



Setup and Calibration of SLAC's Peripheral Monitoring Stations

C.Cooper, Cornell University, A. Wood, University of New Orleans,
J. Colon, J. Liu, and R. Seefred, Stanford Linear Accelerator Center

Stanford Linear Accelerator Center
Menlo Park, CA 94025

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1.0 ABSTRACT

The goals of this project were to troubleshoot, repair, calibrate, and establish documentation regarding SLAC's (Stanford Linear Accelerator Center's) PMS (Peripheral Monitoring Station) system. The PMS system consists of seven PMSs that continuously monitor skyshine (neutron and photon) radiation levels in SLAC's environment. Each PMS consists of a boron trifluoride (BF_3) neutron detector (model RS-P1-0802-104 or NW-G-20-12) and a Geiger Müller (GM) gamma ray detector (model TGM N107 or LND 719) together with their respective electronics. Electronics for each detector are housed in Nuclear Instrument Modules (NIMs) and are plugged into a NIM bin in the station. All communication lines from the stations to the Main Control Center (MCC) were tested prior to troubleshooting. To test communication with MCC, a pulse generator (Systron Donner model 100C) was connected to each channel in the PMS and data at MCC was checked for consistency. If MCC displayed no data, the communication cables to MCC or the CAMAC (Computer Automated Measurement and Control) crates were in need of repair. If MCC did display data, then it was known that the communication lines were intact. All electronics from each station were brought into the lab for troubleshooting. Troubleshooting usually consisted of connecting an oscilloscope or scaler (Ortec model 871 or 775) at different points in the circuit of each detector to record simulated pulses produced by a pulse generator; the input and output pulses were compared to establish the location of any problems in the circuit. Once any problems were isolated, repairs were done accordingly. The detectors and electronics were then calibrated in the field using radioactive sources. Calibration is a process that determines the response of the detector. Detector response is defined as the ratio of the number of counts per minute interpreted by the detector to the amount of dose equivalent rate (in mrem per hour, either calculated or measured). Detector response for both detectors is dependent upon the energy of the incident radiation; this trend had to be accounted for in the calibration of the BF_3 detector. Energy dependence did not have to be taken into consideration when calibrating the GM detectors since GM detector response is only dependent on radiation energy below 100 keV; SLAC only produces a spectrum of gamma radiation above 100 keV. For the GM detector, calibration consisted of bringing a ^{137}Cs source and a NIST-calibrated RADCAL Radiation Monitor Controller (model 9010) out to the field; the absolute dose rate was determined by the RADCAL device while simultaneously irradiating the GM detector to obtain a scaler reading corresponding to counts per minute. Detector response was then calculated. Calibration of the BF_3 detector was done using NIST certified neutron sources of known emission rates and energies. Five neutron sources ($^{238}\text{PuBe}$, ^{238}PuB , $^{238}\text{PuF}_4$, $^{238}\text{PuLi}$ and ^{252}Cf) with different energies were used to account for the energy dependence of the response. The actual neutron dose rate was calculated by date-correcting NIST source data and considering the direct dose rate and scattered dose rate. Once the total dose rate (sum of the direct and scattered dose rates) was known, the response vs. energy curve was plotted. The first station calibrated (PMS6) was calibrated with these five neutron sources; all subsequent stations were calibrated with one neutron source and the energy dependence was assumed to be the same.

2.0 INTRODUCTION

Stanford Linear Accelerator Center (SLAC) is operated under contract with the United States Department of Energy (DOE) to perform experimental and theoretical research in elementary particle physics. These experiments are carried out using high-energy electron and positron beams that produce neutron and gamma radiation. Seven Peripheral Monitoring Stations (PMSs) were set up to measure the environmental radiation levels and the dose to the public. DOE Order 5400.5 states that the public shall receive no more than 100 mrem per year of radiation, excluding natural background. The stations were installed in strategic locations to estimate the maximum public dose from various accelerator operations. For example, PMS6 is located approximately 30 meters from the Positron Vault at sector 20. This PMS is constantly monitoring both neutron and gamma radiation generated during the process of positron production inside the vault as well as during klystron operation in the accelerator. The locations of the all PMSs (except PMS6) are shown in Figure 1. GPS coordinates for all stations can be found in Appendix 1.

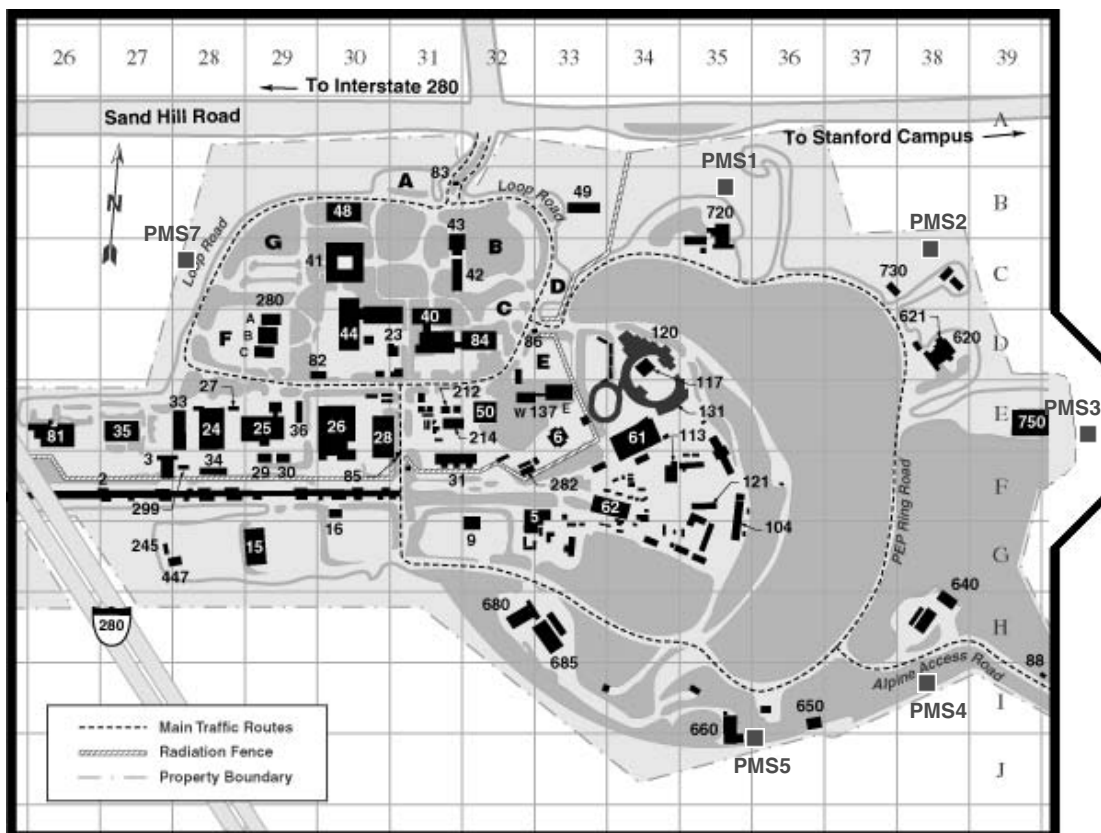


Figure 1. Locations of six Peripheral Monitoring Stations around SLAC facility. PMS6 in Sector 20 is not shown on this map.

The PMSs were established by the Radiation Protection Department to monitor the amount of skyshine radiation (neutron and gamma) in the environment surrounding SLAC. Skyshine radiation is one of many environmental concerns for acceleration facilities since it can

produce radiation a substantial distance away from the source of the original radiation. Skyshine radiation is radiation that emerges from a shielded area, and then scatters off of the air molecules in the atmosphere. This radiation is capable of scattering over long ranges in the atmosphere, thus producing radiation a significant distance from the shielded enclosure.

Each PMS consists of a large aluminum box elevated approximately one meter above ground level and mounted to a concrete slab. Housed within the aluminum box are a boron trifluoride (BF_3) neutron detector and a Geiger-Müller (GM) gamma detector. TLDs (thermoluminescent dosimeters) are also placed in the PMS as an extra measure to monitor the radiation levels. The BF_3 and GM detectors are connected to a series of commercially available Nuclear Instrument Modules (NIMs). These modules process signal pulses corresponding to the radiation levels sensed by the detectors. The modules then send the pulses to one of the two CAMAC (Computer Automated Measurement and Control) crates in the Main Control Center (MCC). A circuit layout of the MCC CAMAC crates can be found in Appendix 2; this circuit layout shows where each of the three channels (GAMMA, NEUTRON, and REM) for each station plug into the CAMAC crate. Once processed, the data may then be viewed on a Virtual Access computer (VAX). For a instructions on how to access PMS data via VAX see Appendix 3.

The detectors must be functioning properly and calibrated periodically to ensure accuracy of the PMSs and monitor public exposure. A four phase study was performed on the PMS system to achieve these goals. The first phase was establishing which stations needed to be repaired. The second phase consisted of troubleshooting and repairing the detectors and NIMs. The third phase was calibration of all detectors using NIST (National Institute of Standards and Technology) certified radioactive sources. The last and final phase was establishing comprehensive documentation for the PMSs. This report provides a detailed description of the PMSs along with calibration instructions and a section on troubleshooting and repair.

3.0 ELECTRONICS

An overhead view of a PMS is shown in Figure 2. Contained within each PMS are the detectors and their respective NIM circuits. As an example, a complete schematic of PMS7 (including MCC) is given in Appendix 4. The circuits are housed in NIMs in a standard NIM bin. Two types of detectors are necessary for monitoring the radiation around SLAC. The BF_3 detectors monitor the amount of neutron radiation, whereas the GM detectors monitor the amount of gamma radiation present in the environment. For a complete record of detector models contained in each station, refer to Tables 1a and 1b. There are two parallel circuits, one for the BF_3 detector and one for the GM detector. Each circuit amplifies the signal, counts it, and then sends it to MCC for recording. There are three channels (GAMMA, NEUTRON, and REM) within each PMS. The signals from each detector are transmitted with the third channel (REM) kept open; this channel is sometimes connected to a ^3He detector which can be used to estimate the energy of the incoming neutron when coupled with a moderated BF_3 detector.

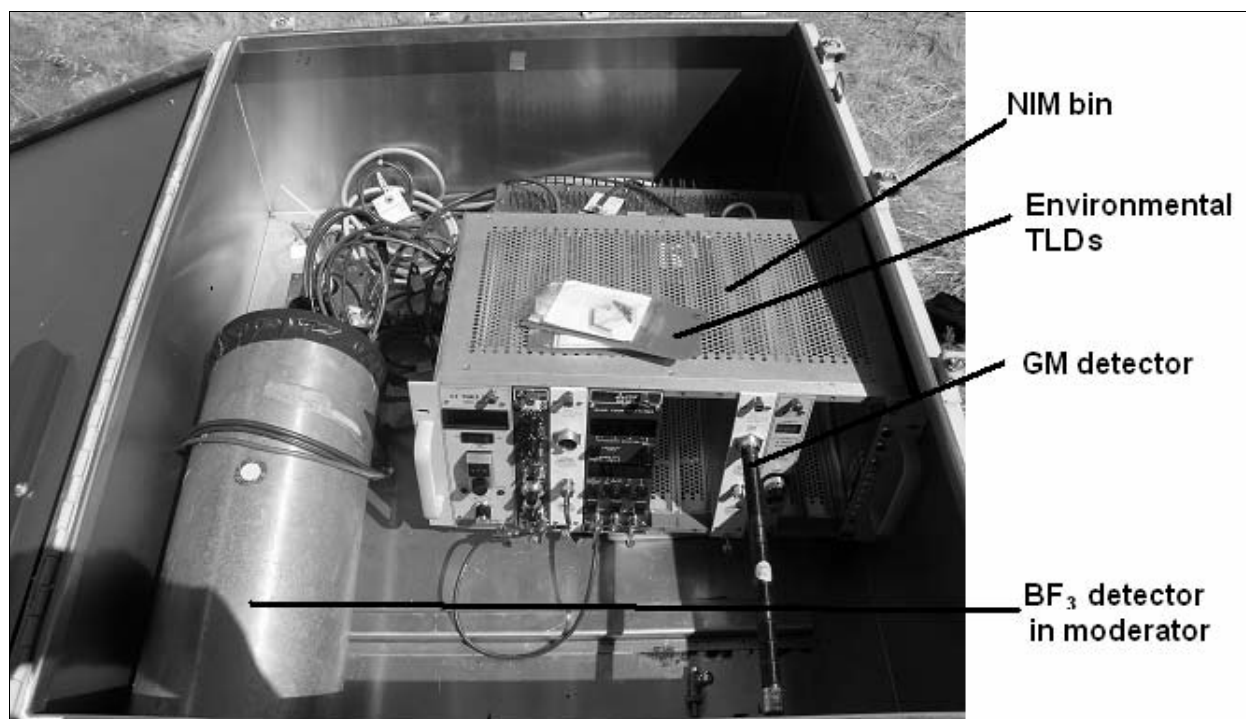


Figure 2. Overhead view of PMS. GM and BF₃ detectors, NIM bin, and TLDs are shown.

Table 1a. Operating parameters of BF₃ detectors for all stations.

PM Station	Model	ID/ Serial No.	Op. Voltage (V)	Gain, C x F	Disc. Voltage (V)	BKG signal (cpm)	Check Source (AmBe) Signal (cpm)
1	RS-P1-0802-104	1	1800	50x2.5	2.0	6.0	52469
2	RS-P1-0802-104	2	1750	50x2.5	2.0		59713
3	RS-P1-0802-104	3	1750	50x2.5	2.0	7.2	52139
4	NW-G-20-12	4	1750	50x2.5	2.0	6.3	38583
5	RS-P1-0802-104	5	1800	50x2.5	2.0	4.5	59876
6	RS-P1-0802-104	6	1750	50x2.5	2.0	9.0	54990
7	NW-G-20-12	7	1800	50x2.5	2.0	6.0	49053

Table 1b. Operating parameters of GM detectors for all stations.

PM Station	Model	ID/Serial No.	Op. Voltage (V)	BKG signal (cpm)	Check Source (⁶⁰ Co) Signal (cpm)
1	TGM N107	1	950	72	1659
2	TGM N107	8054	1100	55	1868
3	TGM N107	8059	950	61	1606
4	TGM N107	6690	1000	63	1523
5	LND 719	5	1050	56	1512
6	TGM N107	6689	1050	87	1624
7	LND 719	7	1050	66	1437

3.1 GM Electronics

The GM detector in each PMS is either a TGM model N107 or a LND model 719 (both are 10 inches in length). These detectors are capable of measuring radiation levels down to a few μrem per hour and energy down to a few hundred keV. The GM detector consists of a cathode and an anode. The outside of the cylinder is the cathode and is held at ground potential. Centered inside the cylinder is a thin wire, or anode, which is held at a positive high voltage. The GM detector uses a special mixture of helium and neon as a medium to enhance gas amplification. When the wall of the GM tube is hit by a gamma ray, secondary electrons are created to ionize the gas. The newly created electrons then ionize other atoms, creating an avalanche of electrons when drifting toward the anode. The reaction terminates when the cumulative effect of the avalanches reaches a critical level proportional to both the geometry of the tube and the applied voltage. Therefore, each gamma ray of any energy detected creates a relatively uniform pulse strength. Due to the avalanches, this pulse is much greater in amplitude than that of the BF_3 and needs no amplification to be interpreted by the electronics.

Figure 3 shows a schematic diagram of the GM circuit. The GM detector is plugged directly into the NIM line driver (model SLAC 125-682 Rev. A); this single NIM houses all of the electronics for the circuit. Contained within the NIM are all of the components required to process the signal before sending it to MCC and a line driver to drive the signal to MCC. The GM circuit is powered by a Canberra (model 3102D) high-voltage power supply. A detailed schematic of the NIM line driver is available from SLAC Engineering library drawing number 125-682.

3.2 BF_3 Electronics

The BF_3 detectors used in the PMS are either Nancy Wood (model G-20-12) or Reuter Stokes (model P1-0802-104) proportional neutron detectors (2 inch diameter and 12 inch active length). As with the GM detectors, the BF_3 detectors consist of a cathode and an anode. Both models of detectors consist of a cylinder filled with pure BF_3 gas enriched with 99% ^{10}B at a pressure between 0.26 and 0.59 atm. The gas acts as the target for any incident neutrons to make secondary ionized particles; the gas also creates a medium for an electron cascade. When a ^{10}B nucleus is hit by a neutron, it is transformed into ^{11}B before it breaks into a ^7Li nucleus and an alpha particle. Since this reaction has a higher cross section for thermal neutrons, the detector is surrounded by a cadmium-covered cylindrical polyethylene moderator (radial thickness 6 cm) that stops incident thermal neutrons and allows fast neutrons to thermalize in the polyethylene. The BF_3 detector and moderator are enclosed in an aluminum cylinder. After the neutron absorption, the newly created alpha particle ionizes more BF_3 molecules in the gas; this creates pairs of positive ions and electrons. The electrons drift toward the positively charged anode, thereby generating a low voltage pulse (on the order of 1 mV) when they hit the anode. The amount of electrons created is proportional to the energy of the alpha particle, which determines the pulse amplitude. Each pulse is then sent through a preamplifier then an amplifier to bring it up to the 5V level and thus interpreted as a count by the electronics. This system is capable of measuring very low levels of neutron radiation, including the cosmic ray neutrons. BF_3 detectors are also sensitive to gamma radiation, which must be filtered out during electronic setup (see Section 5.2 on “Plotting a Discriminator Curve”).

A schematic diagram summarizing the operation of the BF₃ circuit is shown in Figure 4. The BF₃ detector is powered by an Ortec 556 (0-3 kV) high voltage power supply. The output signal of the detector is processed by a Canberra 1706 preamplifier and then an Ortec 590A linear amplifier. The signal is then recorded by either an Ortec 871 scaler timer and counter or an Ortec 775 single counter and discriminator. The window discriminator function is used to filter out background noise (gamma and cosmic neutron radiation) by adjusting the lower level discriminator. The signal is then sent to a line driver (model SLAC 125-682 Rev. B) that drives the signal down 600Ω cables to MCC.

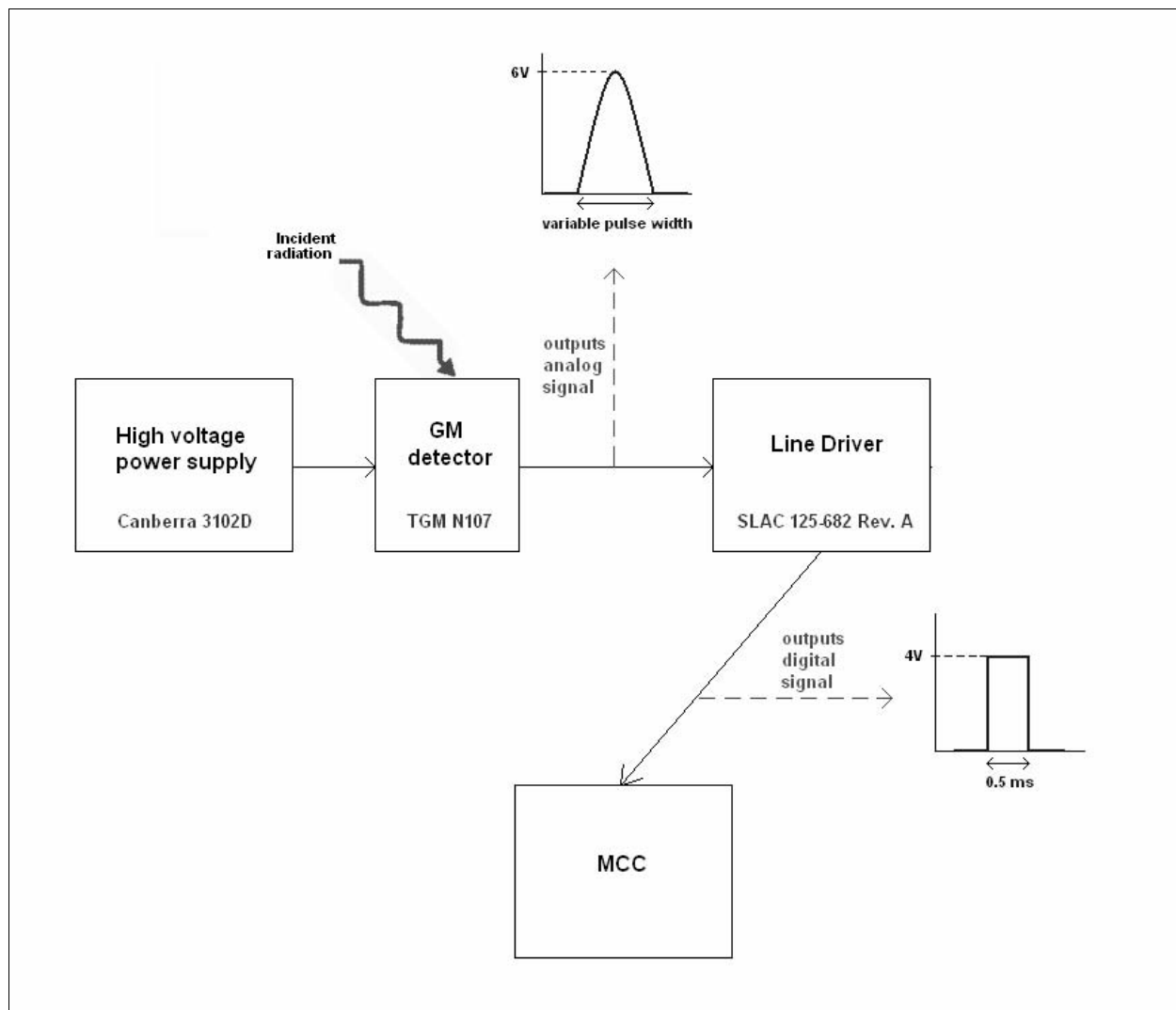


Figure 3. Summary of the operation of the GM circuit. Model numbers indicated in purple may vary from station to station. Refer to Table 1b for a complete record of detector models contained in each station.

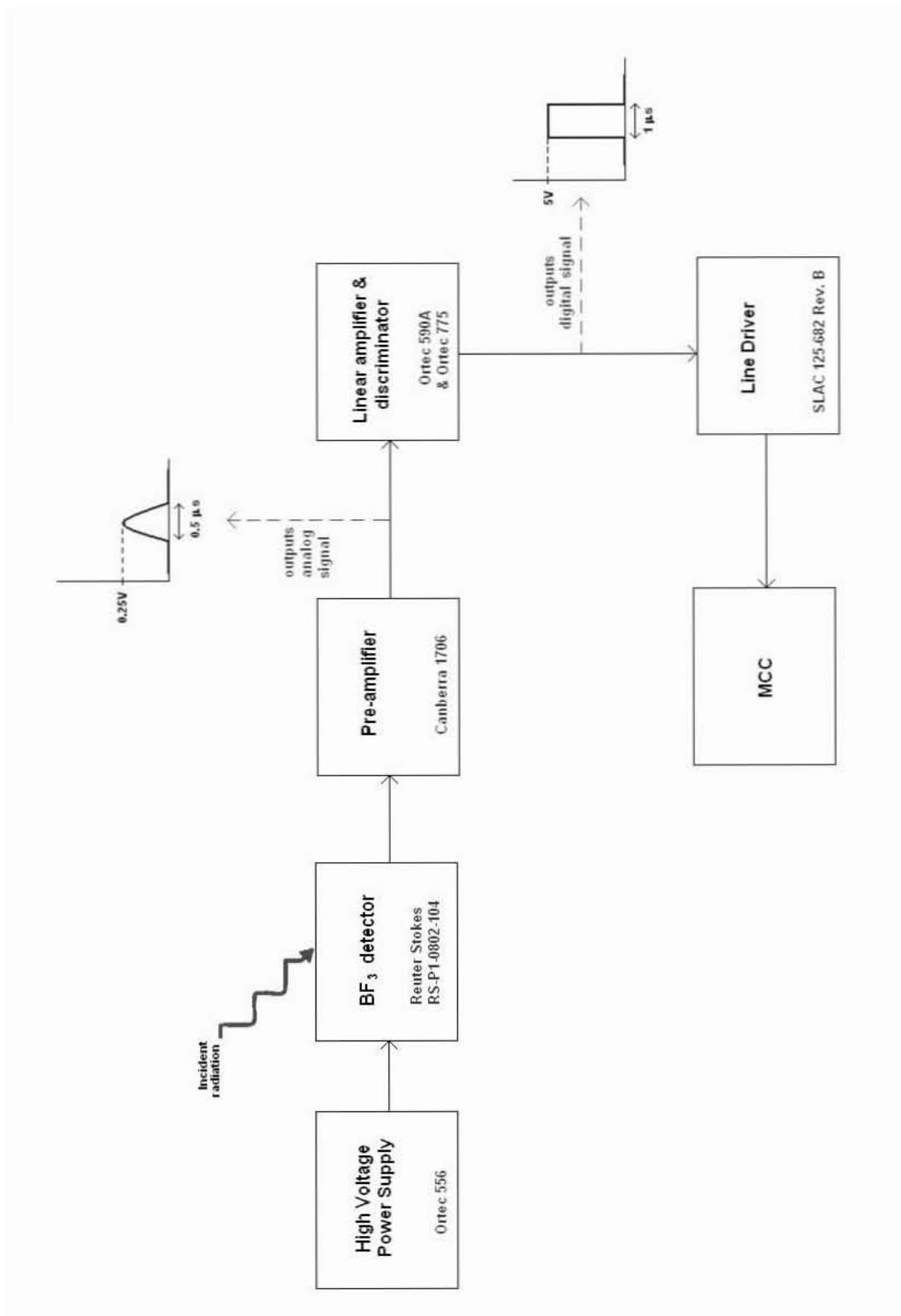


Figure 4. Summary of the operation of BF₃ circuit. Model numbers are indicated in purple and may vary from station to station. For a complete record of detector models contained in each station, see Table 1a.

3.3 PMS Data

Data from each PMS is recorded at MCC and may be displayed on any computer equipped with X-Windows. The data for each detector is presented as a graph of IDAT (counts per second) versus time. An example of this graph is shown in Figures 5a and 5b. Figure 5a is the graph for the PMS1 neutron channel and Figure 5b is for the PMS1 gamma channel. These graphs are representative of background radiation levels in the environment surrounding SLAC. The data points of Figure 5a are centered at 0.10 counts per second (6 counts per minute), which falls in the normal neutron background range of 6-9 counts per minute. The same is true for Figure 5b; the data points are centered at 1.2 counts per second (72 counts per minute), which falls in the normal gamma background range of 60-90 counts per minute.

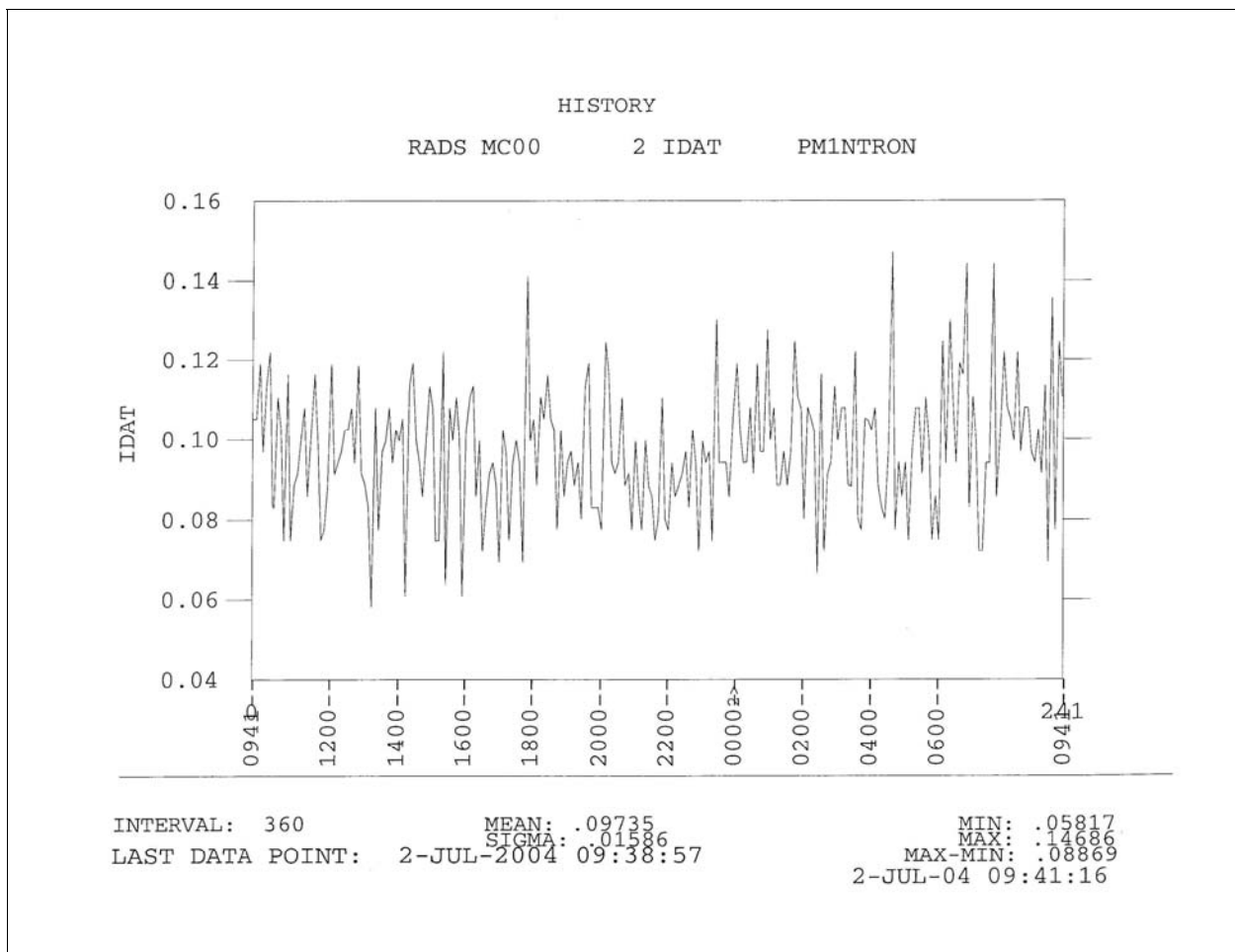


Figure 5a. Graph of number of counts as a function of time as displayed on MCC VAX. IDAT on the y-axis represents counts per second. The text in the upper right corner (PM1NTRON) identifies the station and channel.

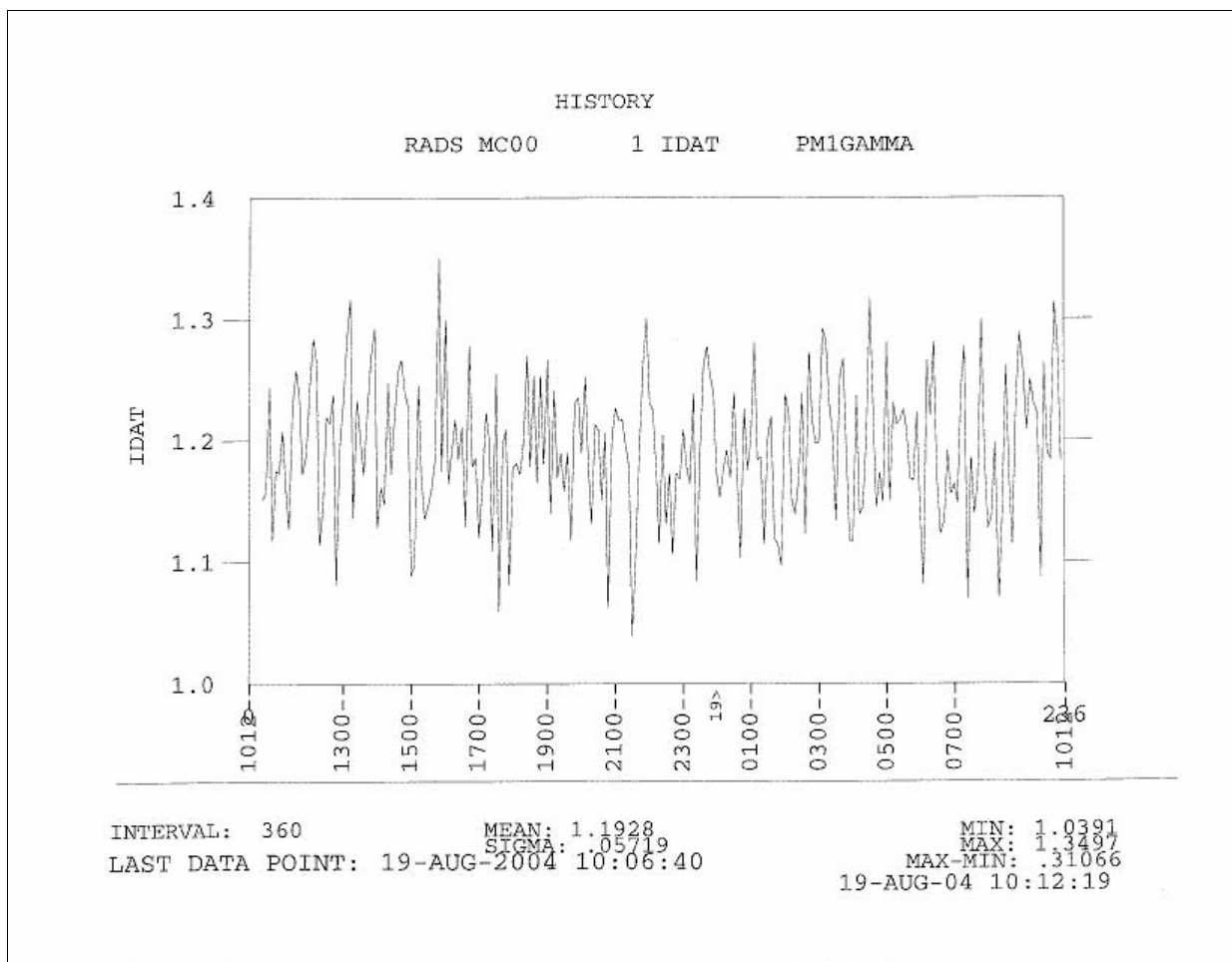


Figure 5b. Graph of number of counts versus time for the PMS1 gamma channel.

4.0 TROUBLESHOOTING AND REPAIR

When PMSs are not functioning properly, troubleshooting should be performed and the problem repaired accordingly. A step-by-step troubleshooting guide can be found in Appendix 5. The first step in troubleshooting is to determine which part of the system is not working (e.g., lines to MCC, detectors, NIMs). When the problem has been isolated, all repairs must be done and the system tested to ensure proper functioning. After any modifications to the system are done, the detectors must be plateaued and recalibrated (see next two sections).

After repairs have been made to the system, a pulse generator should be used to verify consistency of data between a local scaler and MCC. The frequency of the input pulse should match that of the pulse read by MCC. Due to a defect in manufacturing of the line drivers, it may be observed that MCC displays twice as many pulses as expected. This problem is due to the two wires on the BNC output being reversed (positive wire to negative pole and negative wire to positive pole). This issue can be resolved easily by disconnecting the positive and negative wires on the BNC output and reversing them. See Appendix 5 for detailed instructions on fixing double pulsing.

5.0 ELECTRONIC SETUP

After repairs or modifications to the electronics, it is necessary to set up the electronics in a NIM bin and plateau the detectors to find the optimal operating voltage. Also, a discriminator curve should be plotted for the BF_3 detectors in order to account for noise from gamma radiation. A background count must be established once the proper operating voltage is set. Once all of these steps are complete, the electronics are ready to be brought to the field for calibration.

5.1 Plateauing the Detectors

It is very important to run the detectors in the PMSs at their proper operating voltages. Although the manufacturer of the detectors provides a range of values for the operating voltage, plateauing the detector is necessary to determine its optimal operating voltage. A plateau curve is obtained by plotting number of counts per minute versus voltage for a specific detector and radioactive source. The end result is a linear relationship between the two variables at low and high voltages on either side of a flat, plateau region. See Figure 6 for an example of a plateau curve obtained for a GM detector. Plateauing is very important since selecting an operating voltage below the plateau region results in varied data for minor voltage fluctuations caused by electronic drift. In addition, selection of a high operating voltage may damage the detector.

The GM detector must be set up with the line driver NIM and radioactive source (usually ^{137}Cs) to begin plateauing. Refer to Figure 7 for an illustration of the plateau setup for a GM detector. It is important that the arrangement of the detector and source is not changed throughout the plateau process. When plateauing, a scaler must be connected to the detector (not shown in Figure 7) to display the number of counts for specified time intervals. The input voltage is adjusted and several measurements of counts per minute are taken at various voltages (refer to Appendix 6 for a detailed explanation of the plateauing process).

When plateauing the BF_3 detector, a neutron source, such as $^{241}\text{AmBe}$, must be used. Refer to Figure 8 for a diagram of the plateau setup for the BF_3 detectors. The BF_3 detector must also be set up with its pre-amplifier, linear amplifier, and counter/discriminator for viewing number of counts measured (not shown in Figure 8). Data acquisition is the same for plateauing the BF_3 detector; input voltage is adjusted and counts per minute is recorded at these voltages. Figure 9 is an example of a plateau curve obtained for the BF_3 detectors. Remember ALARA (As Low As Reasonably Achievable) should be practiced at all times; radioactive warning signs must be posted whenever using radioactive sources and appropriate shielding should be used. Contact the Radiation Protection Field Operations Group for proper precautionary procedures (ext. 4299).

Once the plateau curve has been plotted, the operating voltage is determined from the curve. The curve obtained may not look exactly like Figure 6 or 9; it is correct as long as there is a plateau region where counts per minute is independent of input voltage. The operating voltage is the voltage corresponding to a point approximately a third of the way across the plateau from the lower end. In the field, the power supply to the detector should be set at this voltage at all times. The optimum operating voltages for all PMS detectors are listed in Tables 1a and 1b. See Appendix 7 for a compilation of plateau curves for the detectors in all seven PMSs.

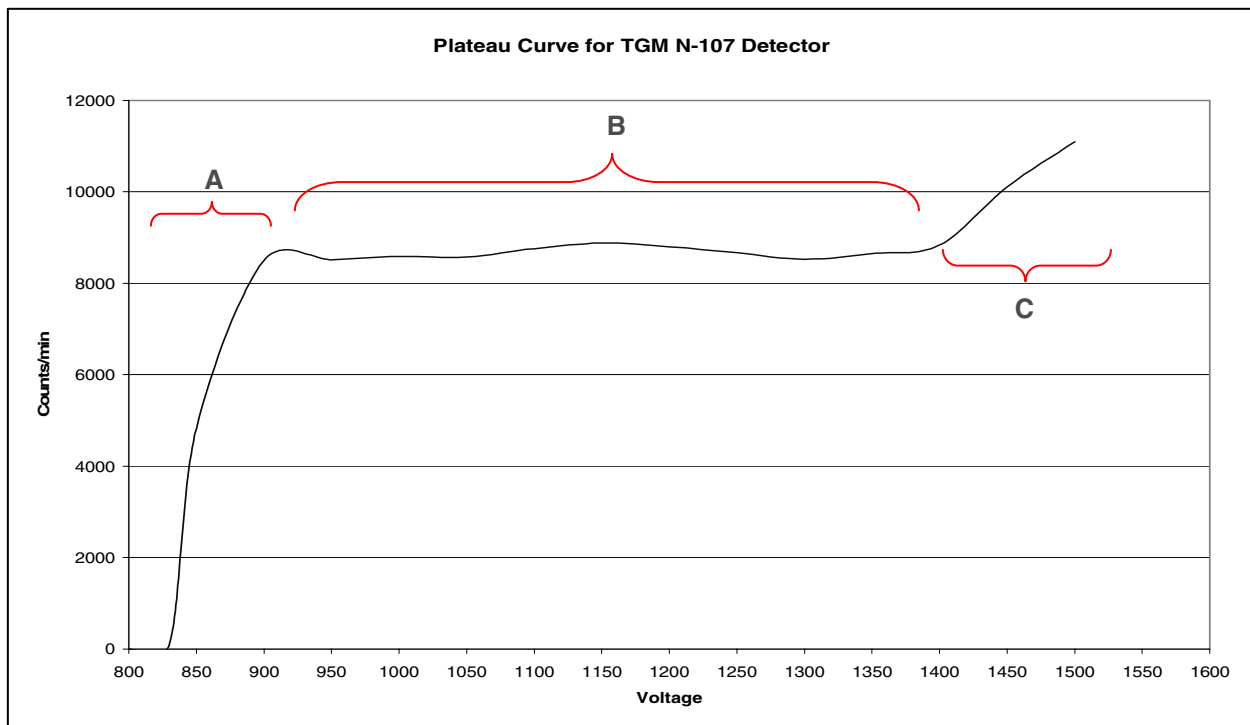


Figure 6. Plateau curve for 10-inch GM detector. The regions labeled as “A” and “C” show a linear relationship between the two variables. The region labeled “B” is the plateau region. The optimum operating voltage for this tube is about 1000V.

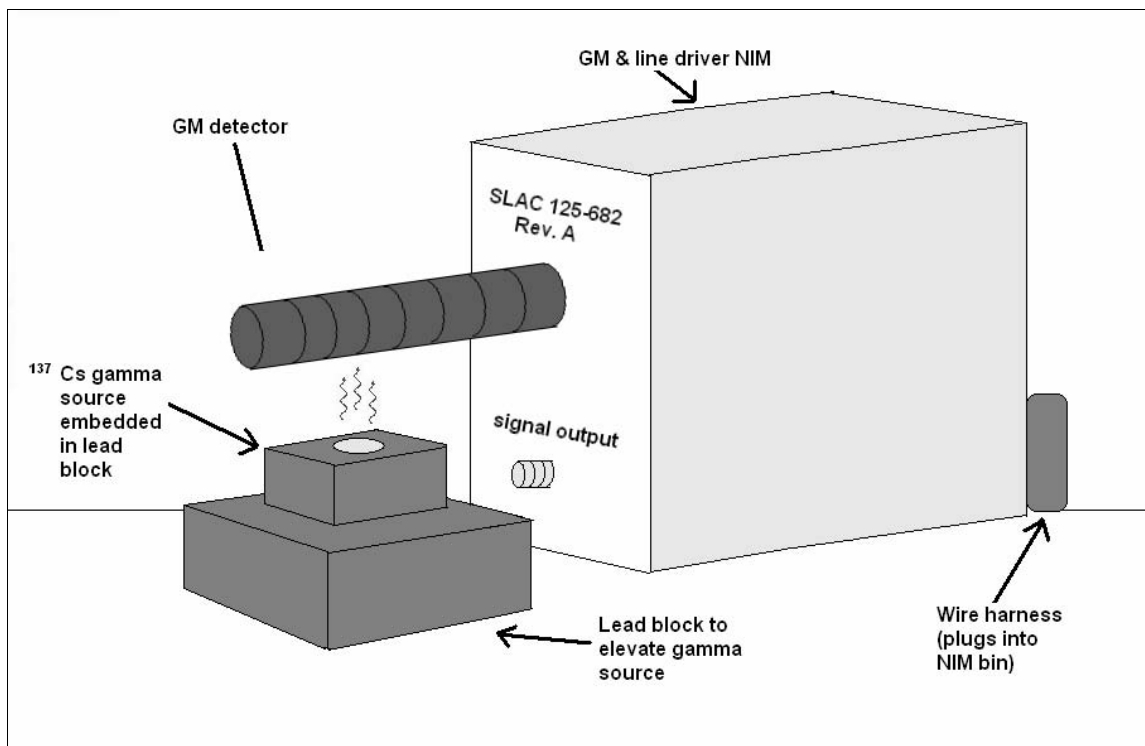


Figure 7. Plateau setup for GM detectors. The signal output is connected to a scaler which displays the number of counts. The source should be positioned so that most of the radiation is incident on the lateral side of the detector to reduce error in measurements.

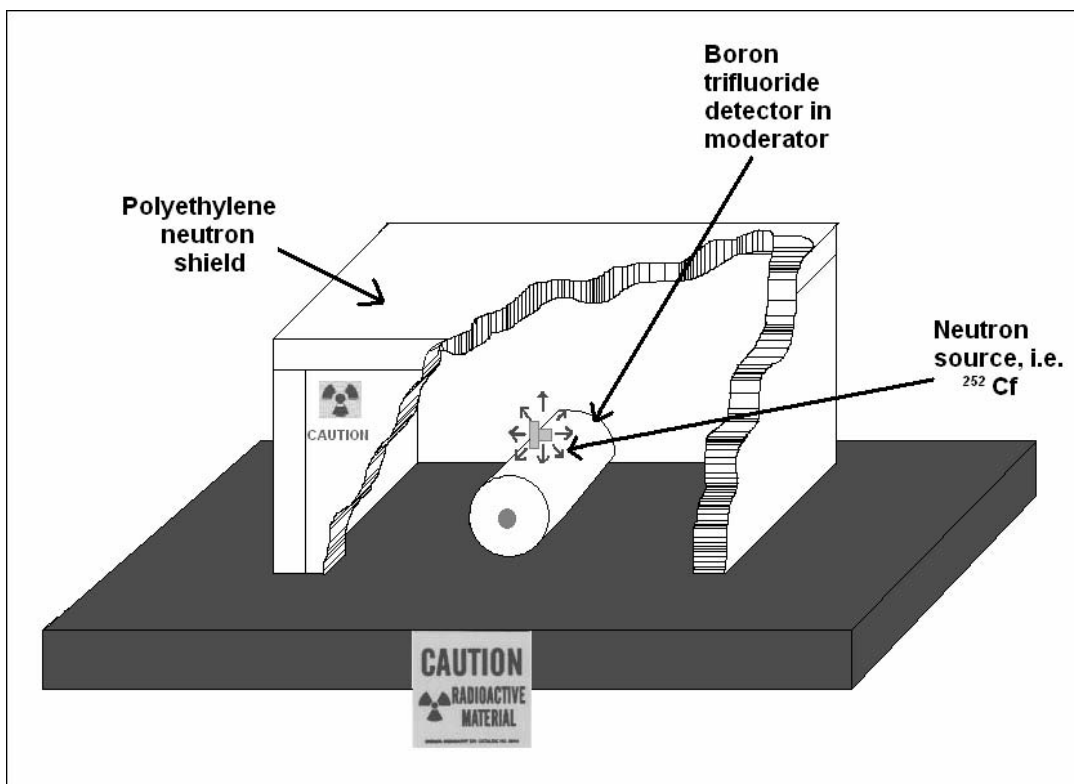


Figure 8. Plateau setup for BF_3 detector. This is a cut-away view of the inside of the shielding; the detector and source should be shielded at all times for maximum safety. No shielding is necessary on the bottom as long as the setup is sitting on a surface of high hydrogen content, such as wood. Not shown here are the wires coming out of the detector that feed the electronics.

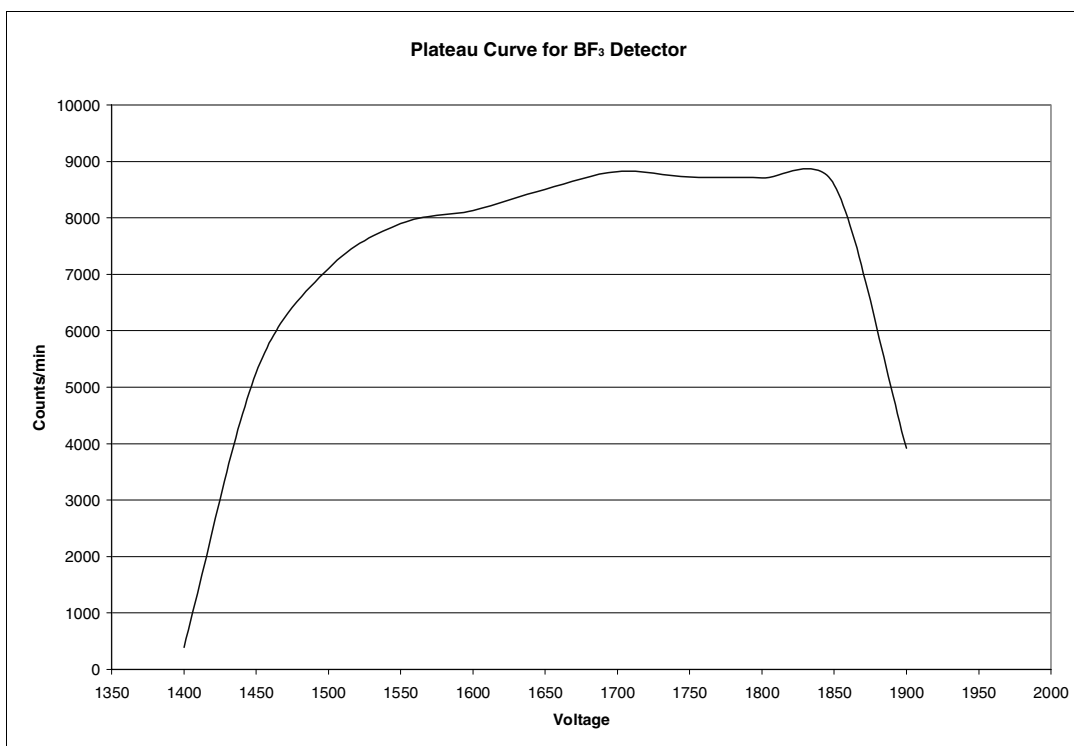


Figure 9. Plateau curve for BF_3 detector. The optimum operating voltage for this detector is 1750V.

5.2 Plotting a Discriminator Curve - BF₃ Detector Only

Plotting a discriminator curve is also important to ensure noise (gamma radiation) is filtered out of the system. The detectors must be running at their optimum operating voltage during this process. The method is the same as plateauing, but the lower level discriminator voltage is changed instead of the input voltage. The upper level discriminator is set to its maximum of 10V. The lower level discriminator voltage ranges from 0 to 10V; data points should be taken in intervals of 0.5V. After all data points are taken, a plot of counts per minute versus discriminator voltage is generated. There will be a region on the graph where counts per minute is independent of discriminator voltage (the flat region). The optimal discriminator voltage is at the higher end of the flat region. The discriminator setting for all BF₃ detectors is at 2V (with a gain of 50x2.5), as shown in Table 1a. An example of a discriminator curve is shown in Figure 10. A step-by-step explanation of generating a discriminator curve is given in Appendix 8.

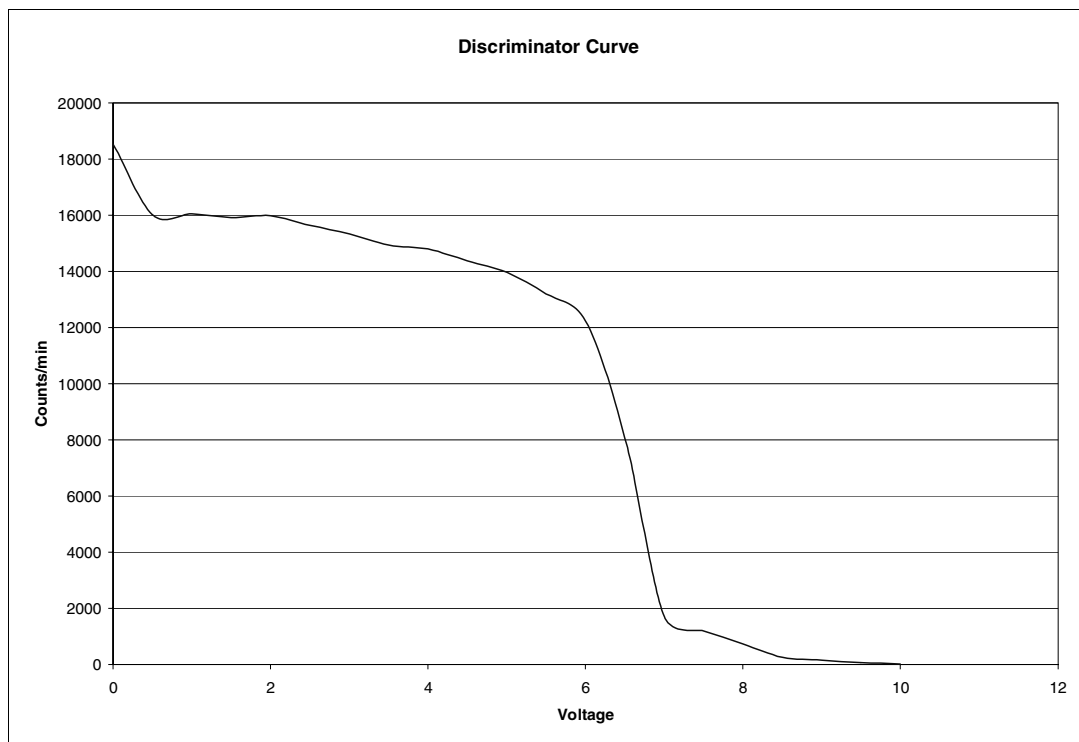


Figure 10. Example of a discriminator curve for BF₃ detector. The discriminator voltage for this linear amplifier should be set at 2V.

5.3 Establishing a Background Count

After the operating voltage and discriminator settings are set, a background count must be established. This is done (in the field at the station where it will be operating) by removing all radioactive sources and running the detector for five minutes at its operating voltage; the number of counts should then be recorded. This process should be repeated at least five times and the average background count calculated. As an informal check on the operation of the detector,

this background count may be compared with pre-established background counts. Tables 1a and 1b list background counts for all stations and summarize the operating parameters of all detectors in the PMSs.

Using different sized GM detectors yields different ranges of values for background counts. During the course of this project, all preexisting GM detectors (5" length) were replaced with longer tubes (10" length). Naturally, this increases the number of background counts registered by the detector due to the higher volume of the 10 inch tube. To verify the new background counts, the GM detector in PMS4 was analyzed; it was operated at different voltages on the plateau and also with different electronics. Background measurements were taken and were found to be in agreement with each other.

6.0 DOSE RESPONSE CALIBRATION

6.1 Calibration of Detectors Using Radioactive Sources

Prior to calibrating any PMSs, certain standard operating procedures must be followed. The Radiation Environmental Protection (REP) Manager must be notified before calibration begins. He/she has useful information such as of the location of environmental TLDs that may be in the vicinity of the PMS to be calibrated. The REP Manager may also have special concerns regarding the calibration in order to protect the public from overexposure. Environmental TLDs must be removed from each station (and any surrounding areas) to avoid miscalculation of radiation levels in SLAC's environment. Immediately after calibration and removal of all sources, environmental TLDs must be placed back into the PMS from which they came.

The main goal of calibration is to establish the dose response of the detector. Dose response is the relationship between signals (counts/minute) and the dose equivalent rate (mrem/h). The detectors should be calibrated annually and also after any repairs or modifications to the electronics. Calibration consists of placing a radioactive source at a fixed distance from the station to obtain a reading at MCC corresponding to counts per second. If the PMS does not have a local scaler/counter, one should be brought out to the station to check for consistency with MCC. NIST certified sources must be used because they are pre-calibrated and their strength in Curies is known. Both BF₃ and GM detectors are sensitive to the energy of the incident radiation; however, this trend must only be considered when calibrating the BF₃ detectors. Energy dependence is accounted for by using five types of neutron sources all with different energies. The five types of neutron sources that are usually used are ²³⁸PuBe, ²³⁸PuB, ²³⁸PuF₄, ²³⁸PuLi and ²⁵²Cf. All five sources are used to calibrate the first detector. Since the relative energy-dependent sensitivity depends on moderator thickness, all BF₃ detectors should have the same relative energy dependence. Therefore, every PMS thereafter requires only one source to be used and the same relative energy-dependent curve is assumed. See Section 6.3 for a instructions on the calibration process for BF₃ detectors. The response of the GM detector only depends on the energy of the incident radiation below 100 keV; since SLAC produces a gamma spectrum above 100 keV, only one source (¹³⁷Cs) must be used. A test for valid calibration (to be performed monthly and after calibration) is to place a check source on the detector in a reproducible geometry and ensure that the number of counts has not changed.

6.2 GM Detector Calibration

During GM calibration, the response of the detector is determined by comparing the number of counts per minute registered by the detector to the absolute dose rate of the incident radiation. A RADCAL (model 9010) Radiation Monitor Controller is used during calibration since it is a secondary standard; this device is NIST calibrated annually to provide accurate dose rate measurements. When the gamma source is obtained, a dose rate measurement at a specific distance (usually one meter) is established by using the RADCAL monitor (see Figure 11). Next, the GM tube to be calibrated is irradiated (in its PMS) with the same source at the same distance and the number of counts is recorded (the distances need not be the same, however calculations are easier if the distances are equal). To determine the response of the detector, number of counts per mrem must be calculated. This is essentially comparing the number of counts registered by the detector to the absolute dose rate measured by the RADCAL device, thereby determining the sensitivity of the detector. See Appendix 9 for detailed instructions and calculations for the calibration of GM detectors.

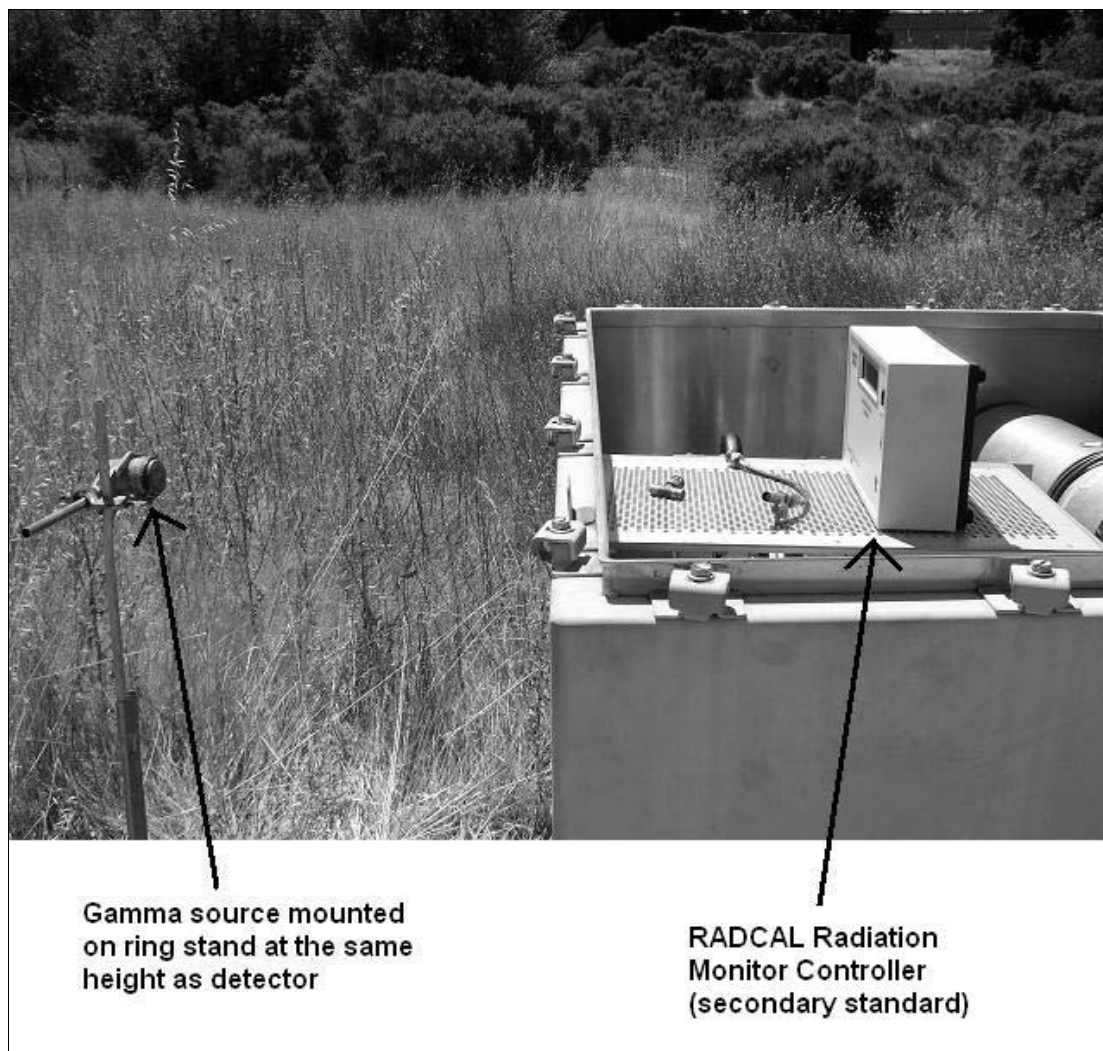


Figure 11. GM calibration setup. The chamber of the RADCAL device is not shown because it is inside the PMS at the same level as the GM detector.

6.3 BF₃ Detector Calibration

Calibration of the BF₃ detectors is more complicated since neutron scattering must be taken into consideration. Neutron scattering can be modeled by picturing another source, called the image source, underground at the same distance as the height of the real source. Figure 12 depicts the relationship between the actual source and the image source. Neutrons incident to the ground scatter and appear to come from this image source. Due to the complexity of neutron scattering, the direct dose equivalent rate and the scattered dose equivalent rate must be accounted for during calibration (see Appendix 10 for a detailed explanation of how to calculate both the direct and scattered dose equivalent rates).

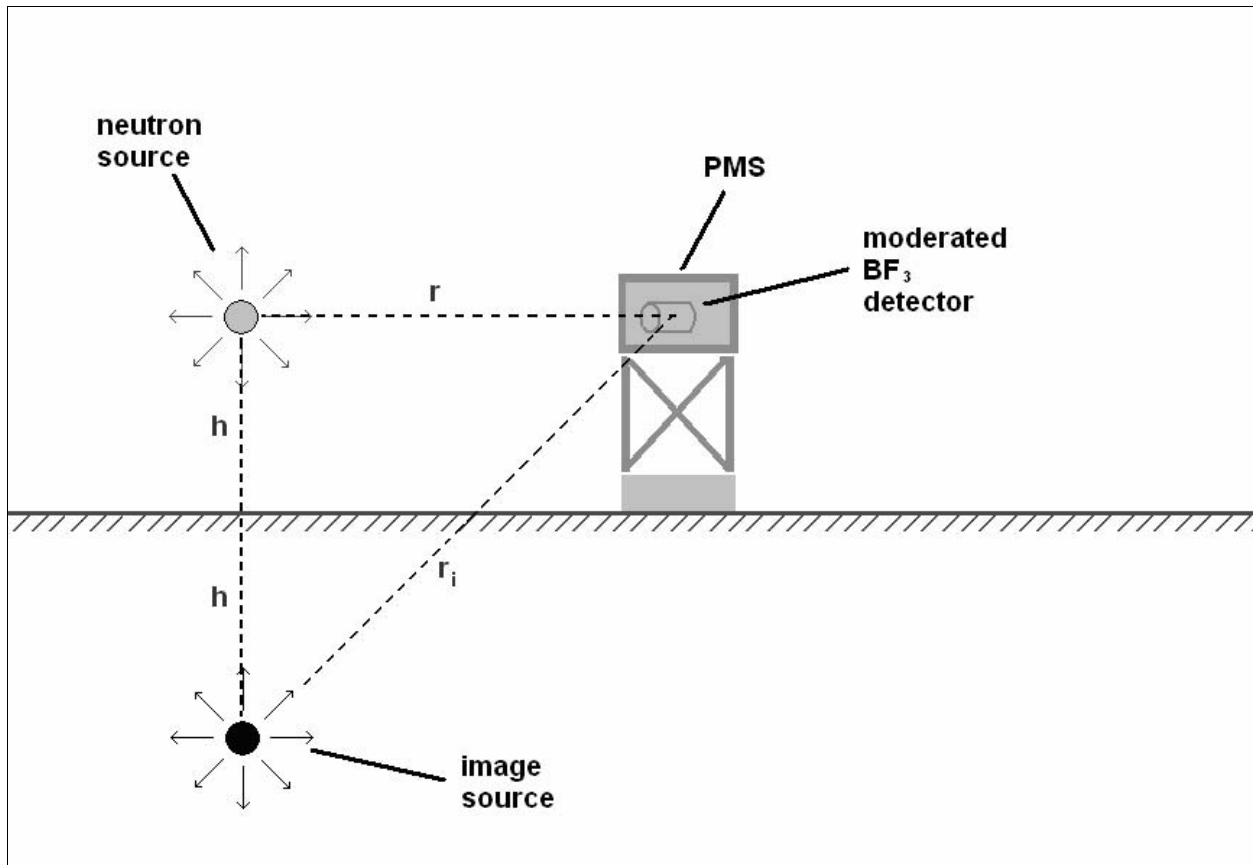


Figure 12. Illustration of actual source and image source during irradiation of BF₃ detector for calibration. The h , r , and r_i are parameters used in the calculation of the scattered and dose equivalent rates (see Appendix 10 for calculations).

Determining the response of the BF₃ detector for a single source is insufficient for calibration purposes since the response of the detector is dependent on the energy of the incident neutron. Therefore, five neutron sources with different average energies are used. Table 2 contains the current specifications on these sources. The dose rate is calculated and compared to the amount of counts registered by the detector. All five sources with different energies are used for the first PMS and the response versus energy curve is plotted. For all other PMSs, only one neutron source needs to be used; the response-energy relationship is assumed to be the same. The end result is a series of parallel exponential decay curves.

Table 2. Current neutron source data as of August 1, 2004.

Source	ID	Isotope Activity (Ci)	Emission Rate, N(s ⁻¹)	Aniso. Factor, F	Ave. Energy, (MeV)	ICRP-21 h ₀ (Sv cm ²)	H _d at 1m (mSv h ⁻¹)	H _y H _n
²⁵² Cf	---	---	1.18x10 ⁷	1.11	2.2	3.3x10 ⁻¹⁰	0.125	0.048
PuBe	N205	6.68	1.57x10 ⁷	1.09	4.3	3.9x10 ⁻¹⁰	0.191	0.053
PuBe	N206	0.32	7.59x10 ⁵	1.06	4.3	3.9x10 ⁻¹⁰	0.010	0.053
PuB	N204	22.6	2.61x10 ⁶	1.08	2.7	3.9x10 ⁻¹⁰	0.032	0.047
PuF ₄	N202	57.4	7.16x10 ⁶	1.07	1.4	3.4x10 ⁻¹⁰	0.075	0.083
PuLi	N203	64.9	2.15 x10 ⁶	1.07	0.5	1.8x10 ⁻¹⁰	0.012	0.400

During the calibration of BF₃ electronics, one major problem may be encountered. When using very strong sources with high emission rates, the lines to MCC tend to become saturated. Saturation is due to the detector sending out more pulses than the 600Ω cable is capable of transmitting. This problem is easily observed when checking MCC and the local scaler for consistency (MCC will display much less counts than the local scaler). Figure 13 is an MCC printout from an actual calibration where this occurred. Table 3 shows the local scaler readings that were obtained during this calibration. An easy resolution to this problem is to increase the distance from the neutron sources to the detector, or use local scaler counts when calculating the detector response. If local scaler counts are used, MCC must still be verified for consistency by using a check source and comparing local scaler counts to counts at MCC.

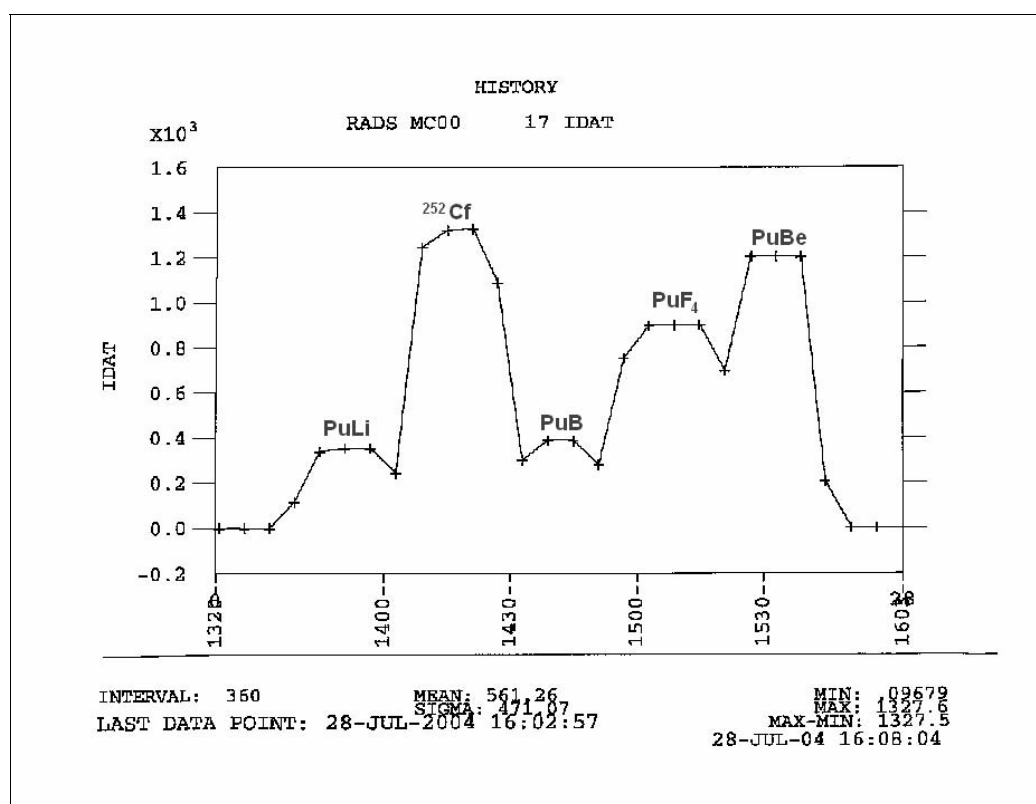


Figure 13. MCC printout from BF₃ calibration (source identifications were superimposed onto the graph). It is not obvious from the graph that the lines were saturated; however, upon comparing the values to local scaler readings (Table 3), it becomes apparent.

Table 3. Comparison of local scaler readings to MCC to exhibit saturation. Percent difference is calculated assuming that the local scaler is correct.

	PuLi	²⁵² Cf	PuB	PuF ₄	PuBe
Local scaler (cps)	426	2930	468	1468	2438
MCC	354	1328	388	902	1205
% difference	17%	55%	17%	39%	51%

6.4 Current Calibration Results

Table 4 shows the local scaler readings obtained during GM and BF₃ (PuLi only) calibration. Table 5 shows the parameters used for calculating detector response for BF₃ detectors using PuLi. All PMSs were calibrated in August 2004 and the results are shown in Table 6. Table 6 only lists BF₃ detector response for PuLi. Refer to the response vs. energy curve in Figure 14 to determine BF₃ detector response for neutrons of different energies. Subsequent to calibration, local scaler readings should be compared to MCC readings to ensure that data is being recorded properly. Table 7 shows an example of this for the BF₃ calibration of PM3.

Table 4. Local scale readings (cpm) obtained during calibration. High number of counts for some stations is attributed to smaller values of r (detector to source distance).

	PMS1	PMS2	PMS3	PMS4	PMS5	PMS6	PMS7
BF ₃ (PuLi)	7900		20438	5116	5377	7108	6635
GM	2180			1740	1816	13520	1761

Table 5. Parameters used for calculating BF₃ detector response (PuLi). mrem/h

Station	H _d	H _s	H _T	r _i	r	h	R (response)
PMS1	0.003	0.000186759	0.00318676	3.073181486	2	1.166666667	1487479.897
PMS2	0.003	0.000186759	0.00318676	3.073181486	2	1.166666667	1343182.824
PMS3	0.012	0.000788705	0.0127887	3.333333333	1	1.166666667	1234070.224
PMS4	0.003	0.000186759	0.00318676	3.073181486	2	1.166666667	963198.0224
PMS5	0.003	0.000186759	0.00318676	3.073181486	2	1.166666667	1012414.169
PMS6	0.003	0.000186759	0.00318676	3.073181486	2	1.166666667	1338362.88
PMS7	0.003	0.000186759	0.00318676	3.073181486	2	1.166666667	1249193.917

Table 6. Calibration results, as of August 2004.

	PMS1	PMS2	PMS3	PMS4	PMS5	PMS6	PMS7
BF ₃	Response (PuLi)	1487480	1343182	1234070	963198	1012414	1338363
	Bkg (cpm)	9.4		7.2	6.3	4.5	9
	Check source (AmBe)	52469	59713	52139	38584	59876	54991
GM	Response (¹³⁷ Cs)	398940	252261	352463	318428	332371	285539
	Bkg (cpm)	72.2	55	75	63	56	87
	Check source (⁶⁰ Co)	1659	1868	1606	1523	1512	1624

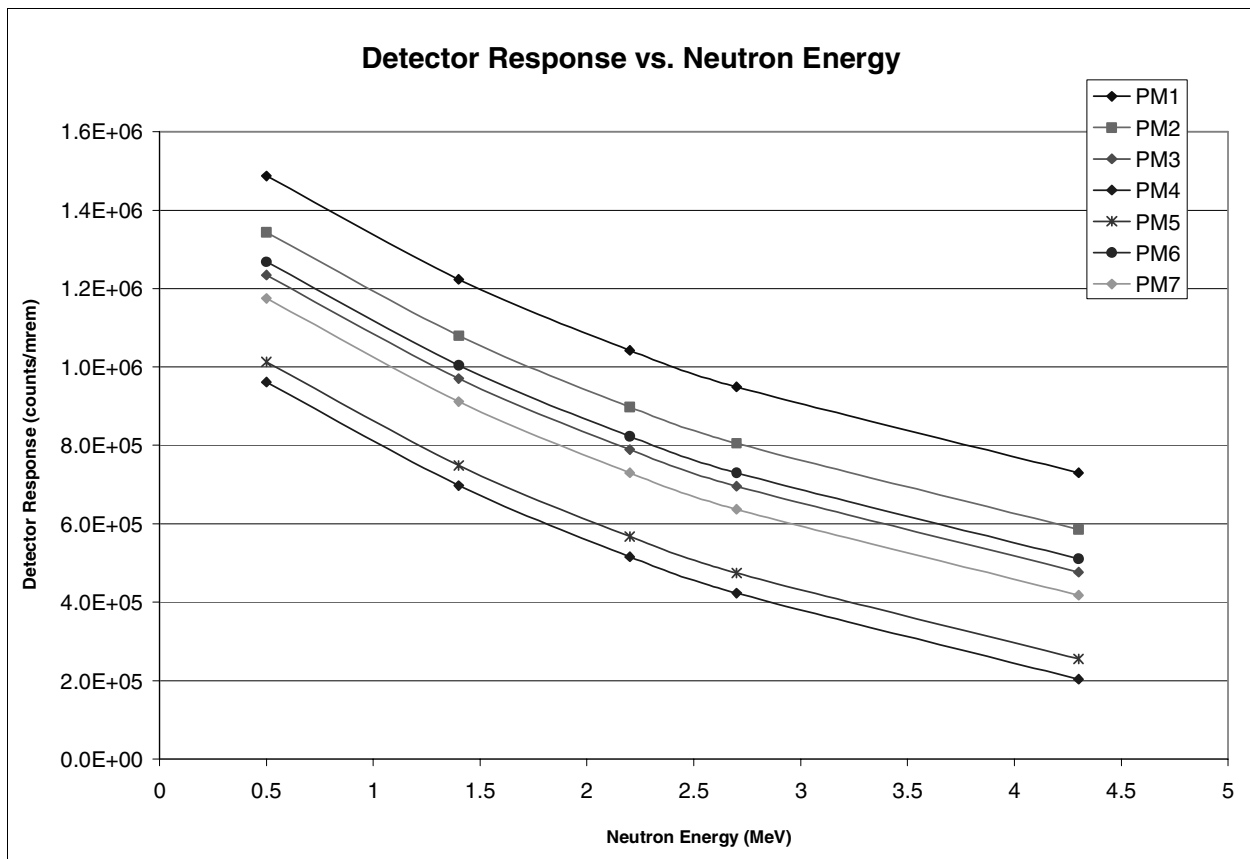


Figure 14. Detector response vs. energy curve for BF₃ detectors in all PMSs.

Table 7. Scaler and MCC readings for the BF₃ calibration of PM3.

	Local scaler	MCC	% difference
BF ₃ (PuLi)	26304	24120	8.3

APPENDIX 1 - GPS Coordinates of Peripheral Monitoring Stations

Station	Latitude	Longitude
1	37° 24.987' N	122° 12.063' W
2	37° 25.238' N	122° 11.802' W
3	37° 25.078' N	122° 11.601' W
4	37° 24.907' N	122° 11.723' W
5	37° 24.822' N	122° 11.933' W
6	37° 24.978' N	122° 12.970' W
7	37° 25.145' N	122° 12.501' W

APPENDIX 2 - Circuit Layout of MCC CAMAC Crates

HP: CAMAC LAYOUT

9529 SCALER CAMAC CHANNEL		9538 DISCRIMINATOR NIM CHANNEL		9529 TTI/NIM CAMAC CHANNEL		MC00-04 SAM S02		16-CH 9519	
S03	00	NIM S02	01	S08	01		00		S20AM
	01		02		02		01		AMS
	02		03		03		02		AMN
	03		04		04		03		AM3
	04		05		05		04		AMAC
	05		06		06		05		AMBC
	06		07		07		06		BDE
	07		08		08		07		AMB-BTR
	08	NIM S03	01		09		08		SPARE
	09		02		10		09		SPARE
	10		03		11		10		SPARE
	11		04		12		11		SPARE
S04	00		05		13		12		SPARE
	01		06		14		13		SPARE
	02		07		15		14		SPARE
	03		08		16		15		SPARE
	04	NIM S04	01		17				
	05		02		18				
	06		03		19				
	07		04		20				
	08		05		21				
	09		06		22				
	10		07		23				
	11		08		24				

SCALER CAMAC CHANNEL		TTI/NIM CAMAC CHANNEL		9513 TB18	
S09	00	A1,A2	01	PM4-REM	01 02
	01	A3,A4	02	AMB-BTR	03 04
	02	A5,A6	03	PM7	05 06
	03	A7,A8	04	PM7	07 08
	04	A9,A10	05	PM7	09 10
	05	A11,A12	06	FTB001	11 12
	06	A13,A14	07	FTB002	13 14
	07	A15,A16	08	FTB110	15 16
	08	B1,B2	09	FTB224	17 18
	09	B3,B4	10		19 20
	10	B5,B6	11		
	11	B7,B8	12		
		B9,B10	13		
		B11,B12	14		
		B13,B14	15		
		B15,B16	16		
			17		
			18		
			19		
			20		
			21		
			22		
			23		
			24		

9513 TB17	
FTB110	01 02
FTB224	03 04
FTB001	05 06
FTB002	07 08
PM7	09 10
PM7	11 12
PM7	13 14
	15 16

APPENDIX 3 - Accessing PMS Data on a Regular PC Using X-Windows

An MCC VMS (Virtual Memory System) account and password must be obtained before access to PMS data is allowed. An account may be acquired by dialing extension 3515 and submitting the required documentation. The computer from which data will be accessed must be equipped with X-Windows and Tera Term Pro SSH, both available from the Knowledge Management Department.

1. Start X-Windows

Some computers automatically start X-windows. Check the taskbar at the bottom right side of the screen for the “X” icon. If the icon is there, X-Windows is already started (proceed to step 2).

1.1 Click the start button.

1.2 Click the tab labeled “X-Win 32”.

2. Start Tera Term

2.1 Click the start button.

2.2 Click the tab labeled “Tera Term Pro SSH”.

2.3 A window will pop up with a text box that says “flora.slac.stanford.edu”.

Change the word “flora” to “mcc”, and then click “OK”.

2.4 Press “Continue” on the security warning window.

2.5 Input your username and passphrase into the active window.

3. Log in to MCC VMS

3.1 At the prompt labeled “MCC>” type in “scp x *your username*”. The program will begin to load (this may take a minute).

Once the program loads, four windows will pop up. The one on the right, labeled “TP CALF91”, is a menu window; this is used this for navigating within the system. The window on the left, labeled “GRAPHICS CALF91”, is for displaying data such as graphs, raw data, etc. The one on the bottom, labeled “MESSAGES CALF91” is for global, input, and local messages. The last window, labeled “KNOBS CALF92”, is irrelevant for viewing PMS data but must remain open while accessing the system.

4. Access PMS Data

4.1 Click “SPECAL DISPLY” under the Display Functions submenu at the bottom of the menu window.

This pulls up the “Radiation Monitoring History Plots” menu. All PMS data is accessible from this menu. Every channel from each PMS has its own button; i.e. the three PMS1 channels are labeled “PM1 GAMMA”, “PM1 NEUTRN”, and “PM1 REM”. The same convention is used for all other PMSs, except for PMS6, which has channels are labeled “20PM6 GAMMA”, “20PM6 NEUTRN”, and “20PM6 REM”. In some cases, the REM channel was used to transmit data from the PMSs until the original channels were repaired.

The graphs of PMS data are automatically scaled; however, it may sometimes be necessary to change the scaling for better interpretation.

5. Changing the scale of the graphs.

5.1 Once you have the desired graph displayed on the monitor, click “HIST PLOT PANEL” in the right corner.

5.2 Select the time interval with which you would like to view the graph.

In addition to viewing graphs of PMS data, it is also possible to view the raw data points.

6. Viewing raw data.

6.1 When the graph of the station/channel is displayed, click the button labeled “Disply Plot Data” to see the raw data corresponding to the graph.

7. Printing graphs and/or data.

7.1 Click “PRINT Graph Display MCCPRINT” in the upper right corner.

The graphs and/or data will be printed out at MCC. A menu exists that allows the user to change the active printer, however, there are a limited number of active printers. In order to locate the printer nearest you, contact Aaron Bator at extension 4584.

8. Changing the active printer.

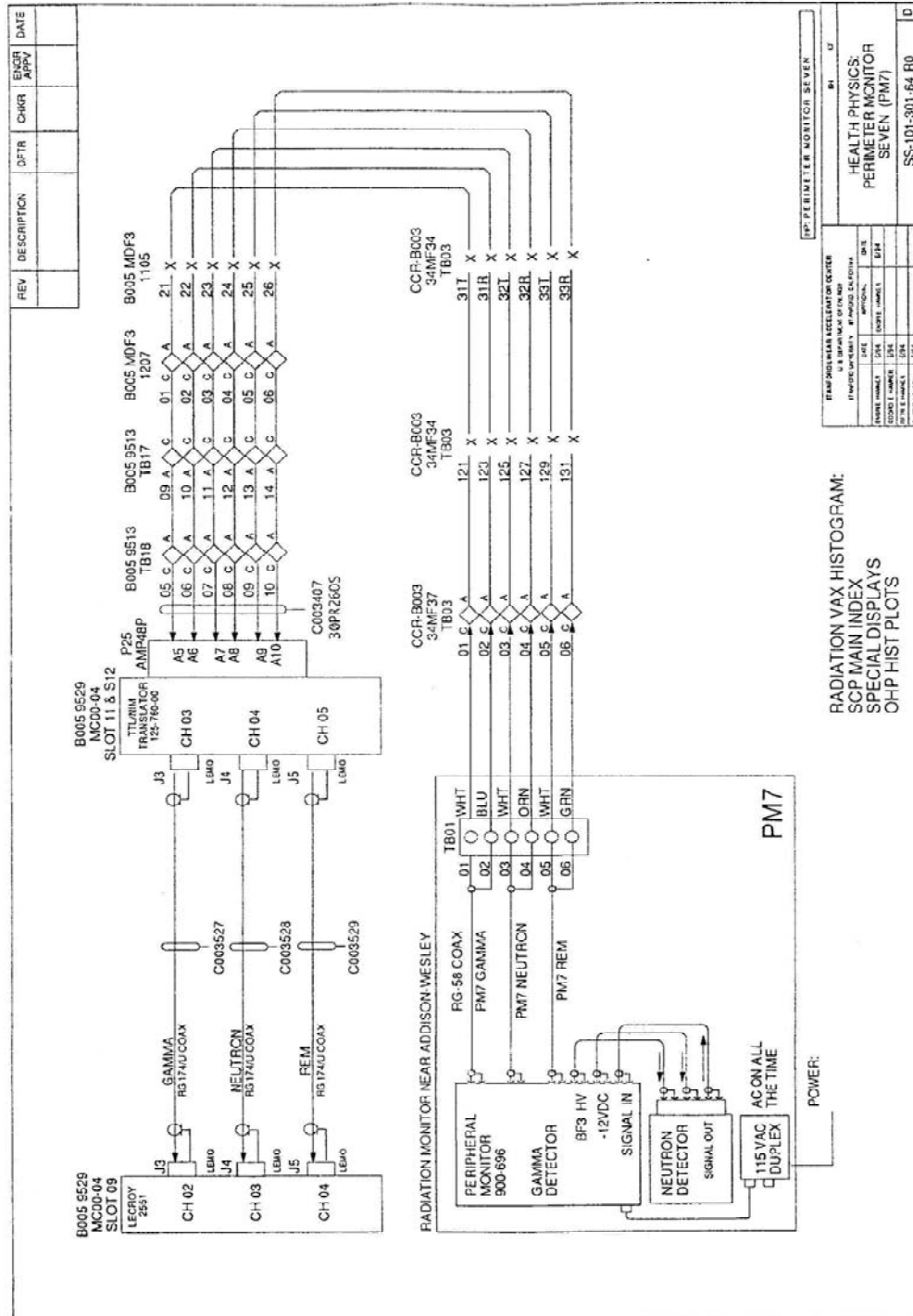
8.1 Click “INDEX” in the upper right corner to pull up the main menu.

8.2 Click “Print Cntrl Panel” in the bottom left corner. There are four print control panels that may be toggled through using the four buttons at the top of the menu.

8.3 Select which printer you want to use and it becomes the active printer.

Remember that every time the program is restarted, the printer setting must be changed, otherwise all printouts will be sent to MCC.

APPENDIX 4 - Complete Schematic of PMS7



APPENDIX 5 – Step by Step Troubleshooting Guide

This appendix is designed to help troubleshoot problems that may arise with the PMS electronics. A systematic method to isolate and repair problems is described. Due to the complexity of the electronics, there are many problems that require training in electrical engineering and circuit design to identify and repair; such problems are beyond the scope of this paper.

WARNING: EXERCISE EXTREME CAUTION WHEN WORKING WITH HIGH VOLTAGE ELECTRONICS DUE TO THE RISK OF DEATH BY ELECTRIC SHOCK.

Symptom: A data readout at MCC shows no signal on a channel in one of the PMSs.

Problem: There is a problem with the detector, NIM electronics, or connection to MCC.

Solution: Check to see if all channels in that PMS are down. If this is the case, verify the PMS is properly powered and that the CAMAC crate receiving the signals is working properly.

1. Verify the connection to MCC.

To verify cable integrity, a pulse generator should be connected to the malfunctioning channel in the PMS going to MCC. The pulse generator should be adjusted to simulate the exact signal from a working line driver.

1.1 Simulate line driver signal with pulse generator.

To make the pulse generator simulate a line driver signal, connect both the output of a working line driver and the pulse generator to different channels on an oscilloscope. Adjust the pulse generator so that the signal has the same duration and amplitude of a line driver generated pulse (approximately 0.5 ms pulse width and a 4V signal).

1.2 Connect pulse generator to channel in question.

After adjusting the pulse generator, connect it directly to the malfunctioning line in the PMS that goes to MCC. The pulse generator will act as mock data being taken.

1.3 Verify consistency of data at MCC.

Check the readouts on a PC to see if data is being recorded (see Appendix 3, “Accessing PMS Data on a Regular PC Using X-Windows”).

If no data is seen at MCC, there is a problem with either the communication lines to MCC or the CAMAC crate where data acquisition occurs. Such problems are beyond the scope of this paper.

If data is seen at MCC, this means there is a problem with the detectors and/or electronics in the actual PMS. Proceed with troubleshooting (see Section 2 of this appendix).

2. Verify that the detectors are working properly.

To verify that the detectors are working, they must be taken out of the PMS and plugged into a working setup. Make sure to power down the stations before removing or replacing any electronics or detectors. Since this is only a test for functionality, a radioactive source can be used to ensure the detector is working, but there is no need to calibrate or test it for accuracy.

2.1 Check to ensure detector is sensing radiation.

Connect the detector in question to a known working setup in the lab. Properly connect all power and signal cables prior to turning the electronics on. Connect the output of the line driver to a scaler or oscilloscope. Test to see if the detector is sensing background radiation or use a weak radioisotope to test it.

If the scaler displays counts, then the detector must be working and there must be a problem with the electronics (in the original PMS) that process the signal and send it to MCC. Proceed with troubleshooting.

3. Verify that the electronics are working.

At this point in the troubleshooting, the electronics have been isolated as the source of the problem with the PMS. This section will be divided to account for the two different circuits in place (one for the BF_3 and ^3He detectors, one for the GM detector).

WARNING: EXERCISE EXTREME CAUTION WHEN WORKING WITH HIGH VOLTAGE ELECTRONICS DUE TO THE RISK OF DEATH BY ELECTRIC SHOCK.

3.1 GM detector electronics.

This circuit consists of a high voltage power supply, NIM bin and a line driver. Always make sure the line driver, NIM bin, and high voltage supply for the detector are off whenever work is performed on the module. Always complete any repairs or exchanges and correctly reconnect all cables before powering the module.

3.1.1 Verify functioning of the power supply.

Verify that the power supply is properly functioning by adjusting and measuring its output with a voltmeter. If the power supply is malfunctioning, replace it with one that works. Once the power supply is changed, test to see if MCC is recording data. If it is, the troubleshooting is done. If it is not, continue with trouble shooting.

3.1.2 Test line driver NIM.

Setup the line driver module to be tested. To monitor progress while testing it, connect the output of the line driver through a 600Ω isolator into an oscilloscope. The line driver module should be mounted onto an Ortec EX100/N extender module to facilitate working on the module while testing

(see Figure A1). Plug a working GM tube into the line driver and, if desired, expose it to a weak gamma source to test it while troubleshooting.



Figure A1. GM and Line Driver module mounted in an Ortec EX100/N extender module. The extender module is used for easily accessing the circuit components during the testing phase of troubleshooting.

Due to the design of the circuit, the least tolerant parts of the line driver are the Texas Instruments TI 75159 line driver chip and TI 74121 timing chip, labeled as A and B, respectively, in Figure A2.

3.1.3 Replace TI 75159 chip.

Power down the detector and electronics, replace the TI 75159 line driving chip with a known working TI 75159 chip, then reconnect and re-power the setup and see if the oscilloscope has the correct readout of a 4V, $\frac{1}{2}$ ms pulse. If the module works, the troubleshooting is done.

3.1.4 Replace TI 74121 chip.

If this is not the case, the problem may be with the TI 74121 timing chip. Power down the detector and electronics, replace the chip with a known working TI 74121 chip, then reconnect and re-power the setup and see if the

oscilloscope has the correct readout of a 4V, ½ ms pulse. If the module works, the troubleshooting is done.



Figure A2. Photo of inside of GM and Line Driver module. The chip labeled “A” is the TI 75159 chip. The chip labeled “B” is the TI 74121 chip.

If neither chip replacement works, the NIM needs to be replaced or repaired by an individual who has advanced training in the electronics of signal amplification.

3.2 BF₃ detector electronics.

This circuit consists of an external high voltage power supply, a preamplifier and a linear amplifier connected to a line driver NIM. Always make sure the line driver, NIM bin, and high voltage supply for the detector are off whenever work is performed on the module. Always complete any repairs or exchanges and correctly reconnect all cables before powering the module. An initial check of the system is done to isolate the malfunctioning component(s). The pulse generator is used to simulate pulses at each different points in the system and the number of counts at various points in the circuit is verified.

3.2.1 Adjust levels on linear amplifier.

To troubleshoot the linear amplifier of the circuit in question, the levels must first be properly adjusted. Set the coarse gain to 50, the fine gain to 2.5, the lower level discriminator to 2V, and the upper level discriminator to 10V.

3.2.2 Verify proper functioning of the linear amplifier.

Connect a pulse generator simulating the signal from the preamp (0.25V, 0.5 μ s) of known repetition rate into the linear amplifier of the circuit in question. Verify the linear amplifier is working by connecting a scaler to the output on the linear amp to count the number of pulses. Compare this to the amount being sent in by the pulse generator using its known repetition rate. If the two rates are within a reasonable tolerance (5%) continue with the troubleshooting. If the rates are outside this range, replace the linear amplifier with a known working one and test the electronics. If the electronics work, the troubleshooting is finished. If the electronics do not work, continue with troubleshooting.

3.2.3 Verify proper functioning of the line driver module.

To troubleshoot the line driver, follow steps 3.1.2-3.1.5 on troubleshooting the line driver module on the GM detector electronics. However, instead of connecting a GM detector to the module, connect a pulse generator to the input set to mimic the signal coming from the linear amplifier (5V, 1 μ s pulse). Once the line driver is repaired, the trouble shooting is not complete because the whole system must be tested to see if it works.

3.2.4 Verify the line driver is reading out pulses.

Plug the working line driver into the setup and test it to see if it is sending out pulses. If it is, continue on to step 3.2.6. If the system is still not working, the problem must be with the preamp.

3.2.5 Replace preamp with a known working preamp.

Replace the preamp with a pre-established working preamp. If there is still no signal at MCC, re-troubleshoot the system or contact a person better trained in NIM electronics.

3.2.6 Verify proper functioning of PMS and lines to MCC.

The final test is to verify the whole system in the field by using a source or a pulse generator input. Check the local counts by connecting a scaler to the output of the linear amp and compare this to what is being seen at MCC. If scaler readings are not consistent with MCC, the cables to MCC and CAMAC crates must be further checked by an expert. Note that occasionally, the line driver in a station may be double pulsing. If the scaler in the PMS and the MCC readings are off by a factor of two, the line driver must be replaced or repaired before calibration (see Section 4.0, “How to Fix Double Pulsing”).

4. How to fix double pulsing

Due to a mix up in the manufacturing process of the line driver NIMs, some of the line drivers will “double pulse” or send two pulses instead of one down the line to MCC. This problem is identified easily since the data seen in MCC is roughly twice that of the input signal (i.e. from a pulse generator). It is suggested that all line drivers on all channels are checked at least once

before calibration. Because of the different electronics for the different detectors, this section is divided by the type of detector that is to be tested for double pulsing.

4.1 Double pulsing on the neutron detector.

Testing for double pulsing is easy on the neutron line driver since the number of signals coming out from the linear amplifier can be compared with the number coming out of the line driver (refer to Figure 3 for signal specifications). Connect a pulse generator simulating the signal from the preamplifier (250 mV, 0.5 μ s) to the linear amplifier for processing. Connect the output of the linear amplifier to the scaler, and take a reading for one minute and record the data. Then connect the output of the linear amplifier to the input on the line driver and connect the output of the line driver to either a 600 Ω isolator to a local scaler or to MCC and wait for the data to be recorded there. Compare the number of pulses recorded going into the line driver to the number coming out. If the number of pulses coming out of the line driver is a factor of two higher than the number coming out of the pulse generator, then there is double pulsing. Proceed to step 4.3.

4.2 Double pulsing on the GM detector.

For the GM line drivers, it is difficult to compare numbers of signals since the detector is integrated into the module. In addition to simply tracing the electronics for the problem (See Section 4.3, Fixing Double Pulsing), a test had to be designed to check for double pulsing. A special cable was designed to test the GM line driver for double pulsing which had a pulse generator compatible BNC connector on one side and a GM detector plug on the other side.

Turn off the high voltage power supply and disconnect it for the GM line driver. Connect the pulse generator to the input of the GM detector using the special cable described above. Change the pulse generator to give off negative pulses as the GM detector does. Connect the output of the line driver through a 600 Ω isolator and then to a scaler and take a one minute reading. Compare the number of counts recorded to the number of counts recorded for a one minute reading from the pulse generator only. Remember to always keep the pulse generator on positive pulses unless testing the GM detector input. If the number of pulses coming out of the line driver is a factor of two higher than the number coming out of the pulse generator, then there is double pulsing. Proceed to step 4.3.

4.3 Fixing double pulsing.

Most of the faulty modules have been located and repaired since the problem was identified. Refer to this section in case an old line driver NIM is found that may not have been repaired and is needed to be used. In addition, if more line drivers are ordered from the manufacturing department, they should be tested for this problem. The problem arises from the positive and negative output wires from the TI 75159 chip being connected backwards (positive to negative and negative to positive) to the BNC output. This inverts the pulse giving it two half-height positive edges, which are both triggered and registered as two counts for every one pulse. This is corrected by re-soldering the connections to the BNC connector in the proper order, with the positive pulse (pin 3) going to the center and the negative pulse (pin 2) going to the

ground. A schematic diagram of the circuit may be obtained from the SLAC Engineering Library Drawing Number 125-682. In addition to this modification, a 100Ω resistor was added between pin 2 and the ground on the BNC connector. This serves to protect the chip against any accidental grounding or shorting out.

APPENDIX 6 - Steps for Plateauing Detectors

If plateauing is done in the field, make sure to remove all environmental TLDs from the PMS before bringing any radioactive sources to the station. After plateauing is finished, be sure to replace all TLDs once all radioactive sources are removed.

1. Set up the detectors/electronics with radioactive source.

- 1.1** Connect the output of the line driver through a 600Ω isolator and then to a scaler to display number of counts.
- 1.2** Keep in mind that a weak source should be used (one that produces at least 2000 counts per minute). Make sure that all equipment is set up and ready for use before obtaining the source in order to reduce the amount of time exposed to the source in accordance with the ALARA policy. This means make sure that all radioactive shielding is in place (for BF_3 plateauing) and electronics are ready for use. When plateauing BF_3 detectors, place the source inside shielding and on top of the detector once it is obtained (see Figures 5 and 6 for plateau setup).
- 1.3** Turn on power supply, NIM bin, linear amplifier, and counter/discriminator (for BF_3).
- 1.4** Set scaler to count for one minute intervals.

2. Establish a lower limit voltage.

- 2.1** Manually adjust the high voltage power supply from zero until the detector just begins to count. This is the lower limit voltage; data should be taken beginning at this voltage.

3. Begin taking data.

- 3.1** Reset the scaler to take the first data point at this voltage in order to have a full minute's worth of counts.
- 3.2** Move up in increments of 50V and record number of counts at each voltage. (Maximum voltage for GM tubes is about 1500V; for the BF_3 tubes it is about 2050V. Running the detectors at voltages higher than these may result in ruining the detector.)

4. Plot the plateau curve.

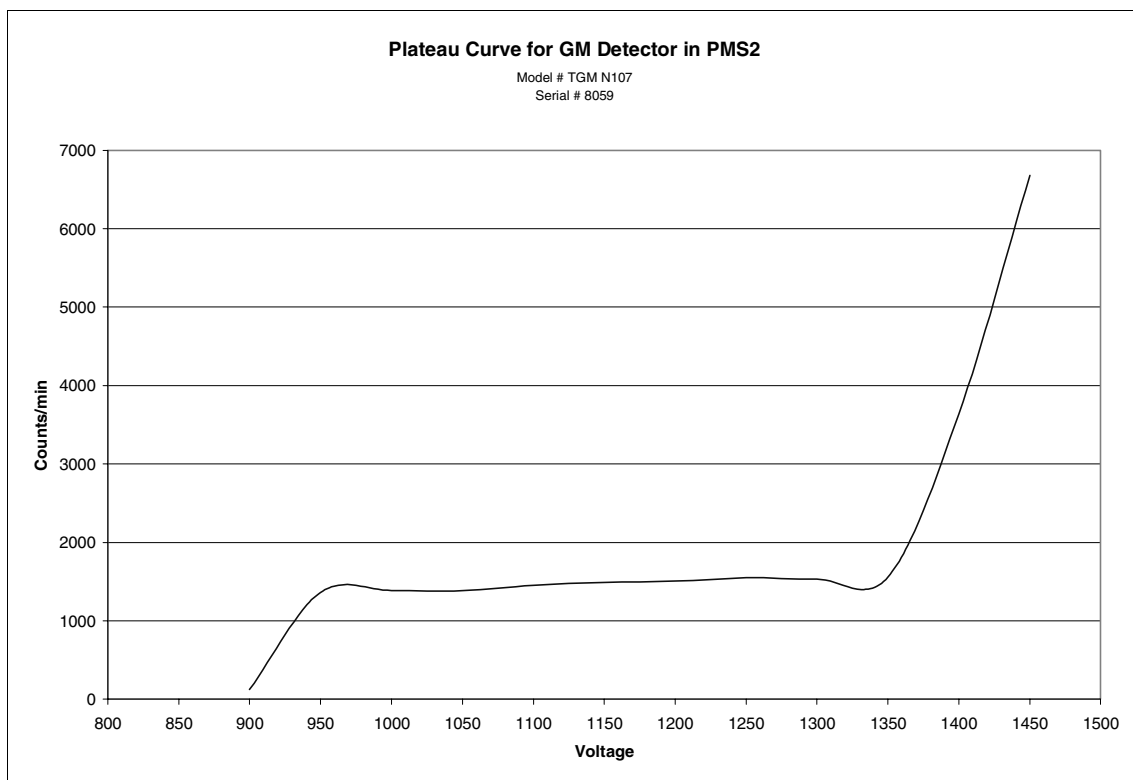
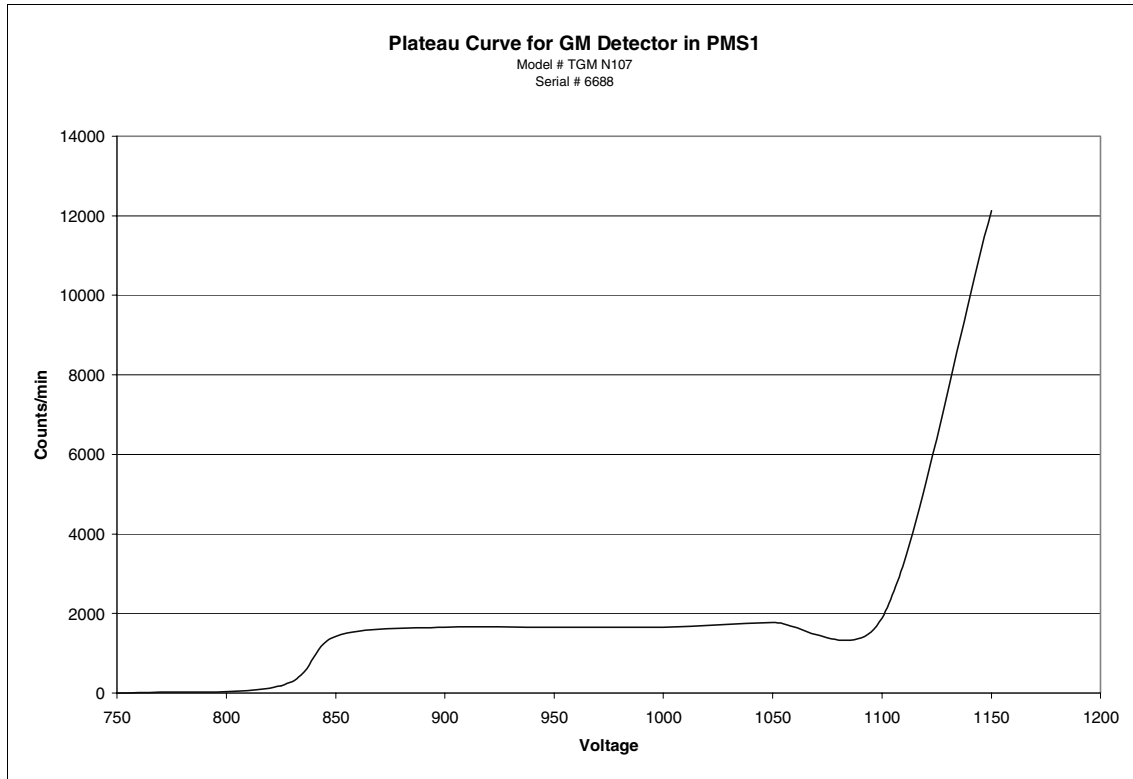
- 4.1** Once the maximum voltage is reached, the plateau curve can be plotted. Plot voltage on the x-axis and counts/min on the y-axis.

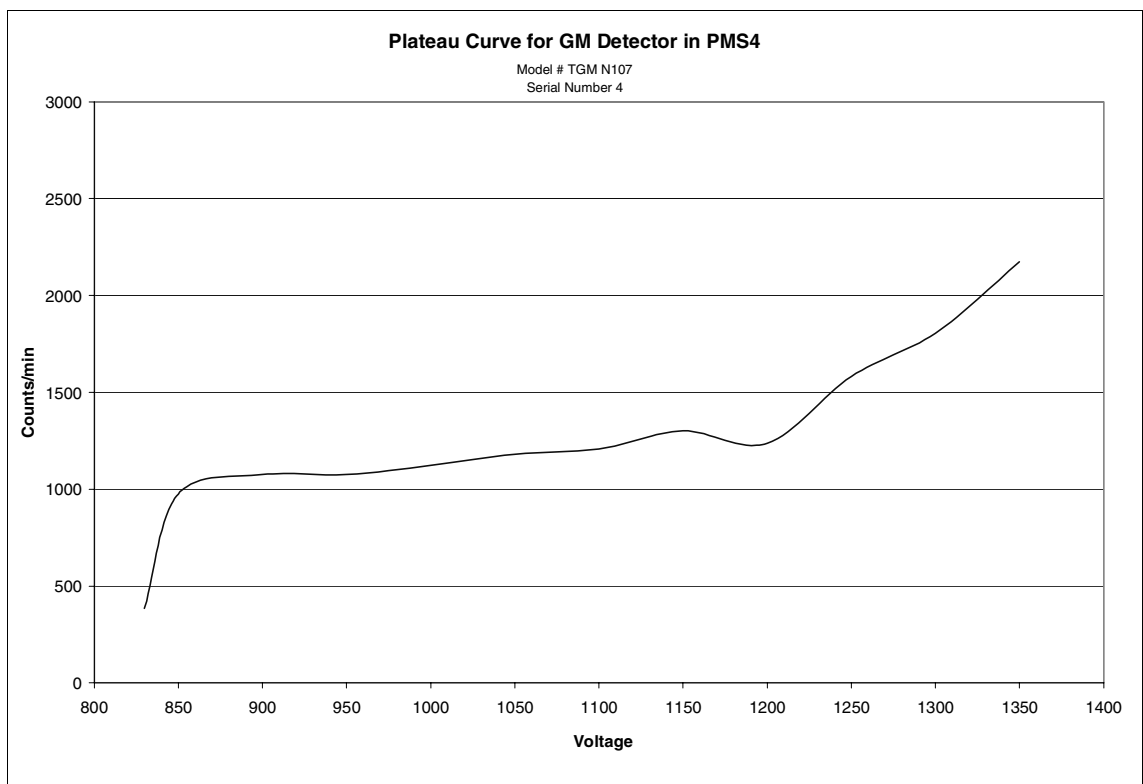
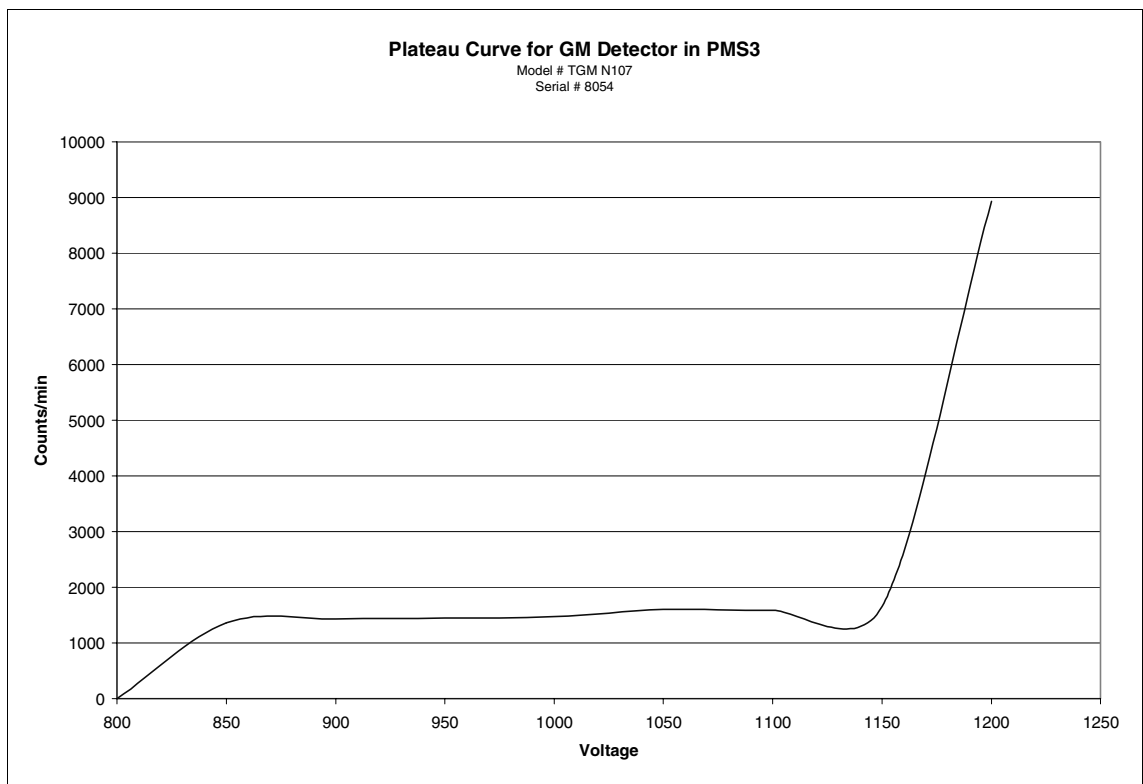
5. Determine the operating voltage.

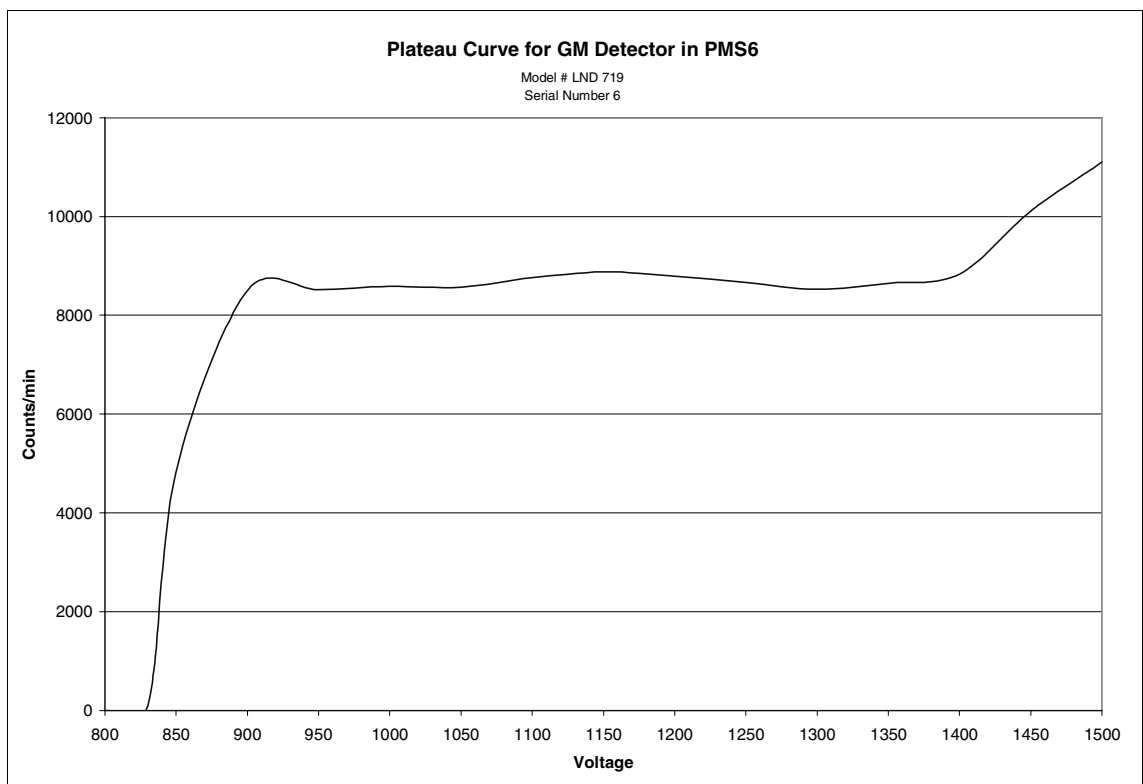
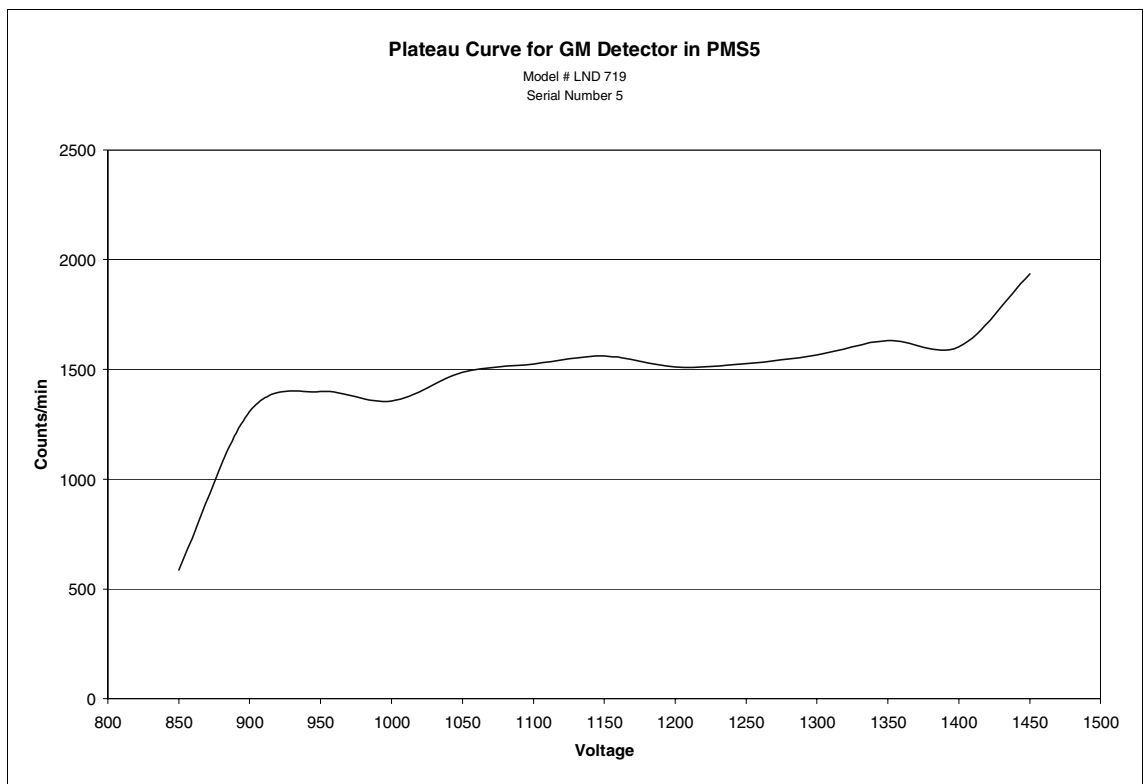
- 5.1** The operating voltage is the voltage corresponding to a point approximately a third of the way across the plateau.
- 5.2** Record this voltage along with the serial number of the detector since this operating voltage is specifically for that detector.

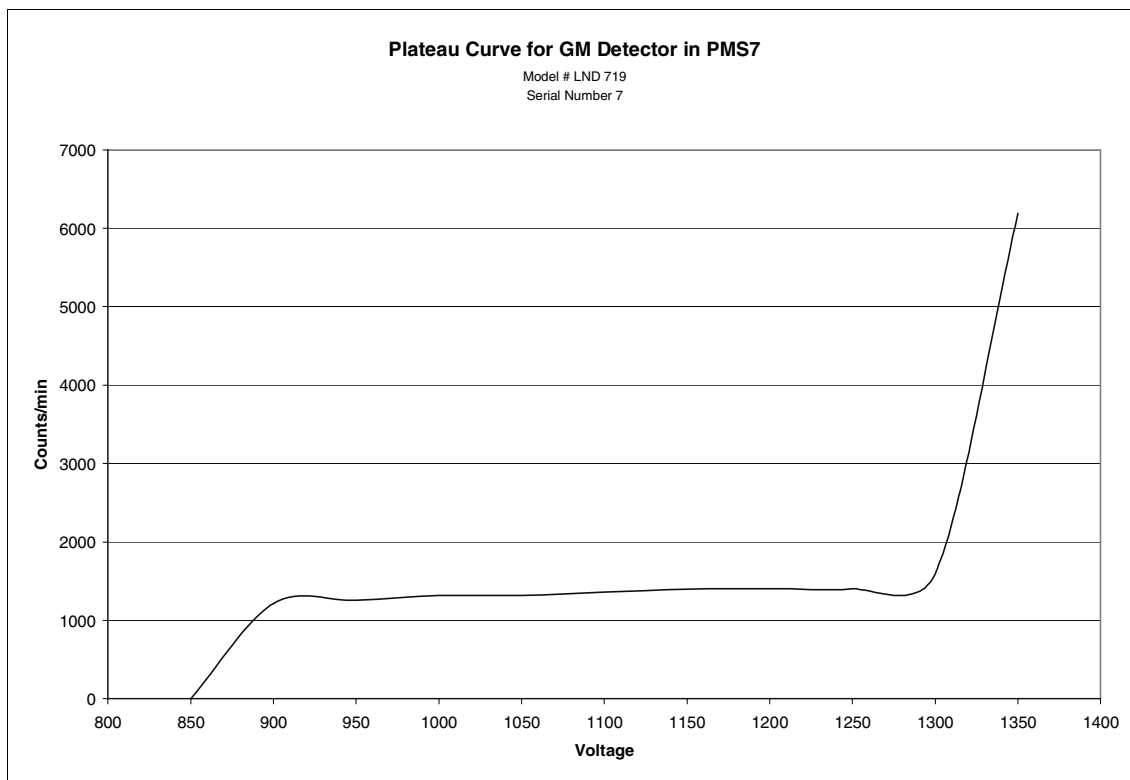
APPENDIX 7 - Plateau Curves for all Stations

I) GM Detectors

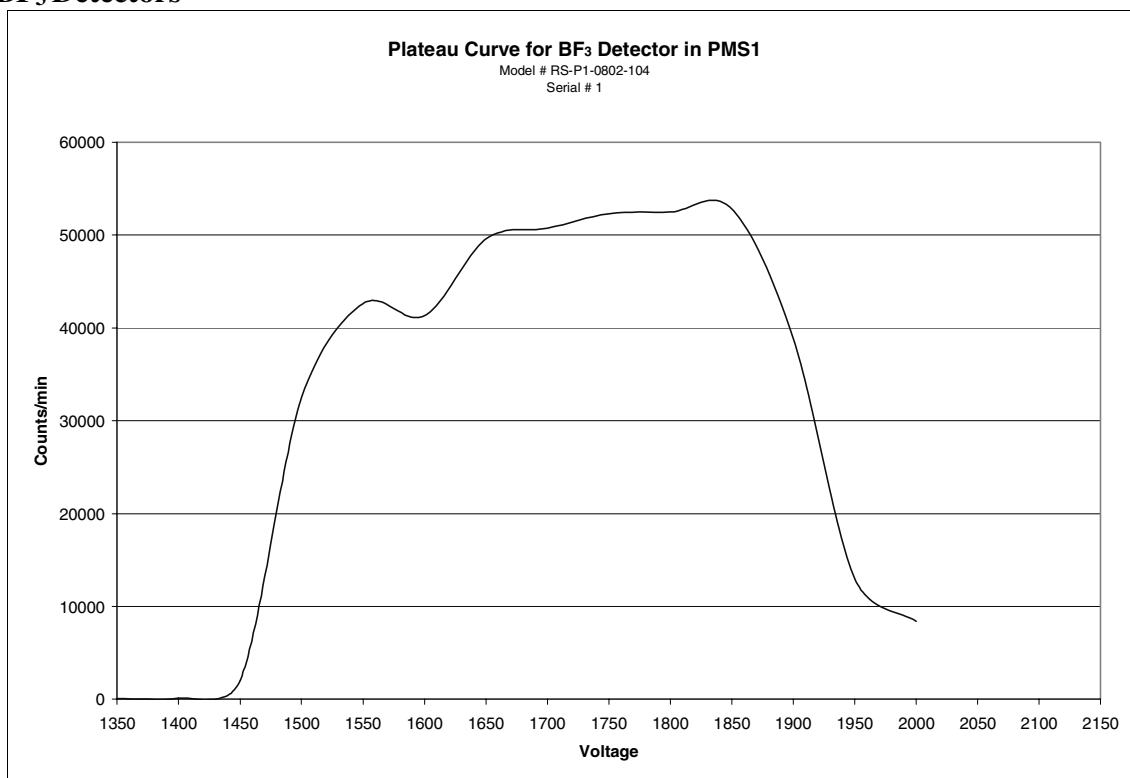


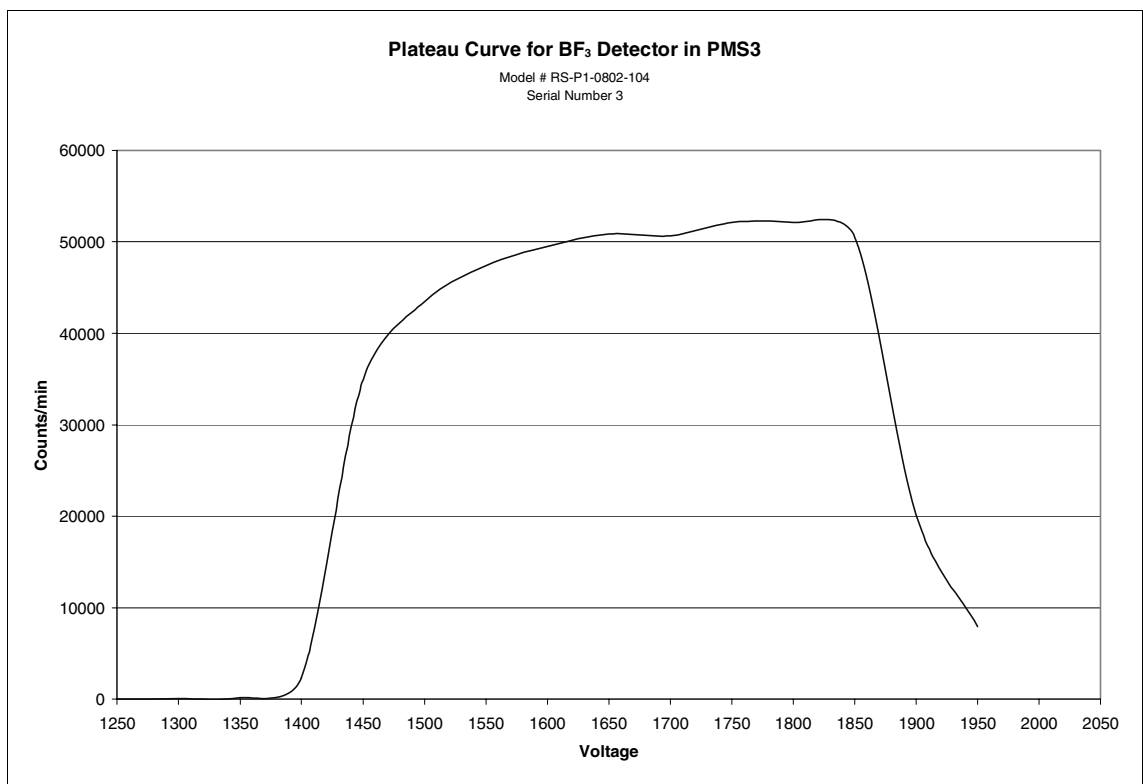
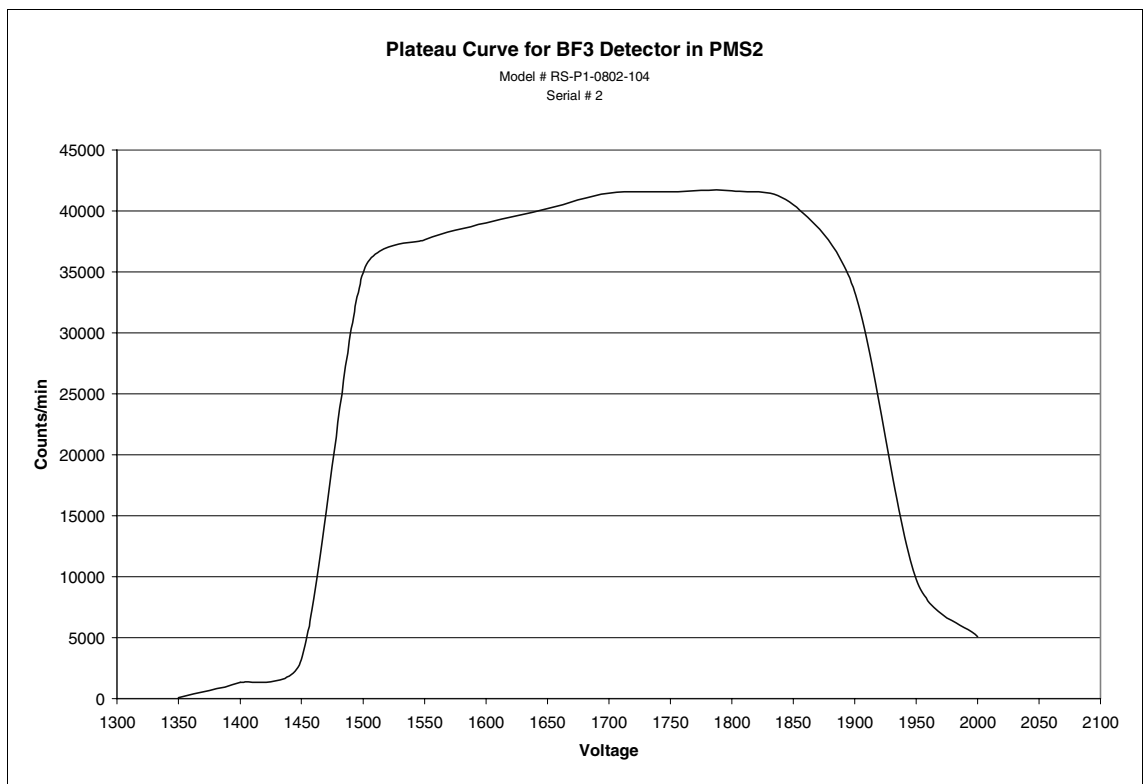


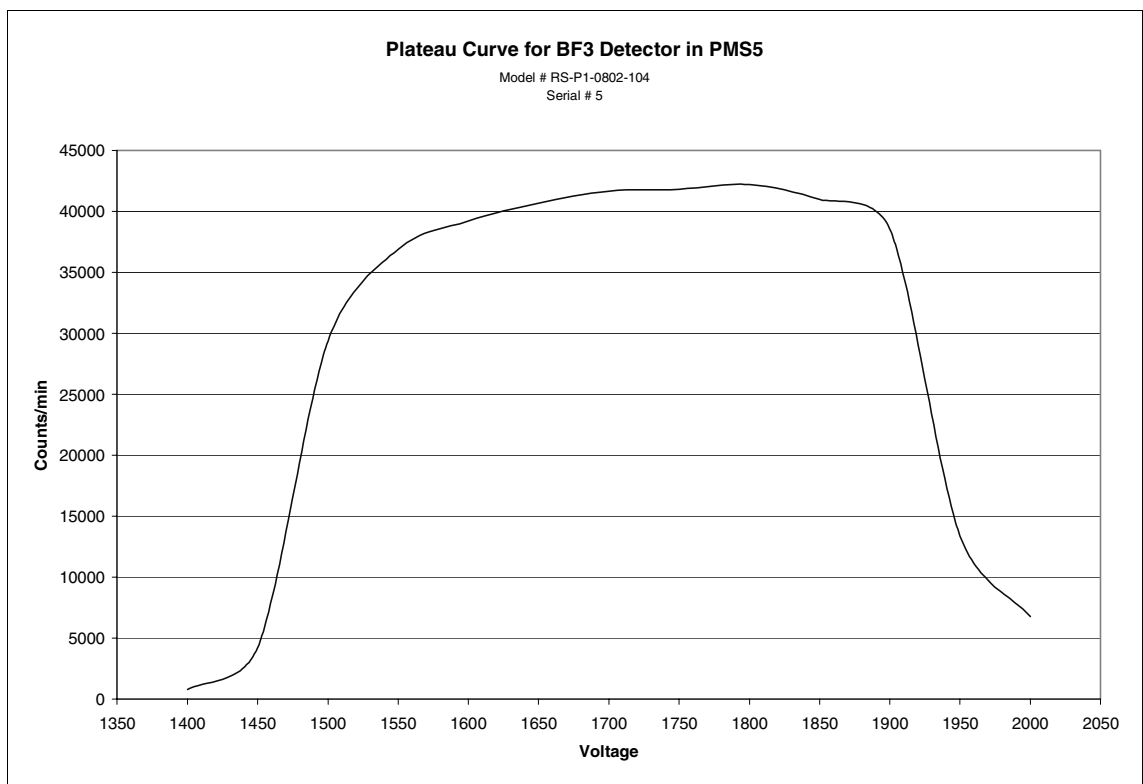
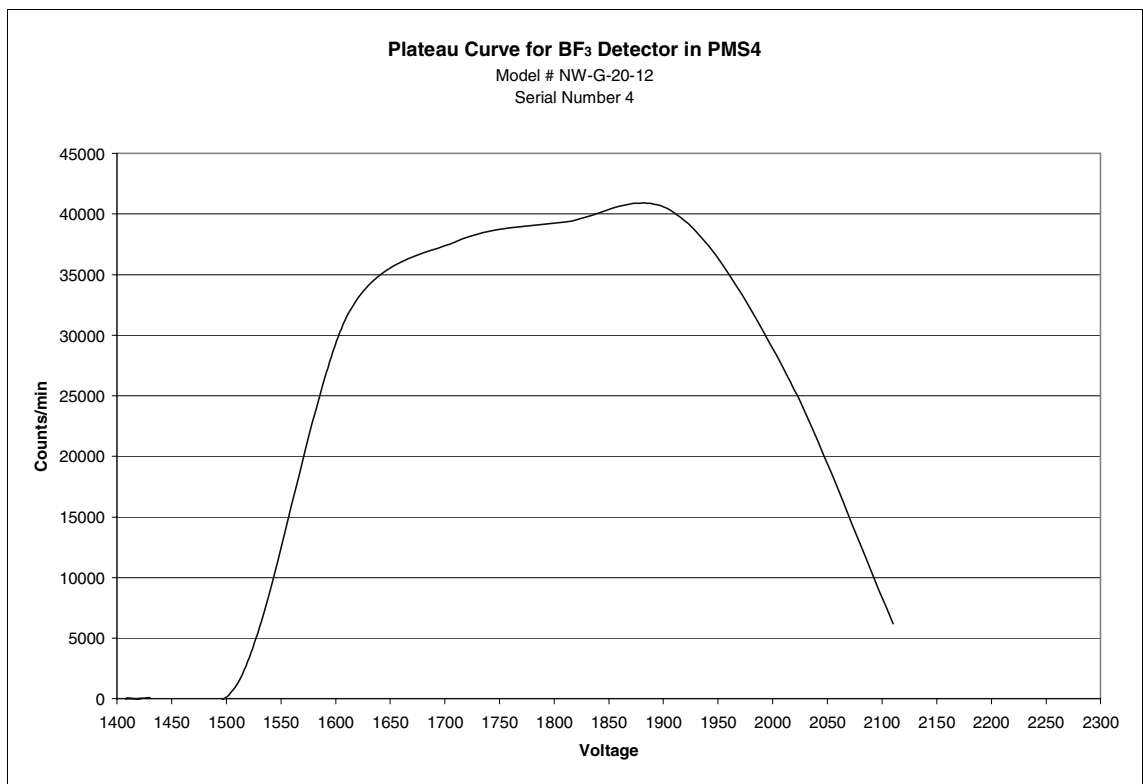


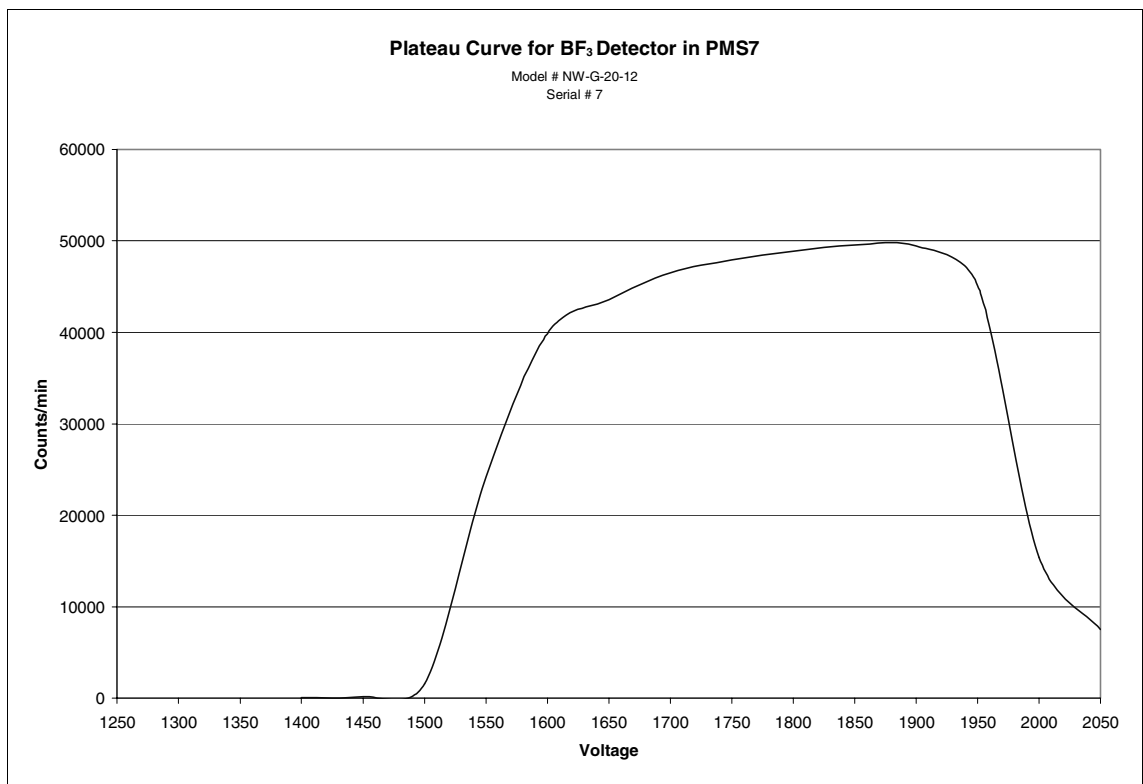
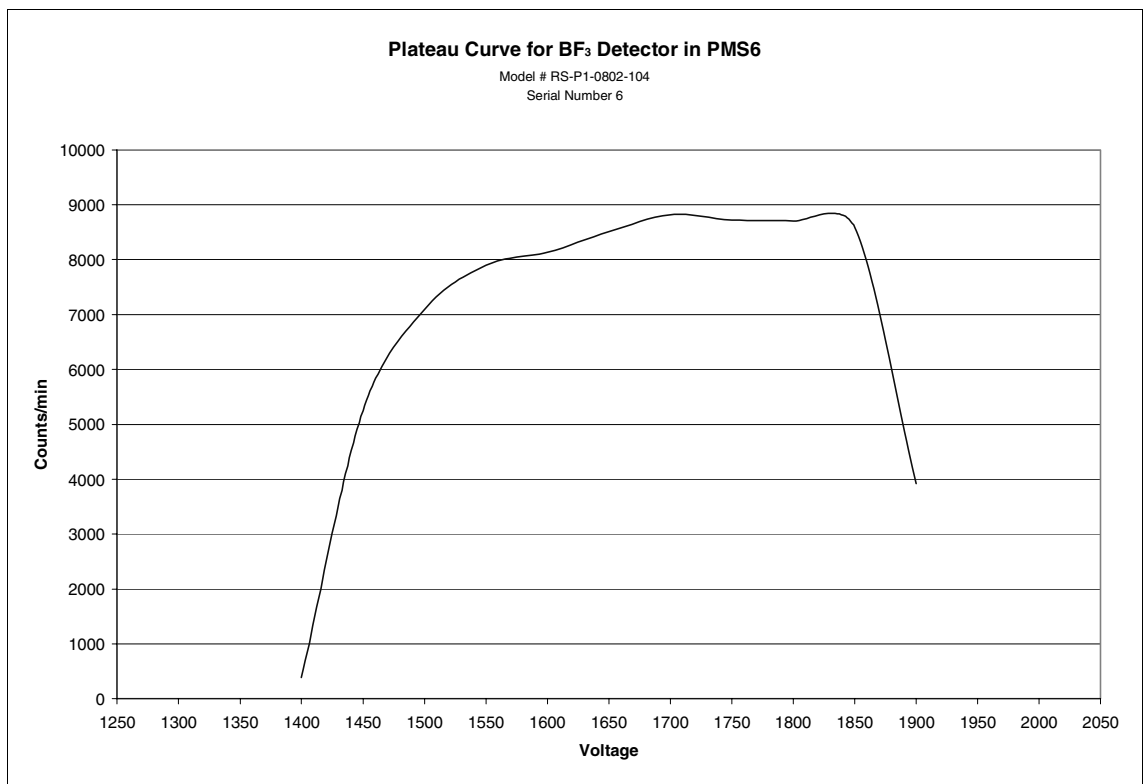


II) BF_3 Detectors









APPENDIX 8 - Generating a Discriminator Curve

The data for a discriminator curve can be obtained in the field or in the lab, however, it is more convenient and accurate when taken in the field. If data is taken in the field, be sure to remove all environmental TLDs from the PMS before bringing any radioactive sources to the station. After data recording is finished, be sure to replace all TLDs once all radioactive sources are removed. If this is done in the lab, the counter/discriminator should be set up with the line driver and detector it will be operating with in the PMS.

1. Prepare electronics for usage.

- 1.1** Put BF_3 detector into NIM bin along with line driver, linear amplifier & discriminator, scaler, and power supply. Make the necessary connections.
- 1.2** Turn power on to NIM bin, counter/discriminator, power supply, and scaler.
- 1.3** Set scaler to take one minute readings.
- 1.4** Set the upper level discriminator at 10V and the lower level discriminator at 0V. The upper level discriminator should remain set at 10V throughout this process.

2. Obtain radioactive neutron source.

Keep in mind that a weak source should be used (one that produces at least 2000 counts per minute) when generating a discriminator curve. Make sure that all equipment is set up and ready for use before obtaining the source in order to reduce the amount of time exposed to the source in accordance with the ALARA policy. This means make sure that all radioactive shielding is in place and electronics are ready for use. Once the source is obtained, place it inside shielding and on top of the detector (see Figure 6).

3. Begin taking data.

- 3.1** Set up a table with a column for discriminator voltage and a column for counts per minute.
- 3.2** Begin by taking your first data point at a lower level discriminator voltage of 0V (set earlier in Step 1.4). The scaler should count for one minute; record this number of counts.
- 3.3** Increase the voltage in increments of 0.5V and record the number of counts registered by the scaler for each increment. Repeat this procedure until the maximum lower level discriminator voltage of 10V is reached.

4. Plot discriminator curve.

- 4.1** Plot the data with the discriminator voltage on the x-axis and the counts per minute on the y-axis (see Figure 9).
- 4.2** Once the curve is graphed, analyze the flat region in a way similar to that of the plateau curve to determine what the proper lower level discriminator voltage should be. Once this is found, the lower level discriminator should be set to this voltage at all times.

APPENDIX 9 – Dose Response Calibration for GM Detectors

Prior to calibrating any PMSs, certain standard operating procedures must be followed. The Radiation Environmental Protection (REP) Manager must be notified before calibration begins. He/she has useful information such as of the location of environmental TLDs that may be in the vicinity of the PMS to be calibrated. The REP Manager may also have special concerns regarding the calibration in order to protect the public from overexposure. Environmental TLDs must be removed from each station (and any surrounding areas) to avoid miscalculation of radiation levels in SLAC's environment. Immediately after calibration and removal of all sources, environmental TLDs must be placed back into the PMS from which they came.

1. Obtain all necessary equipment.

Acquire a stand for elevating the gamma source (i.e. a ring stand and clamp), RADCAL device, scaler/counter, radiological warning signs, rope, tape measure, flathead screwdriver (for opening the lid of PMS) and a stopwatch. Load all equipment into the vehicle before obtaining the radioactive source.

2. Obtain ^{137}Cs source.

Make sure that all equipment is ready for use before obtaining the source in order to reduce the amount of time exposed to the source in accordance with the ALARA policy.

Authorization must be obtained before acquiring radioactive sources. Once authorization is granted, sign all radioactive sources out.

3. Prepare site for calibration.

Calibration must be done in the field at the PMS where the GM detector will be operating.

3.1 Set up RADCAL device and note how far away from the source it will be.

3.2 Connect scaler to GM line driver. Turn it on and set it to count for at least twelve minutes. This amount of time is chosen to obtain a reading at MCC and later verify these readings (against the local scaler) for consistency.

3.3 Set up ^{137}Cs on ring stand and note how far away it is from the detector. It is best to have the source one meter away (from side or top of detector) to simplify calculations. Do not attempt to calibrate by irradiating the end of the GM detector since readings are far more accurate when irradiating the lateral portions of the detector. Take note of how far away the source is from the center of the detector.

3.4 Secure the area by putting up radiological hazard signs and rope.

4. Begin calibration.

4.1 Start scaler to begin recording counts.

4.2 Set the stopwatch for an interval of at least 5 minutes.

4.3 Set RADCAL device to begin measuring dose equivalent; simultaneously, start timing with the stopwatch.

4.4 Once the stopwatch alarms, stop RADCAL device from monitoring and record the amount of dose equivalent measured by the RADCAL. Divide this amount by the time interval used to obtain dose equivalent rate.

4.5 Note how many counts (and the amount of time) the scaler has read at the end of its cycle.

5. Calculating the response of the GM detector.

GM detector response is easily calculated using the formula

$$C_f = \frac{\text{detector count rate (cpm)}}{\text{absolute dose rate (mrem/h)}} \quad (10)$$

Once this value is calculated, it can be used to determine the amount of dose equivalent for every count registered by the detector.

APPENDIX 10 - Dose Response Calibration for BF₃ Detectors

Since BF₃ detector response is a function of the energy of the incident neutrons, a response curve must be established to accurately determine the actual amount of radiation present based on detector readouts at a specific energy. Thus, the stations are calibrated with five neutron sources ranging in energy from 0.5 to 4.5 MeV (see Table 2). The results are plotted as the response in counts/mrem versus energy. Since any differences in detector response would be minor and linear to first order, it is only necessary to calibrate a single station with all five sources. The relationship between detector response and neutron energy is assumed to be the same for all other stations; hence, the remaining stations are calibrated with a single source of known energy. The response curve for all other stations is drawn through the point obtained for that station and parallel to the original curve obtained with the five sources. The data from the five source calibrated station are fit to an exponential decay curve taking the form

$$C_{ini}(E) = Ae^{-\beta E} \quad (1)$$

In this equation, E is the energy of the neutron radiation, β is the decay constant and A is the y-intercept. E is given by the energy of the neutrons from that source, and β and A are calculated by minimizing the square difference of the data to the best fit curve using the solver function in Microsoft Excel. For the other n stations, a constant k_n is determined so that the response curve for that station is essentially the same curve as the initial one, but just shifted up or down depending on the results. Thus, all other stations calibration factor curves take the form

$$C_n(E) = Ae^{-\beta E} + k_n \quad (2)$$

where

$$k_n \equiv C_{ini}(E_{calib}) - C_n(E_{calib}) \quad (3)$$

E_{calib} is the energy at the neutrons from the source used to calibrate all other stations.

Calculating the Calibration Factor

1. Plotting initial response vs. energy curve.

1.1 Selecting the station.

Choose a station to make the initial response curve. Since this station must be calibrated with multiple strong sources, choose the most isolated station which is already troubleshot and plateaued. For the calibration performed for this paper, PMS6 was chosen because it was properly working, easily accessible, and isolated from any other employees.

1.2 Prepare the station.

Consult the Radiation Environmental Protection Manager for instructions about calibrating in the area chosen. Always remove any environmental TLDs in the station. Secure the area around the station with radiological warnings signs and rope. Alert any people in the area of the calibration and have them move if possible. Set up a calibration stand above the detector so that when a source is placed on it, it will lay parallel to the detector such that the middle of the source is one meter above the center of the detector. For the calibration performed in this paper, a beaker clamp was attached sideways to a tube of scrap pipe approximately 1.4 meters tall which was mounted on a ring stand (see Figure 11). A scaler should be added to the circuit of the neutron detector to register the number of counts locally. Although a scaler is not necessary for calibration, it should be used to verify consistency of local scaler readings with those of MCC. Also bring a tape measure, screwdriver (for opening the lid of PMS), radiological warning signs, and rope.

1.3 Calibrating with a local scaler.

Power down the NIM bin, slide in the scaler, connect the linear amplifier to it, and re-power the crate. Program the scaler to take data for at least ten minutes. To record data at MCC while recording it locally on the scaler, a BNC T-connector must be placed on the output of the linear amp, connecting one side to the local scaler and the other side to the line driver to MCC. Refer to step 1.4, “Calibrating with MCC.” If only the local scaler is to be used in taking data, skip step 1.4 and continue to step 1.5, “Calibration.”

1.4 Calibrating with MCC.

Verify that the output of the linear amp goes to the line driver to MCC. Since MCC takes a data point every 6 minutes, it is necessary to run the calibration for longer periods of time than when calibrating with a scaler. In order to ensure at least one accurate point, data must be taken for more than 12 minutes. For the calibration performed in this paper, data was taken for 20 minutes. NOTE: since the pulses being sent to MCC are 0.5 ms pulses, it is important to keep the number of counts low in order to not saturate the line. In general, there is minimal error when the signal is on less than 10% of the time. In this scenario, this means there should be no more than 200 counts/sec (IDATs) showing up at MCC. If this is the case, the source must be moved farther away from the detector or a scaler must be used locally to verify the readings.

1.5 Calibration.

Select the desired sources to calibrate the station. They should range energy to cover a modest spectrum. For a list of which sources were used in the calibration for this paper and their energy, refer to Table 2. When handling the sources, always transport them in paraffin lined containers and practice ALARA in accordance with SLAC regulations. In addition, the handler of the sources must be at RWT 1 trained. (No neutron sources should ever be handled by hand.) Take all the sources out to the site to be calibrated. Place them all as reasonably far away as possible (20-30m away) so that they may be monitored to protect others in the area, but will not interfere with the

calibration. Set up radiological warning signs and rope off the PMS for safety. Place one source at a time in the calibration setup for the amount of time determined by the method of data collection (see steps 1.3-1.4). Move away from the area while taking data to eliminate unnecessary radiation in accordance with ALARA. A distance of 10 or more meters is suggested to cut the dose to at least 1/100 the dose at 1 meter. Repeat for all sources.

1.6 Calculating the initial response curve (five sources).

In order to make the response curve, the detector response must be calculated for all the sources. The response, R , is found using the following formula:

$$R = \frac{C}{H_d + H_s} \quad (4)$$

where C is the counting rate in counts/hr, H_d is the Direct Dose Equivalent Rate in mrem/hr, and H_s is the scattered Direct Dose Equivalent Rate. H_d is found by using the relation

$$H_d = 3.6 \times 10^6 \phi_d \cdot h_\phi \quad (5)$$

where the 3.6×10^6 is a conversion to from Sv/hr to mSv/hr, h_ϕ is ICRP calculated fluence to dose equivalence conversion factor, and

$$\phi_d = \frac{A \cdot F}{4\pi r^2} \quad (6)$$

where A is the neutron emission rate (N/s), F is the anisotropic factor, and r is the distance at which ϕ_d is calculated (in this case, one meter). At this distance, H_d can be simplified to

$$H_d = 28.65 A \cdot F \cdot h_\phi \quad (7)$$

The scattered dose equivalent rate, H_s , is calculated indirectly using Jenkins' recipes (1) for the scattered/direct dose equivalent ratio

$$f_H = \frac{0.75 \cdot r_i / r}{\left[1 + \left(\frac{r_i}{r} \right)^3 \right]} = \frac{H_s}{H_d} \quad (8)$$

where r_i is the image source-to-detector distance in cm and r is the source-to-detector distance in cm. Once f_H has been calculated, H_s can easily be calculated

$$H_s = f_H \cdot H_d \quad (9)$$

Using the data found in Table 2, H_d was calculated using equation (7). H_s for each source was calculated using equations (8) and (9), and then the calibration factor was calculated from equation (4). These points were fit to a line of the form of equation (1). A spreadsheet with the formulas programmed into it can be found on the V drive at V:\ESH\OHP\INSTRUMENTS\PMS and PS Procedures\Calibration calculator.

2. Plotting curves for other stations.

2.1 Getting calibration data.

Repeat the above Steps 1.1-1.5 for all other stations using only one source. For safety purposes, it is suggested to use the weakest of all the sources to minimize dose received by workers and others in the proximity of the other stations. In this case, the PuLi source is the weakest source and was used for all other stations.

2.2 Calculating other station's response curve.

In order to make the response curve, the detector response for the single source must be calculated. See the beginning of step 1.6 for how to calculate detector response. Next, the offset factor k_n is calculated using equation (3). This factor is then added to the equation of the line and the response curve is plotted for that station. These calculations are also available in the spreadsheet program on the V drive. Repeat for all remaining stations, each time calculating the offset with the initial response curve.

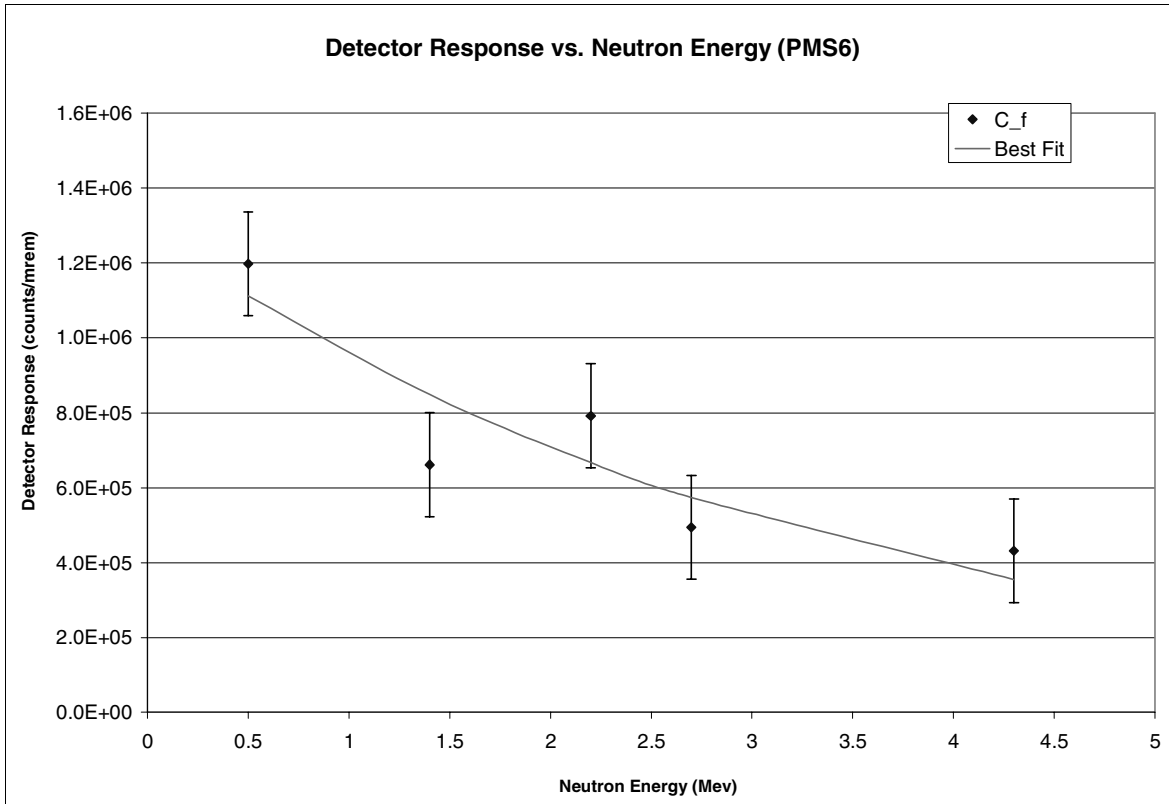


Figure A3. Calibration factor curve for PMS6 using five sources, fit to an exponential decay curve.

REFERENCES

1. Jenkins, T.M. *Simple Recipe for Ground Scattering in Neutron Detector Calibration*. Health Phys. **39**. 41-17 (1980).