	<u>Unit #</u>	<u>Response</u>	<u>$1/r^2$ fit</u>
$r = 30\text{m}, \theta = 0^\circ$	M-1 #1	25	25
$r = 45\text{m}, \theta = 0^\circ$	M-1 #2	12	11
$r = 160\text{m}, \theta = 0^\circ$	M-1 #1	0.93	0.88
$r = 320\text{m}, \theta = 0^\circ$	M-1 #2	0.19	0.22

- ^a The measurements were performed at the PHERMEX facility at LANL. To reduce ground scatter effects the radiation cone was collimated to 3° full cone angle. To reduce the intensity a 15.2 cm lead shield was placed approximately 1 m down stream from the convertor target.
- ^b Detector position given in polar coordinates with the polar axis along the electron beam direction.

6.3 Detector Response versus Electron Energy

As indicated in Section 5, the multiple detector design of the MARK series detection systems is capable of providing information concerning the photon energy distribution coming from a source. The intent in this design was to identify the basic features of the source; e.g., for a radiation cone device, the energy of the electron beam.

Outside Radiation Cone and Not in Direct Line of Sight - In many applications the energy information may be lost because there is not a direct line of sight between the source and the detection system. In such a case the detector response would be due to a combination of

secondary photons scattered off the atmosphere and/or other structures in the area. To test how much energy information could be obtained when the source and the detector unit are not in direct line-of-sight, two tests were performed using accelerators with variable energy capability.

The first of these tests was performed at the TITAN facility. The experimental arrangement for this test is shown in Figure 6.3. The "log slope" versus electron energy is shown in Figure 6.4. In this test, radiation at the detector is primary photons attenuated through the 20 cm of concrete and 0.05 cm of lead placed between source and the detector. Secondary scattered photons from the surrounding walls will also contribute to the detection response. These effects will alter the photon spectrum coming from the source. Yet, if one compares the data in Figure 6.4 with the computed data for a direct line-of-sight situation as shown in Figure 5.5 ("normal to detector" curve), it is evident that energy sensitivity is preserved even when line of sight is not possible. Even the magnitudes of the calculated and experimental curves are reasonably consistent. The differences can be attributed to loss of low energy photons in the experimental case due to the concrete/lead placed between the detector and the source.

The second test of response versus electron energy was performed at the HESCO facility. The layout of this facility and the detector locations are shown in Figure 6.5. For the response versus electron energy test, the detection unit was placed outside the test cell at position 11. In this case there is 60 cm of concrete between the photon source and the detector. The "log slope" versus electron energy for this test is shown in Figure 6.6. As was the case with the TITAN test, the HESCO test showed similar energy sensitivity.

Figure 6.3. TITAN Experiment Configuration.

Figure 6.4. "Log Slope" versus Electron Energy for TITAN Test.

However, in the HESCO results the magnitudes of the log slopes are greater. The larger magnitudes indicate the presence of a larger component of low energy photons in the radiation field at the detector for the HESCO test than at the TITAN test. This lower energy spectrum is due to the 60 cm thick concrete shield at the HESCO test whereas in the TITAN test the shield thickness was only 20 cm. This large shield severely attenuates the primary photons and converts some of those photons to lower energy secondary photons.

Within Radiation Cone and in Direct Line of Sight - There were only two "line-of-sight" and "within the radiation cone" experiments which could be analyzed to experimentally determine the detector response versus energy for this condition. Both of which involved fixed-energy electron accelerators.

The first was at the HESCO facility where a 6-MeV accelerator was operated in the open air and a MARK-1 detection unit was located approximately on the accelerator axis and approximately 55 m from the source. The experiment layout for the open air operation is

Figure 6.5. HESCO site plan view and detector locations for accelerator inside cell and detection units outside.

Figure 6.6. "Log Slope" versus electron energy for HESCO test.

shown in Figure 6.7 and the detector location of interest is position 2. For this case the "log slope" is -0.65 cm^{-1} . This compares favorably to a calculated value of -0.53 cm^{-1} .

The second test involving "line-of-sight" and "within radiation cone" measurements was performed at the PHERMEX facility with an electron energy of 25 MeV. In this test the "log slope" was measured at four locations along the radiation cone axis ranging from 30 m to 320 m. The average slope for those four measurements was $-0.374 \pm 0.058 \text{ cm}^{-1}$. The computed slope for the same energy is -0.38 cm^{-1} .

6.4 Comparison of Detector Dose Response with TLD Dose Readings

The LANL M/4 Group rely on thermal luminescent dosimeters (TLD's) to monitor the radiation fields at or near the exclusion area boundaries around their pulsed X-ray sources. These surveys afforded the opportunity for INEL to compare the TLD results with the measured dose responses from the MARK-1 and MARK-1A detection units. Ideally this comparison should be performed where the MARK series detection units and the TLD's are exposed to the same gamma field for the same exposure time. However due to operational constraints, the detection units and the TLD's were not exposed to the same radiation field in a side by side comparison. The TLD measurements were performed earlier and represented averages over extended periods of operation where conditions were varied depending on the LANL tests performed. The detection units were exposed for a much shorter period of time and their results represent the specific conditions at that time.

The comparison of the detection systems responses with TLD data are given in Table 6.3. Given the less than ideal experimental conditions, these results do show that the MARK detection system results are consistent with TLD dose data.

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Figure 6.7. HESCO site plan view and detector locations for accelerator outside cell and detectors outside.

Table 6.3

COMPARISON OF MARK SERIES DATA WITH TLD DATA

(Detector responses and TLD data are given in $\mu\text{rad}/\text{accelerator pulse.}$)

<u>Accelerator</u>	<u>Detector</u>		<u>Response</u>	<u>TLD Response</u>
	<u>Detector Position</u>	<u>Unit #</u>		
New Gun	Hill next to tree	M-1 #1	16.9	6.5
New Gun	Hill next to pole	M-1 #2	21.7	19
ITS	West corner of perimeter fence	M-1 #2	27	40
ITS	East side of access gate	M-1A	85	40

REFERENCES

1. "Radiation Cone Signature Project Year End/Progress Report", Francis Y. Tsang, Robert S. Lawrence, Jerry M. Hoggan, DOE Informal Report AA-2727-1A, October 1991.
2. "Volume 1: Technical Specifications Manual for the MARK-1 Pulsed Ionizing Radiation Detection System", R. S. Lawrence, Y. D. Harker, J. L. Jones, J. M. Hoggan, DOE Report WINCO-1121, March 1993.
3. "Volume 2: Operations Manual for the MARK-1 Pulsed Ionizing Radiation Detection System", Y. D. Harker, R. S. Lawrence, J. L. Jones, J. M. Hoggan, DOE Report WINCO-1108, September 1992.

APPENDIX A

COMPONENT DESCRIPTION OF THE MARK-1A DETECTION SYSTEM

This section contains detailed descriptions of the MARK-1A circuits that are different from corresponding MARK-1 circuits, and the schematic diagrams for these circuits are included at the end of this appendix.

Details of the MARK-1 system circuits are given in Section 4 of Reference 2. Many of the descriptions from Reference 2 are directly applicable to the MARK-1A. Given below are section references from Reference 2 and their applicability to the MARK-1A.

Section 4.1.1 "Power Supply System"

Directly applicable to the MARK-1A, except the high voltage module (Section 4.1.1.3) is eliminated from the MARK-1A. A low voltage distribution and photodiode bias battery box is installed in the MARK-1A. The wiring diagram for this box is included in Figure A.1.

Section 4.1.2 "Photon Detectors"

Does not apply to the MARK-1A. Rewritten below under "Photodiode Detectors".

Section 4.1.3 "Analog Front-End Electronics"

Not directly applicable to the MARK-1A. Rewritten below under "Analog Electronics".

Section 4.1.4 "Logic Circuits"

Partially applicable to the MARK-1A (see below).

Figure A.1. MARK-1A power distribution box for low voltage supply and bias batteries.

4.1.4.3 "Function Decoder"

The SEL5 and SEL6 functions are dropped in the MARK-1A. These are automatic gain control signals in the MARK-1.

4.1.4.4 "Gain Control system"

Eliminated in the MARK-1A.

Section 4.1.5 "Operator Control"

Directly applicable to the MARK-1A except for the following:

4.1.5.1 (#2) Ten coincidence select switches instead of eight.

(#5) Analog signal monitors are not available on the control panel.

They are available on the amplifier boxes of the MARK-1A. Figure A.2 is a layout and wiring diagram for the MARK-1A monitor/control panel.

Photodiode Detectors - The MARK-1A photodiode detectors, built by eV PRODUCTS Corporation, use cesium iodide (CsI) scintillation crystals optically coupled to silicon photodiodes (PD). The photodiodes are then connected to low noise charge-sensitive preamplifiers. The MARK-1A system uses ten of these detector assemblies divided into two groups of five detectors. In a group of five detectors, two have lead shields surrounding the scintillator and three are unshielded. For the unshielded detectors, the CsI/PD assembly is combined with the preamplifier in a single package. For the shielded detectors, the CsI/PD assembly is in one package that plugs into a second package containing the preamplifier. This allows lead shielding to surround only the CsI/PD assembly. Simplified detector assembly drawings are shown in Figures 3.9 and 3.10. The gain of a CsI/PD/preamp assembly is fixed via the conversion gain of the preamplifier. The conversion gain is given as output voltage per unit charge and is proportional to the inverse of the preamplifier feedback capacitance.

MARK-1 AND MARK-1A: RADIATION DETECTION SYSTEMS EXPERIMENTAL APPLICATIONS

Appendix A

Figure A.2. MARK-1A monitor/control panel layout and wiring.

Appendix B gives an evaluation the performance of a CsI/PD/preamp assembly including the selection of the feedback capacitors used in the MARK-1A detector preamplifiers.

Analog Electronics - The analog electronics for the MARK-1A consist of functions involving analog signal processing. These functions are "Analog Front-Ends" (AFE), "Analog Multiplexers" (MUX), and "Analog-to-Digital Converter" (ADC). Simplified block diagrams for these functions are shown in Figures A.3 and A.4.

The block diagram for the AFE in Figure A.3 is for one detector. There are ten such circuits in the MARK-1A. The preamplifier feeds the high gain fast amplifier to generate trigger pulses for the coincidence select circuits, and feeds the variable gain buffer amplifier. The buffer amplifier is used for channel gain adjustment or calibration. The signal then passes to the shaping amplifier, peak detector, and multiplexer.

The components shown on the MUX and ADC block diagram, Figure A.4, are located on the logic board. The signals from eight of ten peak detectors are fed to MUX #1, and two to MUX #2. The two MUX modules are serially multiplexed, fed through a common buffer amplifier to the ADC, and then to the microcontroller.

As indicated at the beginning of this Appendix, many of the analog circuit functions are identical for both the MARK-1 and MARK-1A systems. Given below are section references from Reference 2, their applicability to the MARK-1A, and detailed descriptions of the MARK-1A that differ from the MARK-1.

Figure A.3. Block diagram for MARK-1A analog front end circuit.

Figure A.4. Block diagram for MARK-1A multiplexer and analog to digital converter circuits.

Section 4.1.3.1 "Preamplifier"

The MARK-1A preamplifier is described in the section of "Photodiode Detectors" in this manual.

Section 4.1.3.2 "Shaping Amplifier"

The description in Reference 2 is directly applicable to the MARK-1A shaping amplifier. The only difference between the two designs is the differentiating capacitor and pole-zero resistors. In the MARK-1, these components are located at the input to the shaping amplifier. In the MARK-1A, a variable-gain buffer amplifier has been added between these components and the shaping amplifier input. A schematic diagram of the MARK-1A analog circuits is shown in Figure A.5. The differentiating capacitor and pole-zero resistors are C6, R3, and R4. The buffer amplifier is a two-stage, non-inverting, wide-band amplifier with an adjustment for variable gain from 1.2 to 13.3. Adding the buffer amplifier does not change the design of the shaping amplifier. Therefore, the description of the MARK-1 shaping amplifier in Reference 2, Section 4.1.3.2 is directly applicable to the MARK-1A amplifiers.

Section 4.1.3.3 "Trigger Circuit"

This section is directly applicable to the MARK-1A.

Section 4.1.3.4 "Optional High Gain Amplifier"

This amplifier does not exist in the MARK-1A.

Section 4.1.3.5 "Peak Detector"

Directly applicable to the MARK-1A.

Section 4.1.3.6 "Multiplexer, Buffer Amplifier, Analog-to-Digital Converter directly applicable to the MARK-1A, except the temperature sensor inputs to the

MARK-1 AND MARK-1A: RADIATION DETECTION SYSTEMS EXPERIMENTAL APPLICATIONS

Appendix A

Figure A.5. Schematic drawing of the MARK-1A analog circuits.

multiplexer have been replaced by two peak detector inputs and the high voltage input has been eliminated. The schematic diagram, entitled "MARK-1A LOGIC BOARD" for the multiplexers is shown in Figure A.6.^a An additional circuit has been added to the MARK-1A analog circuits that was not a part of the MARK-1 system. This is a zener-controller voltage regulator used to stabilize the voltages applied to d.c. offset adjustments in the input buffer amplifier shaping amplifier and fast high-gain trigger amplifier. A 6.8 volt zener diode is used as the input signal to both inverting and non-inverting operational amplifiers; each with a gain of 1.5. The ± 10.2 Vdc stable outputs are used as reference voltages for the d.c. offset adjustment potentiometers. This circuit minimizes any d.c. drift problems in the amplifiers.

Schematic Diagrams - The MARK-1A is a modified version of the MARK-1 Radiation Detection System. The hardware differences between the MARK-1 and MARK-1A are documented in Section 2, of this manual. The schematic diagrams in this appendix show only those system modules that have been modified for the MARK-1A. The MARK-1 schematic diagrams for the same modules are included for comparison purposes. Modules not shown in this appendix are identical for both the MARK-1 and MARK-1A and the reader is referred to Reference 2, Appendix A for schematics of modules common to both MARK-1 and MARK-1A. The common modules are the low voltage power supply and portions of the logic board. Note that the high voltage module is eliminated from the MARK-1A.

a. The schematics for the MARK-1A LOGIC BOARD are divided into four pages. Pages 1 of 4 and 2 of 4 are included in this Appendix. The remaining two pages, 3 of 4 and 4 of 4, are the same as the MARK-1 and are included in Reference 2.

Figure A.6. Schematic drawing of the MARK-1A logic board.

MARK-1A LOGIC BOARD - PAGE 2 OF 4

Figure A.6. Schematic drawing of the MARK-1A logic board. (Continued)

APPENDIX B

EVALUATION OF THE PERFORMANCE OF CsI/PD/PREAMP ASSEMBLY

The intensity of the light produced by an inorganic scintillator is a function of the wavelength of the light. The peak value of the intensity versus wavelength occurs at a different wavelength for each scintillator compound. Relative scintillation efficiencies can be given with respect to the efficiency of thallium-activated sodium iodide (NaI(Tl)) at the peak response of an S-11 photocathode in a photomultiplier tube (PMT). The scintillators used in the MARK-1A system are thallium-activated cesium iodide (CsI(Tl)). The wavelengths at which the peak intensity values occur are approximately 415 nm for NaI(Tl) and 550 nm for CsI(Tl). The peak response is approximately 450 nanometers (nm) for the S-11 cathode. For a S-11 photocathode, the scintillation efficiency of CsI(Tl) is about 45% of the scintillation efficiency of NaI(Tl).

The CsI(Tl) scintillator is about 3 times more efficient at its peak wavelength of 550 nm than at the S-11 peak wavelength of 450 nm, or about $(45\%) \times 3 \approx 1.35$ times more efficient at 550 nm than NaI(Tl) at 450 nm.

The absolute scintillation efficiency of NaI(Tl) is approximately 13%. Then, the relative efficiency of CsI(Tl) at 550 nm will be about $(1.35 \times 13\%) \approx 17.5\%$. Therefore, for 1 MeV of energy deposited in CsI(Tl), there will be 175 KeV of light energy in the crystal. The energy of a photon can be given by:

$$E = (hc)/\lambda$$

where E = photon energy

h = Planck's constant (4.136×10^{-15} eV•sec)

c = speed of light (3×10^8 m/sec)

λ = wavelength of photon

(for this case, $\lambda = 550$ nm = 550×10^{-9} m)

then: $E = (4.136 \times 10^{-15}) \times (3 \times 10^8) / 550 \times 10^{-9}$ eV

$E = 2.256$ eV/photon

The number of photons in 175 KeV of light energy = $(E_{\text{TOTAL}}/E_{\text{PHOTON}})$

= $(175 \text{ KeV} \div 2.256 \text{ eV/photon}) \approx 77 \times 10^3$ photons

The quantum efficiency (QE) of a silicon photodiode at 550 nm is about 70%, and is defined as:

$$QE = \frac{\text{number of emitted photoelectrons}}{\text{number of incident photons}}$$

Then for 77×10^3 photons: $(70\% \times 77 \times 10^3 \text{ photons}) \approx 54 \times 10^3$ electrons emitted from the silicon photodiode. Given, that there are 1.60209×10^{-19} coulombs/electron:

$$(54 \times 10^3) \times (1.60209 \times 10^{-19}) \approx 0.0086 \times 10^{-12} \text{ coulombs.}$$

Therefore, there are 0.0086 picocoulombs (pC) of charge output from the photodiode for 1 MeV of energy deposited in the CsI(Tl) crystal.

The detector assemblies from eV PRODUCTS used in the MARK-1A system have fixed gains to measure either 250 MeV full-scale energy or 25 GeV full-scale (see Section 3, "General System Description"). The conversion of 0.0086 pC/MeV to output voltages

proportional to either 250 MeV or 25 GeV full-scale is a function of the conversion gain of the preamplifier. It has been determined that the maximum output voltage from a standard eV PRODUCTS preamplifier is at least 6.5 volts. The standard eV PRODUCTS preamplifier has a conversion gain of 1.9 volts/picocoulomb. The feedback capacitor is ≈ 0.5 picofarads (the inverse of the gain). For a full-scale energy of 250 MeV, the output voltage of a standard preamplifier is:

$$(0.0086 \text{ pC/MeV}) \times (250 \text{ MeV}) \times (1.9 \text{ V/pC}) \cong 4.08 \text{ volts.}$$

Because this is within the maximum output voltage, the standard eV PRODUCTS preamplifier is used for the 250 MeV full-scale energy detectors. For the 25-GeV detectors, the full-scale output voltage must be less than +6.5 Vdc.

$$6.5 \text{ V} > (0.0086 \text{ pC/MeV}) \times (25 \times 10^3 \text{ MeV}) \times \text{gain}$$

$$6.5/215 > \text{gain}$$

The gain must be less than 0.0302 V/pC. Because the gain is inversely proportional to the feedback capacitor, the capacitor must be greater than $1/0.0302 = 33$ pf. A feedback capacitor of 35 pf was selected. The output voltage for a full-scale energy of 25 GeV is:

$$V_{\text{out}} = (0.0086 \text{ pC/MeV}) \times (25 \times 10^3 \text{ MeV}) \times (1/35 \text{ V/pC})$$

$$V_{\text{out}} = 6.14 \text{ volts}$$

This is within the maximum possible output voltage of +6.5 volts.

A check to verify the calculations above for a 250 MeV full-scale detector was made by measuring the preamplifier output voltage pulse from a cesium source (Cs-137). The energy peak from Cs-137 is 661.7 keV. The measured output on an oscilloscope was 10 - 11 millivolts. Calculations indicate an expected output of:

$$V_{\text{out}} = (0.0086 \text{ pC/MeV}) \times (0.6617 \text{ MeV}) \times (1.9 \text{ V/pC})$$

$$V_{\text{out}} = 10.8 \text{ millivolts}$$

The measured output verified the calculations.

APPENDIX C

MARK-1A ACQUISITION AND ANALYSIS SOFTWARE

This appendix contains software documentation for the MARK-1A system and is a modified version of the MARK-1 software. Both software systems perform two basic functions; i.e., data acquisition and data analysis. Because the MARK-1A system operates with fixed gain detectors, its software does not require functions related to automatic gain change or reporting gain status. The MARK-1A system uses ten detectors; i.e., five with high gain signal amplification (i.e., low dose range) and five with low gain signal amplification (i.e., high dose range). Therefore, the MARK-1A data results contain two parallel sets of data reports, one for the high gain (low dose range) detectors and one for the low gain (high dose range) detectors; whereas, the MARK-1 data provides only one set with the gain status indicated. In addition, the MARK-1A system does not contain temperature sensors; therefore, the acquisition and analysis software does not contain any functions related to acquiring and reporting that data. Instead, those data channels were used to support the acquisition of data from the two extra detectors in the MARK-1A system which are not in the MARK-1 system.

Given in Figures C.1 - C.4 are the flow charts for the acquisition programs MAIN and EVENT1 for the MARK-1A and MARK-1 systems. (The MARK-1 flow charts are given for comparison purposes only.) Figures C.1 and C.2 show the MAIN program flow charts for the MARK-1A and MARK-1 systems, respectively. Figures C.3 and C.4 show the same comparison for the EVENT1 program. From these comparisons, one can see that the subroutines dealing with gain change or status have been dropped from the MARK-1A

Figure C.1. Flowchart for MARK-1 data acquisition routine "MAIN".

Figure C.2. Flowchart for MARK-1A data acquisition routine "MAIN".

Figure C.3. Flowchart for MARK-1A data acquisition routine "EVENT1".

Figure C.4. Flowchart for MARK-1A data acquisition routine "EVENT1".

programs. Those subroutines are: CHGHV, SELGN, RDTEMP, STGN, and SETGAIN. In addition, the RDET subroutine was changed in the MARK-1A software to read 10 detectors versus 8 detectors in the MARK-1 software.

The program listings for the MARK-1A analysis software are given below. The flowcharts for the MARK-1 analysis software, as contained in Reference 2, are applicable to the MARK-1A software except specific instructions related to gain or temperature are deleted.

Data Analysis Program Listing
for
MARK-1A Detection System

```

10      '
20      '   Program to read data from disk and plot PHA/RATIOS USING
SA-10 DATA FORMAT.
30      '
35      '   Program Name:  PRGMK1A.BAS
40      '   MODIFIED FROM PROGSAM.BAS - DELETE AUTO GAIN - ADD 2
DETECTORS
41      '
70      '           REVISION 12/06/90 BY R. LAWRENCE
71      '
72      '           CHECKED 04/24/91 BY R.S.L.
73      '
74      '           REVISION 06/20/91 BY R. LAWRENCE
75      '           MODIFIED FOR SA-10 CARD READER, INCLUDING NEW
DATA FORMAT USING PB-10 PROGRAMMER
76      '
77      '           REVISION 07/09/91 BY R. LAWRENCE
78      '           MODIFIED TO INCLUDE DOSE EQUIVALENT VALUES IN
REM
79      '
80      '           REVISION 07/24/91 BY R. LAWRENCE
81      '           MODIFIED TO CORRECT GRAPHS FOR AMPLITUDE VS
BLOCK NUMBER
82      '
83      '           REVISION 07/09/92 BY R. LAWRENCE
84      '           MODIFIED ENERGY CALCULATIONS AND DOSE
85      '           USE GNSTEP FOR FULL-SCALE ENERGY CALCULATIONS
86      '
87      '           REVISION 04/01/93 BY R. LAWRENCE
88      '           MODIFIED PROGSAM.BAS(MARK-1) FOR USE WITH
MARK-1A
94      '
95      '!!!!!! VALID ONLY FOR MARK-1A SYSTEM AND SA-10 OR PB-10 CARD
READERS !!!!!
96      '
97      '
98      '
99      '   set up dimensions and turn default key trapping off
100     '
110     OPTION BASE 1
120     DIM MX(10), MXCH(10)
142     DIM UNSH%(5, 4100), SHLD%(5, 4100)
160     DIM IR#(10), DAT1#(5, 1001), DAT2#(5, 1001), TOT#(10),
MAS#(10), DTNRG#(10)
170     KEY OFF
171     KEES = 0
172     SCREEN 2
173     CLS
1       7           6           D           A           T           A
4.51,9.02,29.2248,29.2248,29.2248,4.51,9.02,29.2248,29.2248,29.2248
177     FOR I = 1 TO 10: READ MAS#(I): NEXT I
180     KEES = 0
182     GOTO 610
183     '

```

```

184          '***** SELECT      SYSTEM      AND
FILENAME.*****
185      '
192      CLS
194      CLOSE
210      KEES = 1
300      IDUN% = 0
305      PHA = 0
310      PLAC% = 4
500      LOCATE 10, 10: BEEP: INPUT "Enter the name of the data file
: ", FILE$
510      PLAC% = PLAC% + 1
520      OPEN FILE$ FOR RANDOM AS #1 LEN = 64
530      FIELD #1, 2 AS DELIM1$, 4 AS DAT$, 10 AS TIM$, 20 AS IR1$,
20 AS IR2$, 8 AS DELIM2$
535      RETURN
580      '
590      ' DEFINE FUNCTION KEYS AND DISPLAY KEY OPTIONS.
600      '
610      GOSUB 192: CLS
620      IDUN% = 1
640      LOCATE 24, 1: PRINT SPACES$(79);
650      LOCATE 25, 1: PRINT SPACES$(79);
660      ON KEY(1) GOSUB 850
670      ON KEY(2) GOSUB 3450
680      ON KEY(10) GOSUB 800
690      KEY(1) ON
700      KEY(2) ON
705      KEY(6) ON
710      KEY(10) ON
720      LOCATE 25, 1: PRINT "F1-DISP RATIO GRAPH";
730      LOCATE 25, 22: PRINT "F2-PRINT DATA";
740      LOCATE 25, 73: PRINT "F10-EXIT";
745      IF (PHA = 0) AND (KEES = 0) THEN ON KEY(3) GOSUB 7300: ON
KEY(6) GOSUB 192: KEY(3) ON: KEY(6) ON: LOCATE 25, 37: PRINT
"F3-COMPUTE PHA F6-SELECT SYS/FILE";
746      IF (PHA = 0) AND (KEES = 1) THEN ON KEY(3) GOSUB 7300:
KEY(3) ON: KEY(6) OFF: LOCATE 25, 37: PRINT "F3-COMPUTE PHA";
748      IF (PHA = 1) AND (KEES = 0) THEN ON KEY(4) GOSUB 7540: ON
KEY(6) GOSUB 192: KEY(3) OFF: KEY(4) ON: KEY(6) ON: LOCATE 25, 37:
PRINT "F4-SEL PHA CH. F6-SELECT FILENAME";
750      '
760      ' wait for the user to decide what he wants to do (i.e. type
a function key).
780      '
790      IF IDUN% = 1 THEN GOTO 660 ELSE GOTO 610
800      END
8      1      0      '
-----
820      ' ----- subroutines
-----
8      3      0      '
-----
840      '

```

```

8          5          0
*****RATIO*****
860      '
870      ' SUBROUTINE TO GET INFORMATION FOR THE RATIO SUBROUTINE
880      '
890      CLS
910      PLAC% = 4
920      COMBIN% = 0
930      KIND% = 1
940      GOSUB 3690      ' see if we want combined data or not !
950      IF COMBIN% = 1 THEN GOTO 1270
960      '
9          7          0
*****REC*****
980      '
990      ' get record numbers to look at
1000     '
1010     LOCATE PLAC%, 1: PRINT "ENTER BLOCK NUMBER : ";
1020     INPUT "", REC
1030     IF (REC < 0) OR (REC > 16383) THEN GOTO 970
1040     PLAC% = PLAC% + 1
1210     '
1220     ' go get the requested data
1230     '
1240     GOSUB 4420
1242     FOR I = 1 TO 10
1243     AVE#(I) = IR#(I)
1244     IF I < 6 THEN FSNRG# = 250: PWR# = 1000 ELSE FSNRG# = 25:
PWR# = 1
1245     DTNRG#(I) = (IR#(I) / 4095#) * FSNRG#
1246     DOSEQ#(I) = (1.60209# * (10 ^ (-5)) * DTNRG#(I)) / (PWR# *
MAS#(I))
1247     NEXT I
1250     CLS
1270     PLAC% = 2
1280     '
1290     ' print the ratio data and then plot it to the screen
1300     '
1307     CLS
1308     CLS : GNFLG% = 1: PLAC% = 2
1310     GOSUB 1350
1312     GOSUB 1940
1313     IF ((p$ = "C") OR (p$ = "c")) THEN GOTO 1325
1314     CLS : GNFLG% = 2: PLAC% = 2
1316     GOSUB 1350
1318     GOSUB 1940
1325     KEES = 0
1330     RETURN
1340     '
1350     ' *****PRINT      RATIO
DATA*****
1360     '
1370     ' SUBROUTINE TO PRINT THE RATIO DATA.
1380     '

```



```

1381 IF GNFLG% = 1 THEN FSNRG# = 250: MNNRG# = 250: GEV$ = "MeV":  
EGEV$ = "E-MeV": I1 = 1: I2 = 5: D1$ = "D1": D2$ = "D2": D3$ =  
"D3": D4$ = "D4": D5$ = "D5"  
1382 IF GNFLG% = 2 THEN FSNRG# = 25: MNNRG# = 25: GEV$ = "GeV":  
EGEV$ = "E-GeV": I1 = 6: I2 = 10: D1$ = "D6": D2$ = "D7": D3$ =  
"D8": D4$ = "D9": D5$ = "D10"  
1385 IF KIND% = 2 THEN GOTO 1472  
1390 IF (COMBIN% = 0) THEN LOCATE PLAC%, 1: PRINT "BLOCK NO. ";  
REC; "WAS FIRED AT "; D$; " "; C$; ". "  
1400 IF (COMBIN% = 1) THEN LOCATE PLAC%, 1: PRINT USING "START  
TIME = \ \ \ . STOP TIME = \ \ \ ." ; STD$;  
STC$; D$; C$  
1405 IF (COMBIN% = 0) THEN LOCATE PLAC% - 1, 1: PRINT USING  
"FILENAME IS \ \ FULL SCALE ENERGY IS ###.#### \ \."  
FILE$; FSNRG#; GEV$  
1406 IF (COMBIN% = 1) THEN LOCATE PLAC% - 1, 1: PRINT USING "FILE  
\ \ ; #### RECORDS:##### TO #####; ENERGY(FULL SCALE) = ## \  
\ \." ; FILE$; S; R; REC; MNNRG#; GEV$  
1430 LOCATE PLAC% + 1, 1: PRINT USING "DETNO: \\  
\ \ \ \" ; D1$; D2$; D3$;  
D4$; D5$  
1450 LOCATE PLAC% + 2, 1: PRINT "AVSIG:";  
1460 FOR I = I1 TO I2: PRINT USING " #####.###"; AVE$(I); :  
NEXT I: PRINT  
1470 IF KIND% <> 2 THEN GOTO 1600  
1472 IF GNFLG% = 1 THEN GEV$ = "MeV": EGEV$ = "E-MeV": FSNRG# =  
250: PWR# = 1000 ELSE GEV$ = "GeV": EGEV$ = "E-GeV": FSNRG# = 25:  
PWR# = 1  
1474 LPRINT USING "FILENAME IS \ \ FULL SCALE ENERGY IS  
## \ \." ; FILE$; FSNRG#; GEV$  
1475 LPRINT USING "BLOCK NO. ##### WAS FIRED AT \ \  
\\" ; REC; D$; C$  
1480 LPRINT USING "DETNO: \\\ \\ \\ \" ; D1$; D2$; D3$; D4$; D5$  
  
1490 LPRINT " _____"  
_____  
1500 LPRINT "SIGNL:";  
1510 FOR I = I1 TO I2: LPRINT USING " #####.###"; AVE$(I); :  
NEXT I: LPRINT  
1600 IF (AVE$(3) = 0) THEN DT$(1) = 1 ELSE DT$(1) = AVE$(3)  
1605 IF (AVE$(8) = 0) THEN DT$(2) = 1 ELSE DT$(2) = AVE$(8)  
1660 '  
1670 ' CALCULATE THE RATIO'S.  
1680 '  
1690 FOR I = 1 TO 5  
1700 RAT$(I) = (AVE$(I) / DT$(1))  
1710 RAT$(I + 5) = AVE$(I + 5) / DT$(2)  
1720 NEXT I  
1725 IF KIND% = 2 THEN GOTO 1840  
1728 IF COMBIN% = 1 THEN PLAC% = 3 ELSE PLAC% = 2  
1750 LOCATE PLAC% + 5, 1: PRINT "RATIO:";  
1760 FOR I = I1 TO I2: PRINT USING " #####.###"; RAT$(I); :  
NEXT I: PRINT  
1770 LOCATE PLAC% + 6, 1: PRINT "XVAL :";
```

```

1780 PRINT USING "      #####.###"; .5; 1!; 1.8; .762; 1.524
1781 LOCATE PLAC% + 3, 1: PRINT USING "\      \:"; EGEV$;
1782 FOR I = I1 TO I2: PRINT USING "      #####.###"; DTNRG#(I);
: NEXT I
1783 LOCATE PLAC% + 4, 1: PRINT "DOSEQ:";
1784 FOR I = I1 TO I2: PRINT USING "      ##.###^ ^ ^ ^"; DOSEQ#(I);
: NEXT I
1785 IF COMBIN% <> 1 THEN GOTO 1790
1787 LOCATE PLAC% + 2, 1: PRINT "STDEV:";
1788 FOR I = I1 TO I2: PRINT USING "      #####.###"; STDEV#(I);
: NEXT I
1790 PLAC% = 10
1800 IF KIND% <> 2 THEN RETURN
1840 LPRINT "RATIO:";
1850 FOR I = I1 TO I2: LPRINT USING "      #####.###"; RAT#(I); :
NEXT I: LPRINT
1860 LPRINT "XVAL :";
1870 LPRINT USING "      #####.###"; .5; 1!; 1.8; .762; 1.524
1872 FOR I = I1 TO I2: DTNRG#(I) = (AVE#(I) / 4095#) * FSNRG#;
NEXT I
1873 FOR I = I1 TO I2: DOSEQ#(I) = (1.60209# * (10 ^ (-5)) *
DTNRG#(I)) / (PWR# * MAS#(I)): NEXT I
1874 LPRINT USING "\      \:"; EGEV$;
1876 FOR I = I1 TO I2: LPRINT USING "      #####.###"; DTNRG#(I);
: NEXT I
1877 LPRINT "DOSEQ:";
1878 FOR I = I1 TO I2: LPRINT USING "      ##.###^ ^ ^ ^"; DOSEQ#(I);
: NEXT I: LPRINT
1880 RETURN
1890 '
1900 ' *****CALL      RATIO
PLOTS*****
1910 '
1920 ' SUBROUTINE TO CALL PLOTS OF RATIO DATA
1930 '
1940 TOP% = PLAC% + 1
1950 TOPPIX% = (200 - ((25 - TOP%) * 8)) + 4
1960 GOSUB 2050
1970 GOSUB 2790
1980 IDUN% = 1
1990 LOCATE 25, 1: PRINT "(1)SHIFT/PRT SC FOR HARDCOPY; (2)'A'
FOR ALTERNATE PLOT; (3)'C' TO CONTINUE";
2000 INPUT "", p$
2020 IF ((p$ = "C") OR (p$ = "c")) THEN GOTO 2022
2021 IF GNFLG% = 1 THEN GOTO 1314 ELSE IF GNFLG% = 2 THEN GOTO
1308
2022 CLS
2025 LOCATE 25, 1: PRINT SPACE$(79);
2030 RETURN
2040 '
2050 ' *****PROCESS GRAPH OF UNSHIELDED
DETECTORS*****
2060 '
2080 '

```

```

090 ' find max and min ratio value that we will be plotting
100 '
105 IF GNFLG% = 1 THEN GAIN = 0 ELSE IF GNFLG% = 2 THEN GAIN = .

110 MX = RAT#(1 + GAIN)
120 IF RAT#(2 + GAIN) > MX THEN MX = RAT#(2 + GAIN)
125 IF RAT#(3 + GAIN) > MX THEN MX = RAT#(3 + GAIN)
135 K = 1
140 IF MX > 1 THEN K = 2
145 IF MX > 2 THEN K = 5
150 IF MX > 5 THEN K = 10
160 IF MX > 10 THEN K = 20
170 IF MX > 20 THEN K = 50
180 IF MX > 50 THEN K = 100
190 IF MX > 100 THEN K = 200
200 IF MX > 200 THEN K = 500
210 IF MX > 500 THEN K = 1000
220 '
230 ' set up some parameters for plotting and gosub to draw the
240 ' basic graph.
250 '
260 RIGHTPIX% = 300
270 CHARS = (LEN(STR$(K)) + 2)
305 LEFTPIX% = 37
320 TYP$ = "A"
330 PLAC% = PLAC% + 2
340 GOSUB 5170
350 PLAC% = PLAC% - 2
360 APOS#(1) = .5
370 APOS#(2) = 1!
380 APOS#(3) = 1.8
400 IF GNFLG% = 1 THEN OFFSET = 0 ELSE OFFSET = 5
420 SLOPE# = 0!
430 INTERCEPT# = 0!
440 '
450 ' plot the actual data now
460 '
470 FOR I = 1 TO 3
480     X = LEFTPIX% + ((APOS#(I) / 2) * (RIGHTPIX% -
LEFTPIX%))
490     Y = 171 - (((RAT#(I + OFFSET)) / K) * (171 - TOPPIX%))
500     LINE (X - 5, Y - 3)-(X + 5, Y + 3)
510     LINE (X - 5, Y + 3)-(X + 5, Y - 3)
520 NEXT I
530 GOSUB 5920
540 '
550 ' plot the fit and write the slope and intercept
560 ' to the screen
570 '
580     LOCATE PLAC% + 1, 6: PRINT USING "SLOPE=##.####^ ^ ^
INT=##.####^ ^ ^"; SLOPE#; INTERCEPT#;
584     GOSUB 2590
585     RETURN
586 '

```

```

2893 IF RAT#(5 + GAIN) < MN# THEN MN# = RAT#(5 + GAIN)
2895 K = 1: MXLOG% = 0
2900 IF MX# > 1 THEN K = 2: MXLOG% = 1
2903 IF MX# > 2 THEN K = 5
2905 IF MX# > 2.71828 THEN MXLOG% = 2
2910 IF MX# > 5 THEN K = 10
2915 IF MX# > 7.389056 THEN MXLOG% = 3
2920 IF MX# > 10 THEN K = 20
2930 IF MX# > 20 THEN K = 50
2935 IF MX# > 20.085536# THEN MXLOG% = 4
2940 IF MX# > 50 THEN K = 100
2945 IF MX# > 54.59815 THEN MXLOG% = 5
2950 IF MX# > 100 THEN K = 200
2955 IF MX# > 148.41359# THEN MXLOG% = 6
2960 IF MX# > 200 THEN K = 500
2965 IF MX# > 403.42879# THEN MXLOG% = 7
2970 IF MX# > 500 THEN K = 1000
2971 IF MN# = 1 THEN MNLOG% = 0
2972 IF (MN# < 1) AND (MN# >= .367879) THEN MNLOG% = -1
2973 IF (MN# < .367879) AND (MN# >= .13533528#) THEN MNLOG% = -2
2974 IF (MN# < .13533528#) AND (MN# >= .049787) THEN MNLOG% = -3
2975 IF (MN# < .049787) AND (MN# >= .018315639#) THEN MNLOG% =
-4
2976 IF (MN# < .018315639#) AND (MN# >= .006737947#) THEN MNLOG%
= -5
2977 LGDEC = MXLOG% - MNLOG%
2980 RIGHTPIX% = 622
2990 IF ((DSP$ = "LN") OR (DSP$ = "ln")) THEN CHARS =
(LEN(STR$(K)) + 2) ELSE CHARS = 4
3025 LEFTPIX% = 359
3040 TYP$ = "B"
3050 PLAC% = PLAC% + 2
3060 GOSUB 5170
3070 PLAC% = PLAC% - 2
3080 APOS#(1) = 0
3090 APOS#(2) = .762
3100 APOS#(3) = 1.524
3120 IF GNFLG% = 1 THEN OFFSET = 2 ELSE OFFSET = 7
3140 SLOPE# = 0!
3150 INTERCEPT# = 0!
3160 FOR I = 1 TO 3
3170 X = LEFTPIX% + ((APOS#(I) / 2!) * (RIGHTPIX% -
LEFTPIX%))
3172 IF ((DSP$ = "LG") OR (DSP$ = "lg")) GOTO 3182
3180 Y = 171 - (((RAT#(I + OFFSET)) / K) * (171 - TOPPIX%))
3181 GOTO 3190
3182 LGEE# = LOG(RAT#(I + OFFSET))
3188 Y = LN2 - (LGEE# * 1 / LGDEC) * YPIX
3190 LINE (X - 5, Y)-(X + 5, Y): LINE (X, Y + 3)-(X, Y - 3)
3200 LINE (X + 5, Y + 3)-(X + 5, Y - 3): LINE (X + 5, Y +
3)-(X - 5, Y + 3): LINE (X - 5, Y - 3)-(X - 5, Y + 3): LINE (X - 5,
Y - 3)-(X + 5, Y - 3)
3210 NEXT I
3220 GOSUB 5920

```

```

3225   GOSUB 2590
3230   LOCATE PLAC% + 1, 46: PRINT USING "SLOPE=##.###^"
INT=##.###^"; SLOPE#; INTERCEPT#;
3236   RETURN
3440   '
3450   ' *****PRINT RATIO DATA WITH NO GRAPH
*****
3460   '
3480   CLS
3501   LOCATE PLAC%, 1: PRINT "VERIFY PRINTER IS AT TOP OF PAPER
FORM.";
3502   LOCATE PLAC% + 1, 1: PRINT "PRESS ENTER KEY WHEN READY.";
3504   INPUT FORM$
3506   CLS
3490   COMBIN% = 0
3500   KIND% = 2
3510   LOCATE PLAC%, 1: PRINT "ENTER STARTING RECORD NUMBER: ";
3520   INPUT "", REC1
3522   CLS
3524   LOCATE PLAC%, 1: PRINT "ENTER NUMBER OF RECORDS: ";
3526   INPUT "", REC2
3528   CLS
3530   PLAC% = PLAC% + 1
3540   FOR REC = (REC1) TO (REC1 - 1 + REC2)
3570       CLS
3590       PLAC% = 4
3610       GOSUB 4420
3614       FOR I = 1 TO 10: AVE#(I) = IR#(I): NEXT I
3616       GNFLG% = 1
3620       GOSUB 1350
3625       GOSUB 7000
3628       GNFLG% = 2
3630       GOSUB 1350
3632       GOSUB 7000
3640   NEXT REC
3641   CLS
3650   IDUN% = 0
3655   KEES = 0
3660   RETURN
3680   '
3690   ' *****COMPUTE COMBINED
DATA*****
3692   '
3700   CLS
3720   PLAC% = 4
3721   LOCATE PLAC%, 1: PRINT "SELECT LINEAR (LN) OR LOG (LG)
DISPLAY FOR SHIELDED DETECTORS."
3722   INPUT "", DSP$
3723   CLS
3730   LOCATE PLAC%, 1: PRINT "COMBINED DATA? [Y/N] : ";
3740   PLAC% = PLAC% + 1
3750   INPUT "", Z$
3760   IF Z$ = "N" OR Z$ = "n" THEN RETURN
3880   COMBIN% = 1

```

```

3890 .CLS
3895 AVE# = 0
3900 FOR I = 1 TO 10: TOT#(I) = 0: T#(I) = 0: T2#(I) = 0: TX2#(I)
= 0: NEXT I
3910 PLAC% = 4
3920 LOCATE PLAC%, 1: PRINT "ENTER STARTING BLOCK NUMBER : ";
3930 INPUT "", R
3940 LOCATE PLAC% + 1, 1: PRINT "ENTER NUMBER OF BLOCKS: ";
3950 INPUT "", S
4070 Q = 1
4080 REC = R - 1
4090 CLS
4110 REC = REC + 1
4112 PRINT Q
4115 GOSUB 4420
4117 IF REC = R THEN STD$ = D$: STC$ = C$
4121 FOR I = 6 TO 10
4122 IF IR#(I) >= 4094 THEN GOTO 4110
4123 NEXT I
4124 FOR I = 1 TO 10
4128 TOT#(I) = TOT#(I) + IR#(I)
4129 T2#(I) = T2#(I) + ((IR#(I)) ^ 2)
4131 NEXT I
4132 IF Q < S THEN Q = Q + 1: GOTO 4110
4133 CLS
4161 FOR I = 1 TO 10
4162 TX2#(I) = ((TOT#(I)) ^ 2)
4180 AVE#(I) = TOT#(I) / Q
4190 STDEV#(I) = SQR((T2#(I) - (TX2#(I) / Q)) / (Q - 1))
4195 IF I < 6 THEN MNNRG# = 250: PWR# = 1000 ELSE MNNRG# = 25:
PWR# = 1
4196 DTNRG#(I) = (AVE#(I) / 4095#) * MNNRG#
4197 DOSEQ#(I) = (1.60209# * (10 ^ (-5)) * DTNRG#(I)) / (PWR# *
MAS#(I))
4200 NEXT I
4210 RETURN
4340 '
4 3 5 0 ' * * * * * READ
*****
4360 '
4370 ' subroutine to read in the proper record and convert the
4380 ' data to numeric format.
4390 '
4400 ' read a record from the data file
4410 '
4420 GET #1, REC
4430 '
4440 ' do the date string
4450 '
4460 D$ = MID$(DAT$, 1, 2) + "-" + MID$(DAT$, 3, 2)
4470 '
4480 ' do the time string, taking care of the milliseconds field
4490 '
4500 C$ = MID$(TIM$, 1, 2) + ":" + MID$(TIM$, 3, 2) + ":" +

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```

MID$(TIM$, 5, 2)
4510 MSEC = VAL(MID$(TIM$, 7, 2)) * 10 + VAL(MID$(TIM$, 9, 1))
4520 MSEC$ = STR$(MSEC)
4530 MSEC$ = RIGHT$(MSEC$, LEN(MSEC$) - 1)
4540 C$ = C$ + "." + MSEC$
4550 '
4560 ' convert amplitude readings 4 at a time
4570 '
4580 ISTRT% = 1
4590 IEND% = 5
4600 TMP$ = IR1$
4610 JJ = 0
4620 FOR I = ISTRT% TO IEND%
4630 JJ = JJ + 1
4640 J = (JJ - 1) * 4 + 1
4650 A$ = MID$(TMP$, J, 2)
4660 GOSUB 4900
4670 IR#(I) = ANUM
4680 A$ = MID$(TMP$, J + 2, 2)
4690 GOSUB 4900
4700 IR#(I) = IR#(I) * 16 + ANUM / 16
4710 NEXT I
4720 IF ISTRT% <> 1 THEN GOTO 4869
4730 ISTRT% = 6
4740 IEND% = 10
4750 TMP$ = IR2$
4760 GOTO 4610
4869 RETURN
4870 '
4880 '***** CONVERT ASCII TO DECIMAL *****
4890 '
4900 B$ = LEFT$(A$, 1)
4910 IF B$ > "/" AND B$ < ":" THEN ANUM = ASC(B$) - 48 ELSE ANUM
= ASC(B$) - 55
4920 B$ = RIGHT$(A$, 1)
4930 T = ANUM
4940 IF B$ > "/" AND B$ < ":" THEN ANUM = ASC(B$) - 48 ELSE ANUM
= ASC(B$) - 55
4950 ANUM = ANUM + T * 16
4960 RETURN
5150 '
5160 ' *****DRAW GRAPH
*****
5170 '
5180 ' subroutine to draw the actual graph axes and tics and to
label
5190 ' the whole mess.
5200 '
5210 LINE (LEFTPIX%, TOPPIX%)-(RIGHTPIX%, TOPPIX%)
5220 LINE (LEFTPIX%, TOPPIX%)-(LEFTPIX%, 172)
5230 LINE (LEFTPIX%, 172)-(RIGHTPIX%, 172)
5240 LINE (RIGHTPIX%, TOPPIX%)-(RIGHTPIX%, 172)
5250 XPIX = RIGHTPIX% - LEFTPIX%
5260 YPIX = 172 - TOPPIX%

```

```

5270 .!
5280 ' draw the tic marks and label the major tics
5290 '
5300 XSTP = XPIX / 10
5310 X = LEFTPIX%
5320 FOR I = 0 TO 9
5330 '
5340 ' major tic so label it
5350 '
5360 X = LEFTPIX% + XSTP * I
5365 IF I MOD 3 <> 0 THEN TIC = 3 ELSE TIC = 5
5370 LINE (X, 172)-(X, (172 - TIC))
5380 LINE (X, TOPPIX%)-(X, (TOPPIX% + TIC))
5390 IF I MOD 3 = 0 THEN VALU = ((I / 3) * .6) ELSE GOTO 5490
5420 XPOS = (X * 8)
5430 IF XPOS MOD 64 <> 0 THEN RNDUP = 1 ELSE RNDUP = 0
5440 XPOS = XPOS / 64 + RNDUP
5450 LOCATE 23, XPOS - 2: PRINT USING "#.##"; VALU;
5490 NEXT I
5500 IF TYP$ = "A" THEN GOTO 5540
5510 XPOS% = (40 - CHARS - 21) / 2 + CHARS
5515 WYE = 39 + XPOS%
5520 LOCATE 24, WYE: PRINT "LEAD SHIELD THICKNESS(cm)";
5530 IF TYP$ = "B" AND ((DSP$ = "LG") OR (DSP$ = "lg")) THEN GOTO
5680 ELSE GOTO 5560
5540 EX = ((40 - CHARS - 18) / 2 + CHARS) - 2: EY = 24

5550 LOCATE EY, EX: PRINT "DETECTOR THICKNESS(cm)";
5560 YSTP = YPIX / 10
5580 FOR I = 0 TO 9
5590 Y = 172 - (YSTP * I)
5600 IF I MOD 3 <> 0 THEN TIC = 4 ELSE TIC = 8
5610 LINE (LEFTPIX%, Y)-((LEFTPIX% + TIC), Y)
5620 LINE (RIGHTPIX%, Y)-(RIGHTPIX% - TIC, Y)
5630 IF I MOD 3 = 0 THEN VALU = (I / 10) * K ELSE GOTO 5678
'
' EMBEDDED SUBROUTINE
'
5650 L$ = STR$(VALU)
5660 L$ = RIGHT$(L$, LEN(L$) - 1)
5670 L = LEN(L$)
5671 XPOS% = (LEFTPIX% * 8! / 64!) - L
5672 IF (XPOS% * 8!) > LEFTPIX% THEN XPOS% = XPOS% - 1
5673 IF XPOS% < 1 THEN XPOS% = 1
5674 YPOS% = (Y + 4) / 8
5675 LOCATE YPOS%, XPOS%: PRINT L$;
5676 IF ((DSP$ = "LG") OR (DSP$ = "lg")) AND (TYP$ = "B")
THEN RETURN
'
' END EMBEDDED SUBROUTINE
'
5678 NEXT I
5679 GOTO 5790
5680 LNZ = 172 + (1 / LGDEC) * YPIX * MNLOG%

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5681 - IF (MXLOG% > 0) THEN GOTO 5682 ELSE GOTO 5700
5682 IF MXLOG% = 1 THEN MXI# = 2.5 ELSE MXI# = 7
5683 FOR I = 1 TO MXI# STEP (.5 * MXLOG%): GOSUB 5687: NEXT I
5684 IF MNLOG% = 0 THEN GOTO 5790 ELSE IF MNLOG% = -1 THEN MNI#
= .4 ELSE MNI# = .2
5685 FOR I = 1 TO MNI# STEP (-.2): GOSUB 5687: NEXT I
5686 GOTO 5790
      '
      ' EMBEDDED SUBROUTINE
      '
5687 Y = LN2 - (LOG(I) * 1 / LGDEC) * YPIX: FLAGG = 0
5688 LINE (LEFTPIX%, Y)-((LEFTPIX% + 4), Y)
5689 LINE (RIGHTPIX%, Y)-((RIGHTPIX% - 4), Y)
5690 IF ((MXLOG% > 0) AND (MNLOG% >= -2) AND (I MOD 1 = 0))
THEN VALU = I: FLAGG = 1
5692 IF ((MXLOG% > 0) AND (MNLOG% <= -3) AND (I MOD 1 = 0))
THEN VALU = I: FLAGG = 1
5693 IF ((MXLOG% = 0) AND (MNLOG% = -1) AND (J% MOD 2 = 0))
THEN VALU = I: FLAGG = 1
5694 IF ((MXLOG% = 0) AND (MNLOG% < -1) AND (J% MOD 2 = 0))
THEN VALU = I: FLAGG = 1
5696 IF FLAGG = 1 THEN GOSUB 5650
5698 RETURN
      '
      ' END EMBEDDED SUBROUTINE
      '
5700 IF MNLOG% = -1 THEN MNI% = 4 ELSE MNI% = 2
5710 FOR J% = 10 TO MNI% STEP (-1): I = J% / 10: GOSUB 5687: NEXT
J%
5790 CHARS = YPIX * 25! / 200!
5800 STRT = PLAC% + (CHARS - 5!) / 2!
5805 WYE = 1
5810 LOCATE STRT, WYE: PRINT "R";
5812 LOCATE STRT + .5, WYE: PRINT "A";
5814 LOCATE STRT + 1, WYE: PRINT "T";
5816 LOCATE STRT + 2.5, WYE: PRINT "I";
5818 LOCATE STRT + 3, WYE: PRINT "O";
5852 WYE = 41
5854 LOCATE STRT, WYE: PRINT "R";
5856 LOCATE STRT + .5, WYE: PRINT "A";
5858 LOCATE STRT + 1, WYE: PRINT "T";
5860 LOCATE STRT + 2.5, WYE: PRINT "I";
5862 LOCATE STRT + 3, WYE: PRINT "O";
5878 RETURN
5879 '
5880 ' ***** FIT *****
5890 '
5900 ' fitting subroutine
5910 '
5920 SY = 0
5930 SX = 0
5940 SX2 = 0
5950 SXY = 0
5980 FOR I = 1 TO 3

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5985 IF ((DSP$ = "LG") OR (DSP$ = "lg")) AND ((OFFSET = 2) OR
(OFFSET = 7)) THEN RATO#(I + OFFSET) = LOG(RAT#(I + OFFSET)) ELSE
RATO#(I + OFFSET) = RAT#(I + OFFSET)
5990 SX = SX + APOS#(I)
6000 SY = SY + RATO#(I + OFFSET)
6010 SX2 = SX2 + APOS#(I) * APOS#(I)
6020 SXY = SXY + APOS#(I) * RATO#(I + OFFSET)
6030 NEXT I
6040 INTERCEPT# = (SY * SX2 - SX * SXY) / (3 * SX2 - SX * SX)
6050 SLOPE# = (3 * SXY - SX * SY) / (3 * SX2 - SX * SX)
6060 RETURN
6070 '
6080 ***** PRINT SLOPE AND INTERCEPT - NO GRAPH
*****
6090 '
7000 APOS#(1) = .5
7010 APOS#(2) = 1!
7020 APOS#(3) = 1.8
7040 IF GNFLG% = 1 THEN OFFSET = 0 ELSE OFFSET = 5
7060 SLOPE# = 0!
7070 INTERCEPT# = 0!
7080 GOSUB 5920
7100 IF GNFLG% = 1 THEN NUM1% = 1: NUM2% = 3 ELSE NUM1% = 6:
NUM2% = 8
7110 LPRINT USING "FOR DETECTORS ## TO ##:"; NUM1%; NUM2%;
7120 LPRINT USING " SLOPE = ###.###^ ^ ^ ^ INTERCEPT =
###.###^ ^ ^ ^"; SLOPE#; INTERCEPT#;
7130 LPRINT
7140 APOS#(1) = 0
7150 APOS#(2) = .762
7160 APOS#(3) = 1.524
7180 IF GNFLG% = 1 THEN OFFSET = 2 ELSE OFFSET = 7
7200 SLOPE# = 0!
7210 INTERCEPT# = 0!
7220 GOSUB 5920
7230 IF GNFLG% = 1 THEN NUM1% = 3: NUM2% = 5 ELSE NUM1% = 8:
NUM2% = 10
7250 LPRINT USING "FOR DETECTORS ## TO ##:"; NUM1%; NUM2%;
7260 LPRINT USING " SLOPE = ###.###^ ^ ^ ^ INTERCEPT =
###.###^ ^ ^ ^"; SLOPE#; INTERCEPT#: LPRINT : LPRINT
7270 RETURN
7300 '
7310 ' ***** COMPUTE PHA *****
7320 '
7330 CLS
7331 COMBIN% = 1
7332 PHA = 1
7333 PLAC% = 2
7334 LOCATE PLAC% + 1, 1: PRINT "SELECT PHA PLOT (P) OR AMPLITUDE
VS. BLOCK NUMBER PLOT (A).": INPUT "", PORAS: CLS
7370 LOCATE PLAC% + 1, 1: PRINT "ENTER STARTING BLOCK NUMBER:";
7380 INPUT "", R
7390 LOCATE PLAC% + 2, 1: PRINT "ENTER NUMBER OF BLOCKS:";
7400 INPUT "", S

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7402  ·ERASE UNSH%, SHLD%
7404  FOR I = 1 TO 10: LOW(I) = 4094: HIGH(I) = 0: MXLVL#(I) = 0:
MNLVL#(I) = 4094: MX(I) = 0: MXCH(I) = 0: NEXT I
7418  Q = 1
7422  REC = R - 1
7426  CLS
7430  REC = REC + 1
7434  GOSUB 4420
7435  IF REC = R THEN STD$ = D$: STC$ = C$
7438  FOR I = 6 TO 10
7442  IF (((PORA$ = "P") OR (PORA$ = "p")) AND (IR#(I) >= 4094))
THEN GOTO 7430
7446  NEXT I
7448  FOR I = 1 TO 10
7450  IF IR#(I) > MXLVL#(I) THEN MXLVL#(I) = IR#(I)
7452  IF IR#(I) < MNLVL#(I) THEN MNLVL#(I) = IR#(I)
7458  IF (((PORA$ = "A") OR (PORA$ = "a")) AND (I < 6)) THEN
DAT1#(I, Q) = IR#(I): GOTO 7518
7460  IF (((PORA$ = "A") OR (PORA$ = "a")) AND (I > 5)) THEN
DAT2#(I - 5, Q) = IR#(I): GOTO 7518
7492  IF I < 6 THEN IF IR#(I) = 0 THEN A% = 1 ELSE A% = IR#(I)
7493  IF I > 5 THEN IF IR#(I) = 0 THEN B% = 1 ELSE B% = IR#(I)
7500  IF I < 6 THEN UNSH%(I, A%) = UNSH%(I, A%) + 1
7502  IF I > 5 THEN SHLD%(I - 5, B%) = SHLD%(I - 5, B%) + 1
7510  IF I < 6 THEN IF UNSH%(I, A%) > MX(I) THEN MX(I) = UNSH%(I,
A%): MXCH(I) = A%
7512  IF I > 5 THEN IF SHLD%(I - 5, B%) > MX(I) THEN MX(I) =
SHLD%(I - 5, B%): MXCH(I) = B%
7513  IF I < 6 THEN IF ((UNSH%(I, A%) > 0) AND (A% < LOW(I))) THEN
LOW(I) = A%
7514  IF I < 6 THEN IF ((UNSH%(I, A%) > 0) AND (A% > HIGH(I)))
THEN HIGH(I) = A%
7515  IF I > 5 THEN IF ((SHLD%(I - 5, B%) > 0) AND (B% < LOW(I)))
THEN LOW(I) = B%
7516  IF I > 5 THEN IF ((SHLD%(I - 5, B%) > 0) AND (B% > HIGH(I)))
THEN HIGH(I) = B%
7518  NEXT I
7520  IF Q < (S + 1) THEN Q = Q + 1: GOTO 7430
7525  CLS
7526  GOSUB 7540
7527  KEES = 0
7532  RETURN
7534  '
7535  '***** PRINT PHA *****
7536  '
7540  PLAC% = 2
7541  CLS
7543  LOCATE PLAC%, 1: PRINT "ENTER DETECTOR NUMBER (1 TO 10) FOR
PHA OR AMPLITUDE VS. BLOCK NUMBER:";
7548  INPUT "", L
7549  CLS
7550  IF L < 6 THEN GEV$ = "MeV": EGEV$ = "E-MeV": DTNRG#(L) = 250
ELSE GEV$ = "GeV": EGEV$ = "E-GeV": DTNRG#(L) = 25
7551  LOCATE PLAC%, 1: PRINT "SELECT AUTOMATIC HORIZONTAL SCALING

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(A) OR FULL-SCALE (F) OR EXPANDED (E).";
7552 INPUT "", X$
7553 IF ((PORA$ = "P") OR (PORA$ = "p")) AND ((X$ = "E") OR (X$
= "e")) THEN CLS : LOCATE PLAC%, 1: PRINT "ENTER LOWEST PHA CHANNEL
TO BE PLOTTED.": INPUT "", MANLO(L): CLS : LOCATE PLAC%, 1: PRINT
"ENTER HIGHEST PHA CHANNEL TO BE PLOTTED.": INPUT
"", MANHI(L): IF MANHI(L) MOD 25 = 0 THEN MANHIPH = MANHI(L) - 1
ELSE MANHIPH = MANHI(L)
7554 IF ((PORA$ = "P") OR (PORA$ = "p")) AND ((X$ = "E") OR (X$
= "e")) THEN MULT = (((((MANHIPH \ 25) + 1) * 25) - ((MANLO(L) \
25) * 25)) / 25): MLSM = (MANLO(L) \ 25) * 25: GOTO 7574
7556 IF ((PORA$ = "A") OR (PORA$ = "a")) AND ((X$ = "E") OR (X$
= "e")) THEN CLS : LOCATE PLAC%, 1: PRINT "ENTER LOWEST BLOCK
NUMBER TO BE PLOTTED.": INPUT "", BLKLO(L): CLS : LOCATE PLAC%, 1:
PRINT "ENTER HIGHEST BLOCK NUMBER TO BE PLOTTED.":
INPUT "", BLKHI(L): IF BLKHI(L) MOD 25 = 0 THEN BLKHIGH = BLKHI(L)
- 1 ELSE BLKHIGH = BLKHI(L)
7558 IF ((PORA$ = "A") OR (PORA$ = "a")) AND ((X$ = "E") OR (X$
= "e")) THEN MULT = (((((BLKHIGH \ 25) + 1) * 25) - ((BLKLO(L) \
25) * 25)) / 25): MLSM = (BLKLO(L) \ 25) * 25: GOTO 7574
7560 IF ((PORA$ = "A") OR (PORA$ = "a")) AND ((X$ = "A") OR (X$
= "a")) THEN IF (R + S) MOD 25 = 0 THEN SUM = (R + S - 1) ELSE SUM
= R + S
7562 IF ((PORA$ = "A") OR (PORA$ = "a")) AND ((X$ = "A") OR (X$
= "a")) THEN MULT = (((((SUM) \ 25) + 1) * 25) - ((R \ 25) * 25))
/ 25): MLSM = ((R \ 25) * 25): GOTO 7574
7564 IF ((PORA$ = "A") OR (PORA$ = "a")) AND ((X$ = "F") OR (X$
= "f")) THEN MULT = 800: MLSM = 0: GOTO 7574
7566 IF ((PORA$ = "P") OR (PORA$ = "p")) AND ((X$ = "F") OR (X$
= "f")) THEN MULT = 200 ELSE MULT = (((((HIGH(L) \ 25) + 1) * 25)
- ((LOW(L) \ 25) * 25)) / 25)
7570 IF ((PORA$ = "P") OR (PORA$ = "p")) AND ((X$ = "F") OR (X$
= "f")) THEN MLSM = 0 ELSE MLSM = (LOW(L) \ 25) * 25
7574 CLS
7575 TOPPIX% = 16
7576 BOTPIX% = 136
7578 LEFTPIX% = 100
7580 RIGHTPIX% = 580
7590 LINE (LEFTPIX%, (TOPPIX% - 4))-(RIGHTPIX%, (TOPPIX% - 4))
7600 LINE (LEFTPIX%, (TOPPIX% - 4))-(LEFTPIX%, (BOTPIX% - 4))
7610 LINE (LEFTPIX%, (BOTPIX% - 4))-(RIGHTPIX%, (BOTPIX% - 4))
7620 LINE (RIGHTPIX%, (TOPPIX% - 4))-(RIGHTPIX%, (BOTPIX% - 4))
7630 XSTP = (RIGHTPIX% - LEFTPIX%) / 25
7640 FOR I = 0 TO 25
7650 X = LEFTPIX% + XSTP * I
7660 IF I MOD 5 <> 0 THEN Q = 3 ELSE Q = 5
7670 LINE (X, (BOTPIX% - 4))-(X, (BOTPIX% - 4 - Q))
7680 LINE (X, (TOPPIX% - 4))-(X, (TOPPIX% - 4 + Q))
7690 IF I MOD 5 = 0 THEN VALU = ((I * MULT) + MLSM) ELSE GOTO
7740
7700 XPOS = X / 8
7722 IF I = 0 THEN XPOS = XPOS - 2
7730 LOCATE 18, XPOS - 2: PRINT USING "#####"; VALU
7740 NEXT I

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7750   LOCATE 19, 36: IF ((PORA$ = "P") OR (PORA$ = "p")) THEN
PRINT "CHANNEL NUMBER" ELSE PRINT "BLOCK NUMBER"
7755   IF ((PORA$ = "A") OR (PORA$ = "a")) THEN GOTO 7822
7760   K = 10
7770   IF MX(L) > 10 THEN K = 20
7780   IF MX(L) > 20 THEN K = 50
7790   IF MX(L) > 50 THEN K = 100
7800   IF MX(L) > 100 THEN K = 200
7810   IF MX(L) > 200 THEN K = 500
7820   IF MX(L) > 500 THEN K = 1000
7821   GOTO 7830
7822   MAX# = MXLVL#(L): MIN# = MNLVL#(L)
7824   MLTV = (((((MAX# \ 25) + 1) * 25) - ((MIN# \ 25) * 25)) /
5000)
7825   MLSV = (MIN# \ 25) * 25
7830   YSTP = (TOPPIX% - BOTPIX%) / 10
7840   FOR I = 0 TO 10
7850   Y = BOTPIX% + (YSTP * I)
7860   IF ((I MOD 2 = 0) AND ((PORA$ = "P") OR (PORA$ = "p"))) THEN
VALU = (K / 10) * I ELSE IF ((I MOD 2 = 0) AND ((PORA$ = "A") OR
(PORA$ = "a"))) THEN VALU = ((I * 500 * MLTV) + MLSV) ELSE GOTO
7880
7870   LOCATE (Y / 8), 9: PRINT USING "####"; VALU
7880   LINE (LEFTPIX%, (Y - 4)) - ((LEFTPIX% + 10), (Y - 4))
7890   LINE (RIGHTPIX%, (Y - 4)) - ((RIGHTPIX% - 10), (Y - 4))
7900   NEXT I
7905   LOCATE 6, 7: IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT
"A"
7910   LOCATE 7, 7: IF ((PORA$ = "P") OR (PORA$ = "p")) THEN PRINT
"C" ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT "M"
7920   LOCATE 8, 7: IF ((PORA$ = "P") OR (PORA$ = "p")) THEN PRINT
"O" ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT "P"
7930   LOCATE 9, 7: IF ((PORA$ = "P") OR (PORA$ = "p")) THEN PRINT
"U" ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT "L"
7940   LOCATE 10, 7: IF ((PORA$ = "P") OR (PORA$ = "p")) THEN PRINT
"N" ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT "I"
7950   LOCATE 11, 7: IF ((PORA$ = "P") OR (PORA$ = "p")) THEN PRINT
"T" ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT "T"
7952   LOCATE 12, 7: IF ((PORA$ = "P") OR (PORA$ = "p")) THEN PRINT
"S" ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT "U"
7953   LOCATE 13, 7: IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT
"D"
7954   LOCATE 14, 7: IF ((PORA$ = "A") OR (PORA$ = "a")) THEN PRINT
"E"
7958   IF ((PORA$ = "P") OR (PORA$ = "p")) AND ((X$ = "E") OR (X$
= "e")) THEN MANLO(L) = MANLO(L): MANHI(L) = MANHI(L) ELSE IF
((PORA$ = "P") OR (PORA$ = "p")) THEN MANLO(L) = LOW(L): MANHI(L)
= HIGH(L) ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) AND
((X$ = "E") OR (X$ = "e")) THEN MANLO(L) = BLKLO(L): MANHI(L) =
BLKHI(L) ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) THEN MANLO(L) =
R: MANHI(L) = R + S - 1
7961   IF ((PORA$ = "P") OR (PORA$ = "p") OR (PORA$ = "A") OR
(PORA$ = "a")) AND ((X$ = "F") OR (X$ = "f")) THEN D = 1 ELSE D =
(MANLO(L) \ 25) * 25

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7962 IF ((PORA$ = "P") OR (PORA$ = "p")) AND ((X$ = "F") OR (X$
= "f")) THEN E = 4094 ELSE IF ((PORA$ = "A") OR (PORA$ = "a")) AND
((X$ = "F") OR (X$ = "f")) THEN E = 16382 ELSE IF MANHI(L) MOD 25
= 0 THEN E = ((MANHI(L) - 1) \ 25) + 1) * 25 ELSE
E = ((MANHI(L) \ 25) + 1) * 25
7970 FOR B = MANLO(L) TO (MANHI(L) - 1)
7980 FOR I = 1 TO 2
7981 IF B = 0 THEN C = B + I ELSE C = B + I - 1
7982 IF ((PORA$ = "A") OR (PORA$ = "a")) THEN GOTO 7996
7986 IF L > 5 THEN GOTO 7994
7990 YPOS(I) = (1 - ((BOTPIX% - TOPPIX%) * (UNSH%(L, C) / K))) +
(BOTPIX% - 4)
7992 GOTO 8000
7994 YPOS(I) = (1 - ((BOTPIX% - TOPPIX%) * (SHLD%(L - 5), C) /
K))) + (BOTPIX% - 4)
7995 GOTO 8000
7996 IF L < 6 THEN NUNM# = DAT1$(L, C - R + 1) ELSE NUNM# =
DAT2$(L - 5, C - R + 1)
7997 YPOS(I) = -((BOTPIX% - TOPPIX%) * ((NUNM# - MLSV) /
(((MXLVL$(L) \ 25) + 1) * 25) - MLSV))) + BOTPIX% - 4
8000 IF ((PORA$ = "P") OR (PORA$ = "p")) AND ((X$ = "F") OR (X$
= "f")) THEN G = (C / 5000) ELSE G = ((C - D) / (E - D))
8005 XPOS(I) = ((RIGHTPIX% - LEFTPIX%) * (G)) + (LEFTPIX%)
8010 NEXT I
8020 LINE (XPOS(1), YPOS(1))-(XPOS(2), YPOS(2))
8030 NEXT B
8032 IF ((PORA$ = "A") OR (PORA$ = "a")) THEN GOTO 8082
8040 LOCATE 20, 7: PRINT USING "FILENAME IS \ \. FULL SCALE
ENERGY IS ### \ \."; FILE$; DTNRG$(L); GEV$
8050 LOCATE 21, 7: PRINT USING "COMBINED #### RECORDS: ####
THROUGH ####."; S; R; REC
8055 LOCATE 22, 7: PRINT USING "START TIME = \ \ \ \.
STOP TIME = \ \ \ \."; STD$; STC$; D$; C$
8060 LOCATE 23, 7: PRINT USING "MAXIMUM COUNTS IN DETECTOR NUMBER
## ARE #### IN CHANNEL NUMBER ####."; L; MX(L); MXCH(L)
8080 LOCATE 24, 7: PRINT USING "LOWEST/HIGHEST CHANNELS WITH DATA
ARE #### / ####"; LOW(L); HIGH(L);
8081 GOTO 9000
8082 LOCATE 20, 7: PRINT USING "FILENAME IS \ \. DETECTOR
NUMBER IS # ."; FILE$; L
8083 LOCATE 21, 7: PRINT USING "AMPLITUDE VS. BLOCK NUMBER:
BLOCKS ##### TO #####."; MANLO(L); MANHI(L)
8084 LOCATE 22, 7: PRINT USING "START TIME = \ \ \ \.
(BLOCK NUMBER #####)"; STD$; STC$; R
8085 LOCATE 23, 7: PRINT USING "STOP TIME = \ \ \ \.
(BLOCK NUMBER #####)"; D$; C$; R + S - 1
9000 RETURN

```