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GOES-NOP HEPAD
In-Orbit Data Study

Approvals			
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Code Ident. No.	Rev.	Procedure No.	Sheet
8L918	–	GOESN-ENG-100	1 of 54

Table of Contents

List Of Figures

Table of Tables

1.0 INTRODUCTION

1.1 Purpose

This Report presents the final results of a study of the operation of the HEPAD in-orbit on the GOES-N, -O, and –P spacecraft. Data from the PMT HV stepping tests performed shortly after HEPAD turn-on in-orbit are evaluated and shown to be similar to that for previous HEPADs. Data from a solar proton event in 2006 shows that the HEPADs on GOES-10, -11, -12, and -13 (-N) are in reasonable agreement.

The format of this report is as follows.

Section 2- lists the applicable documents, mainly the GOES-NOP EPS/HEPAD Data and Calibration Handbook, and the Calibration Reports of the GOES-NOP HEPADs.

Section 3- contains a short description of the HEPADS, with information on the ground-based alpha lamp data needed to determine PMT gain and operating HV step.

Section 4- contains a detailed investigation of the HEPAD and EPS in-orbit operation for the GOES-NOP (GOES-13, -14, and -15) spacecraft, with comparisons to the responses from GOES-10, -11, and -12 instruments.

Section 5- contains a detailed discussion of the in-orbit PMT gain measurement, using data from the PMT HV stepping operations performed shortly after instrument turn-on. A method of using the S4 count increase above the S4 plateau is used as a more precise method of determining PMT gain than using the S4/S3 count ratio.

Section 6- Conclusions, is a short summary of the report findings and recommendations.

1.2 SOW Items and Where Addressed

The SOW lists 10 items that should be addressed. These items have changed in importance as the HEPAD data have been reviewed, and are addressed in the various Sections of this report. The SOW items and where they are addressed are as follows.

The SOW requests that the unit vendor (ATC) modify the procedure for calibrating the HEPAD PMT high voltage gain setting in the HEPAD Data & Calibration Handbook that corrects for the effects of GCR protons on the background count levels. The documentation shall include a technical discussion of the following:

1. Potential methods to determine the background counts in S4. This is addressed in Section 5.

2. Determination of the energies of GCR protons that the S3 channel is measuring and using a GCR spectrum appropriate to this solar minimum to come up with a reasonable number of background counts in S4. This is addressed in Section 5.

3. The best method for setting the high voltage step in the presence of a large cosmic ray background. This is addressed in Section 5.

4. Determine whether changes in the gain setting (observed S4/S3 ratios) are due to some degradation in the PMT; in the alpha lamp; or as a result of temperature changes. This is addressed in Section 5.

5. Document HEPAD S4/S3 ratios observed in ground system test for each of the GOES N/P HEPADs. This is addressed in Section 2, with additional discussion in Section 5.

6. Determine the best value to use as the "ground" value of S4/S3. This is addressed in Sections 3 and 5.

7. Determine the sensitivity of the channel energies to the tolerance in S4/S3 ratio, or more generally to a change in voltage step. This is addressed in Sections 3 and 5.

8. Provide an assessment on how the voltage steps compare between previous HEPAD series and the HEPAD series on GOES-N/P. This is addressed in Section 2, with additional discussion in Sections 4 and 5.

9. Confirm the HEPAD serial numbers on each satellite and that the high voltage step identifiers documented by ATC in GOESN-ENG-048 are the same as those used to command the HEPAD high voltage on-orbit. This is addressed in Section 2, with additional discussion in Sections 4 and 5.

10. Using the new method derived under this task, provide an analysis of the on-orbit HV optimization tests of GOES N/P HEPADs conducted to date with recommended S4/S3 settings and associated channel energy ranges and uncertainties. This is addressed in detail in Section 5.

The general findings of this work are that the GOES-NOP HEPADs are operating properly in-orbit, but that they are being operated 4 PMT HV steps low (GOES-13 and GOES-14), and 12 PMT HV steps low (GOES-15). Their proton response is essentially identical to that of previous HEPADs. It is found that a better method of determining PMT gain is to observe the increase in the S4 count rate after the S4 count rate reaches a plateau from the high energy GCR proton background, setting this increase to the ground test measured increase.

2.0 APPLICABLE DOCUMENTS

The relevant documents for this Report are listed in Table 2-1.

Table 2-1. Applicable Documents

Document/ Drawing Number	Revision	Document Title Or Description
GOESN-ENG-048	C	EPS/HEPAD Calibration and Data Handbook
GOESN-ENG-056	C	F1 (SN#003) HEPAD Calibration Report (GOES-N, -13)
GOESN-ENG-075	A	F2 (SN#004) HEPAD Calibration Report (GOES-O, -14)
GOESN-ENG-026	B	PM (SN#002) HEPAD Calibration Report (GOES-P, -15)
PANA-SEM-3	9/11/1981	Preliminary Report on the Operation of the EPS S/N 002 and XRS S/N 002 on GOES-E (GOES-5)
PANA-SEM-5	5/2/1983	GOES –D, -E and –F HEPAD's Report on Ground-Based Tests and on In-Orbit Operations for GOES-D and –E
PANA-SEM-6	8/26/1983	Determination of the Operating H.V. Step of the HEPAD S/N 3 In-Orbit on the GOES-F (-6) Satellite
Handbook of Geophysics and the Space Environment	1985	A. S. Jursa, Editor; AFGL, AFSC, USAF

3.0 HEPAD DESCRIPTION

3.1 HEPAD Configuration

The High Energy Proton and Alpha Detector (HEPAD) provides flux measurements of high energy proton and alpha particles. The instrument faces in the zenith (away from earth). It contains a telescope assembly with two solid state detectors and a photomultiplier tube (PMT) as shown in Figure 3-1. Inside the housing are all the electronics necessary to detect flux, digitally process flux data, and then communicate both flux and state-of-health data to the DPU.

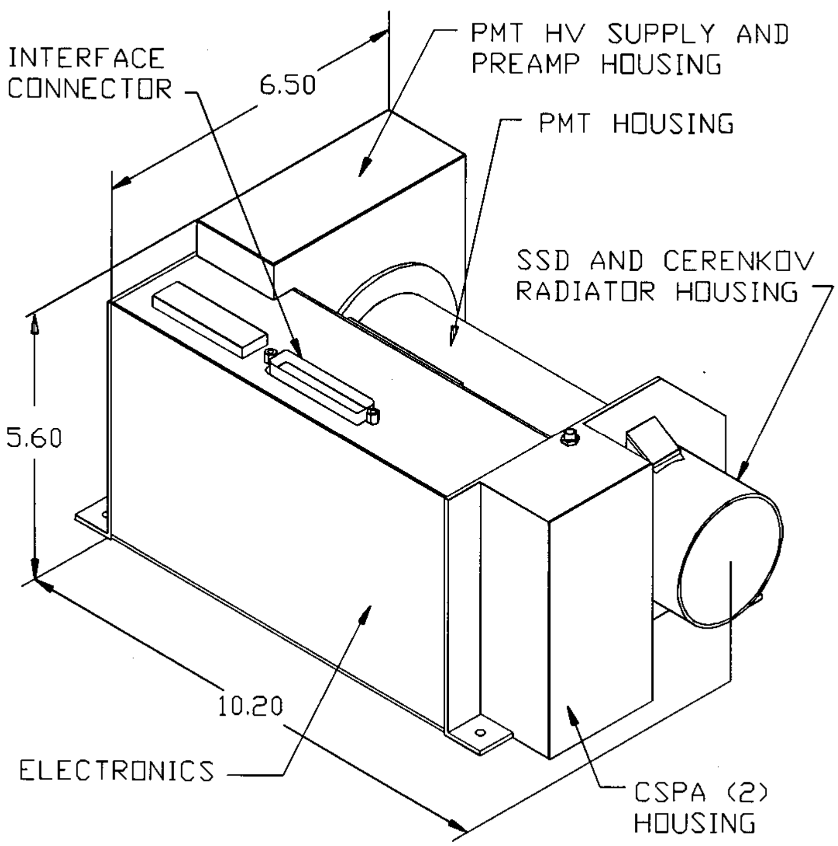

Figure 3-1. HEPAD Isometric

3.1.1 Functional Description

A single interface connector on the HEPAD housing provides all the electrical connectivity to the DPU. The DPU provides the HEPAD with power, program instructions, and timing signals. The HEPAD provides the DPU with primary science and state-of-health data via a serial communication link.
A basic description of the HEPAD particle detection follows with detailed descriptions described in subsequent sections. The charged particle detecting elements in the telescope are two Solid State Detectors (SSD) followed by a Photomultiplier Tube (PMT). The SSDs are mounted in a telescope

configuration with the field of view defined by the geometry of mounting hardware. The SSD is essentially a large area surface barrier diode that is reverse biased with a high DC voltage to guarantee the p-n junction is totally depleted – optimized for charged particle detection. Charge from a particle detected in the SSD is AC coupled to a Charge Sensitive Preamplifier (CSPA) that converts the impressed charge to a voltage pulse. The CSPA voltage pulse is then passed to the Analog Signal Processing (ASP) electronics that consists of shaping amplifiers that are specifically designed to examine the voltage profile of charged particles from the CSPA and discriminate charged particles from noise. The output amplitude of the shaping amplifiers is proportional to the energy of the detected charged particle. The output voltage of the shaping amplifiers are then provided to a set of six voltage comparators (level detectors) to provide a bi-level output corresponding to six energy thresholds of the incident particle. The level detector outputs are then processed in the digital processing electronics, which count the number of input particles within a specific energy range. The PMT detects particles that pass through both SSDs.

3.1.2 Telescope Description

The GOES-NOP HEPAD telescope configuration is identical to GOES I-M, and is illustrated in Figure 3-2.

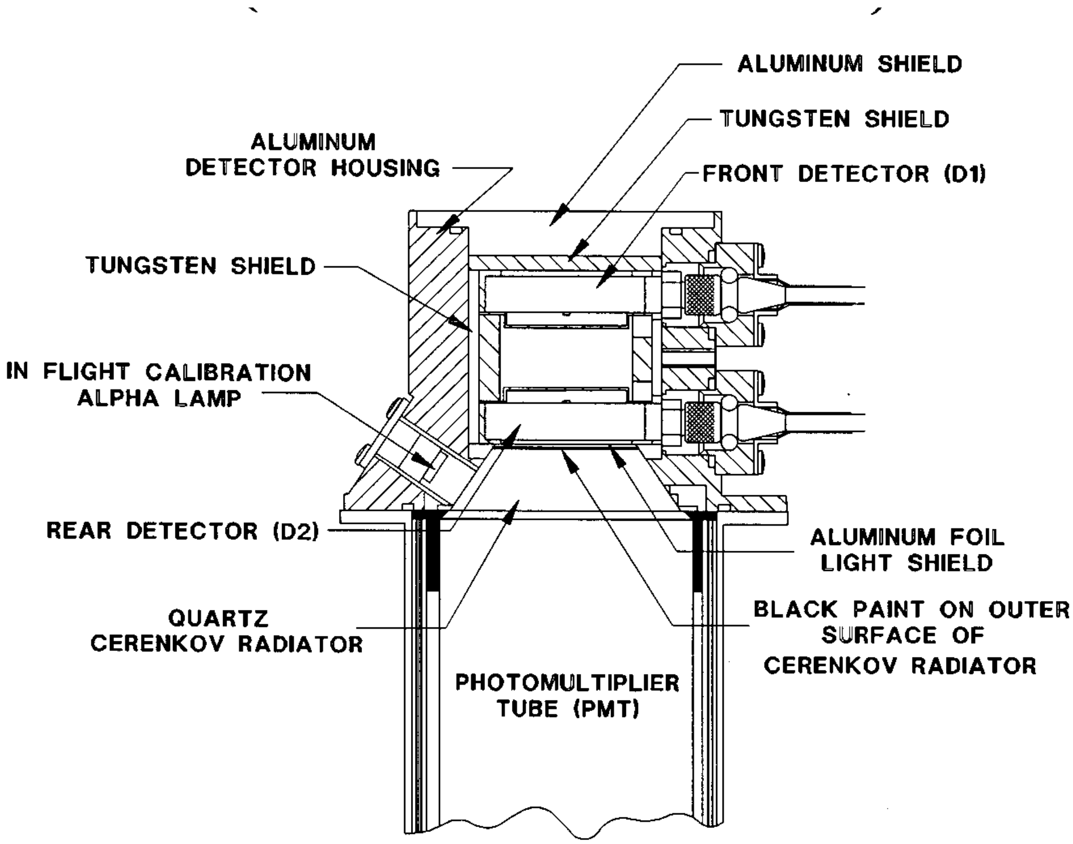

Figure 3-2. HEPAD Telescope Configuration

The HEPAD telescope consists of two 500 micron 3 cm2 solid state detectors (Part Number ORTEC EB-020-300-500-S) and a quartz Cerenkov radiator/PMT arranged in a telescope configuration. The solid state detectors define the geometric factor and differentiate between minimum ionizing protons and alpha particles.

The Cerenkov radiator/PMT provides directional (front/rear incidence) discrimination and provides energy selection. Aluminum and tungsten shields are used to shield the detectors from protons below 70 MeV and electrons below 15 MeV. Energy Loss in the HEPAD SSDs is shown in Figure 3-3.

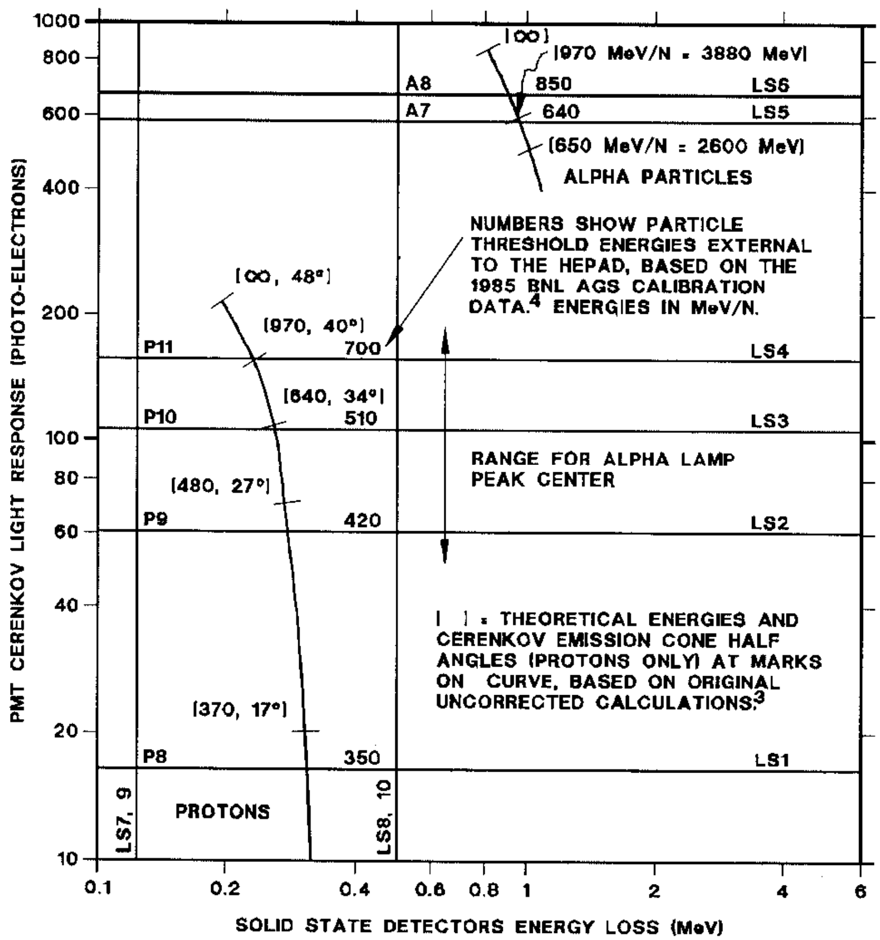

Figure 3-3. HEPAD Telescope Energy Loss Curves

3.1.3 Signal Coincidence and Event Counting

The output signals of the SSD ASP PCB and the PMT ASP PCB are processed by the HEPAD Microcontroller PCB. The counting logic for HEPAD events requires that the three sensing elements (SSD1, SSD2, and PMT) be stimulated simultaneously (referred to as triple coincidence).

The FPGA implements coincidence logic to determine the number of detected events within given energy ranges. For example, a P8 Proton (range 330 to 420 MeV) is defined by a triple coincidence event where:

1. SSD1 is at least 110 keV but less than 500 keV,
2. SSD2 is at least 110 keV but less than 500 keV, and
3. Only PMT threshold 1 is triggered.

The threshold values, channel logic, and ranges are given in Table 3-1.

Table 3-1. HEPAD Threshold Values and Coincidence Logic

Threshold Values	
Threshold Level Number	**Threshold Value**
PMT (LS1)	13.5 pe
PMT (LS2)	69.0 pe
PMT (LS3)	114.0 pe
PMT (LS4)	164.0 pe
PMT (LS5)	608.0 pe
PMT (LS6)	729.0 pe
D2 (LS7)	110 keV
D2 (LS8)	500 keV
D1 (LS9)	110 keV
D1 (LS10)	500 keV

Channel Logic and Ranges			
Particle Type	**Channel Designation**	**Coincidence Logic**	**Energy Range**
Proton	P8	9·~~10~~·7·~~8~~·1·~~2~~	330 to 420 MeV
Proton	P8	9·~~10~~·7·~~8~~·2·~~3~~	420 to 510 MeV
Proton	P10	9·~~10~~·7·~~8~~·3·~~4~~	510 to 700 MeV
Proton	P11	9·~~10~~·7·~~8~~·4·~~5~~	>700 MeV
Alpha	A7	10·8·5·~~6~~	2560 to 3400 MeV
Alpha	A8	10·8·6	>3400 MeV
D1/Singles	S1	9	Diagnostic (D1)
D2/Singles	S2	7	Diagnostic (D2)
PMT/LS1	S3	1	Alpha Lamp (Low)
PMT/LS2	S4	2	Alpha Lamp (High)
D1/D2 Coincident	S5	9·7 (Fast)	Fast D1/D2 Coincidence
	1·~~2~~ is read as level 1 but not level 2		

Channels P8, P9, P10, and P11 measure protons of various energy ranges. A proton event is defined as a triple coincident event where:

1. SSD1 is at least 110 keV but less than 500 keV,
2. SSD2 is at least 110 keV but less than 500 keV, and
3. The relevant PMT thresholds are triggered.

Channels A7 and A8 measure alpha particles of in two energy ranges. A alpha event is defined as a triple coincident event where:

1. SSD1 is at least 500 keV,

2. SSD2 is at least 500 keV, and
3. PMT thresholds level 5 or levels 5 and 6 are triggered.

There are five channels, S1 through S5, that are used for diagnostics or calibration purposes. S1 and S2 each measure the single events in SSD1 and SSD2 without regards to coincidence. S5 measures the double coincidence of D1 and D2 within the 90 ns window. S3 and S4 provide Alpha Lamp low and high responses for PMT gain measurement.

3.2 GOES-N/-13 HEPAD Information

The GOES-N/-13 HEPAD is the F1 (SN/003) unit. The Calibration Report for this HEPAD is GOESN-ENG-056, Rev. C.

The proper PMT gain is determined by monitoring the ratio of S4 counts to the S3 counts in response to an alpha lamp with a known spectrum. The operating high voltage is adjusted until the S4/S3 ratio is between 0.1and 0.2. This is first determined during ground-based measurements where the incidence of background cosmic ray energy is minimal. The ground-based determination of the S4/S3 ratios is provided in Table 3-2 and Table 3-3. Table 3-2 provides the lower PMT high voltage steps to show the level at which S3 counts begin to be indicated. Table 3-3 shows the S4/S3 ratios in the area of the PMT operating high voltage as determined in ground-based testing. It will be necessary to adjust the PMT operating high voltage in-orbit because of likely changes in the HV supply, and possibly the PMT, because of the dry high vacuum.

Table 3-2. GOES-13 HEPAD PMT S4/S3 Ratio, Low High Voltage Steps

PMT High Voltage Step	S3 Counts (Average of 10)	S4 Counts (Average of 10)	S4/S3 Ratio
0	0	0	0
16	0	0	0
32	0	0	0
48	0.9	0	0
64	12.7	0	0
80	193.9	0	0
96	540.2	0.7	0.0013

Note that for ground (pre-launch) operation in air, the operating HV step (OPHV) for the PMT is 150,that the S4/S3 count ratio is 0.1473, and that the S4 count is 102.2 per readout (1 readout for the S counts is a 4 minor frame accumulation, with a minor frame time being 1.024 seconds). In-orbit operation generally results in a shift of a few HV steps, mostly because of the effects of a dry vacuum on the HV supply, and possibly on the PMT.

Table 3-3. GOES-13 HEPAD PMT S4/S3 Ratio, Operating High Voltage Range of Steps

PMT High Voltage Step		S3 Counts (Average of 10)	S4 Counts (Average of 10)	S4/S3 Ratio
Name	Step			
OPHV-5	145	693.4	54.4	0.0784
OPHV-4	146	687.0	67.6	0.0984
OPHV-3	147	690.2	71.9	0.1027
OPHV-2	148	677.4	78.6	0.1160
OPHV-1	149	690.2	90.5	0.1311
OPHV	150	693.4	102.2	0.1473
OPHV+1	151	687.2	116.0	0.1688
OPHV+2	152	693.4	136.1	0.1962
OPHV+3	153	696.6	145.6	0.2090
OPHV+4	154	696.6	172.6	0.2477
OPHV+5	155	696.6	187.0	0.2684

3.3 GOES-O/-14 HEPAD Information

The GOES-O/-14 HEPAD is the F2 (SN/004) unit. The Calibration Report for this HEPAD is GOESN-ENG-075, Rev. A.

The proper PMT gain is determined by monitoring the ratio of S4 counts to the S3 counts. The operating high voltage is adjusted until the S4/S3 ratio is about 0.05 to 0.10. The S4/S3 ratio depends on the properties of the alpha lamp in the HEPAD in question, and varies from one lamp to another. The S4/S3 ratio for proper operation is first determined during ground-based measurements where the incidence of background cosmic ray energy is minimal. The ground-based determination of the S4/S3 ratios is provided in Table 3-4 and Table 3-5. Table 3-4 provides the lower PMT high voltage steps to show the level at which S3 counts begin to be indicated. Table 3-5 shows the S4/S3 ratios in the area of the PMT operating high voltage as determined in ground-based testing. It will be necessary to adjust the PMT operating high voltage in-orbit because of likely changes in the HV supply, and possibly the PMT, because of the dry high vacuum.

Table 3-4. GOES-14 HEPAD PMT S4/S3 Ratio, Low High Voltage Steps

PMT High Voltage Step	S3 Counts (Average of 10)	S4 Counts (Average of 10)	S4/S3 Ratio
0	0	0	0
16	0	0	0
32	0.9	0.1	0.111
48	2.3	0.1	0.043
64	62.6	0	0
80	432.0	0.3	0.0007
96	632.6	1.4	0.00221
128	751.0	5.7	0.0076
129	738.8	8.4	0.0114
130	735.0	9.7	0.0132
131	754.2	12.3	0.0163

Table 3-5. GOES-14 HEPAD PMT S4/S3 Ratio, Operating High Voltage Range of Steps

PMT High Voltage Step		S3 Counts (Average of 10)	S4 Counts (Average of 10)	S4/S3 Ratio
Name	Step			
OPHV-5	133	751	16.5	0.0220
OPHV-4	134	735	19.0	0.0259
OPHV-3	135	735	25.4	0.0346
OPHV-2	136	747	31.8	0.0425
OPHV-1	137	741	30.4	0.0410
OPHV	138	735	36.1	0.0491
OPHV+1	139	738.2	44.1	0.0597
OPHV+2	140	735	47.6	0.0648
OPHV+3	141	735	61,8	0.084
OPHV+4	142	738.2	66.1	0.0895
OPHV+5	143	719	70.7	0.0983

Note that for ground (pre-launch) operation in air, the operating HV step (OPHV) for the PMT is 138, that the S4/S3 count ratio is 0.0491, and that the S4 count is 36.1 per readout (1 readout for the S counts is a 4 minor frame accumulation, with a minor frame time being 1.024 seconds). In-orbit operation generally results in a shift of a few HV steps, mostly because of the effects of a dry vacuum on the HV supply, and possibly on the PMT.

3.4 GOES-P/-15 HEPAD Information

The GOES-P/-15 HEPAD is the PM (SN/002) unit. The Calibration Report for this HEPAD is GOESN-ENG-026, Rev. B.

The proper PMT gain is determined by monitoring the ratio of S4 counts to the S3 counts. The operating high voltage is adjusted until the S4/S3 ratio is 0.38 ± 0.05. This is first determined during ground-based measurements where the incidence of background cosmic ray energy is minimal. The ground-based determination of the S4/S3 ratios is provided in Table 3-6 and Table 3-7. Table 3-6 provides the lower PMT high voltage steps to show the level at which S3 counts begin to be indicated. Table 3-7 shows the S4/S3 ratios in the area of the PMT operating high voltage as determined in ground-based testing. It will be necessary to adjust the PMT operating high voltage in-orbit because of likely changes in the HV supply, and possibly the PMT, because of the dry high vacuum.

Note that for ground (pre-launch) operation in air, the operating HV step (OPHV) for the PMT is 154, that the S4/S3 count ratio is 0.3791, and that the S4 count is 232.7 per readout (1 readout for the S counts is a 4 minor frame accumulation, with a minor frame time being 1.024 seconds). In-orbit operation generally results in a shift of a few HV steps, mostly because of the effects of a dry vacuum on the HV supply, and possibly on the PMT.

Table 3-6. GOES-15 HEPAD PMT S4/S3 Ratio, Low High Voltage Steps

PMT High Voltage Step	S3 Counts (Average of 10)	S4 Counts (Average of 10)	S4/S3 Ratio
0	0	0	0
16	0	0	0
32	0.7	0	0
48	2	0	0
64	57	0	0
80	345.1	0.2	0.00058
96	505.9	0.7	0.00140

Table 3-7. GOES-15 HEPAD PMT S4/S3 Ratio, Operating High Voltage Range of Steps

PMT High Voltage Step		S3 Counts (Average of 10)	S4 Counts (Average of 10)	S4/S3 Ratio
Name	Step			
OPHV-5	149	601.1	152.3	0.2534
OPHV-4	150	597.9	167.5	0.2801
OPHV-3	151	594.7	184.3	0.3099
OPHV-2	152	597.9	199.1	0.3330
OPHV-1	153	604.3	216.9	0.3589
OPHV	154	613.9	232.7	0.3791
OPHV+1	155	617.1	258.9	0.4195
OPHV+2	156	613.9	273.1	0.4449
OPHV+3	157	604.3	273.3	0.4523
OPHV+4	158	591.5	290.9	0.4918
OPHV+5	159	591.5	309.9	0.5239

3.5 GOES-4 (-D) HEPAD Operation

A short description of the GOES-4 (-D) HEPAD (old SN/7) operation is given in PANA-SEM-5. This is a NOAA supplied HEPAD, and is specified to operate on the ground in air at HEPAD PMT step 39, with an S4/S3 ratio of 0.45. Some HEPAD proton spectra are shown for an in-orbit S4/S3 of 0.50 (actual PMT HV step not specified), but this is with the high energy CR proton background added to the ground-based count rates. Because the in-orbit HEPAD operates in a hard vacuum, the PMT operating HV step may be slightly different than the ground/air specified HV step. A better set of in-orbit data were obtained for the GOES-5 (-E) HEPAD, as described in the next section.

3.6 GOES-5 (-E) HEPAD Operation

A description of the GOES-5 (-E) HEPAD (old SN/8) operation is given in PANA-SEM-3 and PANA-SEM-5. This is a NOAA supplied HEPAD, and is specified to operate on the ground in air at HEPAD PMT step 35, with an S4/S3 ratio of 0.51. Some HEPAD proton spectra are shown for an in-orbit S4/S3 of 0.40, but this is with the high energy CR proton background added to the ground-based count rates. Ground-based and in-orbit S4/S3 ratios are shown for this HEPAD in Table 1.1 of PANA-SEM-3, and in Table 3.1 of PANA-SEM-5. The S3 plateau count rate in-orbit was 32 cps higher than the ground-based plateau (187 cps vs. 155 cps). Correcting the in-orbit S4/S3 ratio by subtracting 32 cps from both measured count-rates indicates that the in-orbit operating HV step is 2 higher than the ground-based operating HV step, and the in-orbit recommended PMT HV step is 37. For this HEPAD a one step HV increase changes the PMT gain by a factor of x1.045, so a 2 step change in the PMT HV corresponds to a gain change of x1.092. Operation of the PMT in-orbit at the ground-based PMT HV step results in the PMT gain being low by that factor, and increases the effective energies of the HEPAD proton channels.

3.7 GOES-6 (-F) HEPAD Operation

A short description of the GOES-6 (-F) HEPAD (old SN/3) operation is given in PANA-SEM-5 and PANA-SEM-6. This is a NOAA supplied HEPAD, and is specified to operate on the ground in air at HEPAD PMT step 38, with an S4/S3 ratio of 0.26. Ground-based and in-orbit S4/S3 ratios are shown for this HEPAD in Table 1 of PANA-SEM-6. The S3 plateau count rate in-orbit was 34.4 cps higher than the ground-based plateau (175.4 cps vs. 209.8 cps). Correcting the in-orbit S4/S3 ratio by subtracting 34.4 cps from both measured count-rates indicates that the in-orbit operating HV step is 3 higher than the ground-based operating HV step, and the in-orbit recommended PMT HV step is 41. For this HEPAD a one step HV increase changes the gain by a factor of 1.045, so a 3 step change in the PMT HV corresponds to a gain change of x1.141. Operation of the PMT in-orbit at the ground-based PMT HV step results in the PMT gain being low by that factor, and increases the effective energies of the HEPAD proton channels.

3.8 GOES EPEAD/EPS and HEPAD Data Reduction

3.8.1 EPEAD/EPS Data Channel Properties

The GOES-NOP spacecraft have two (2) EPEAD sensors, one viewing east and one viewing west. The EPEADs are identical to the EPS on the GOES-I to –M spacecraft. All energy channels are the same, with accumulation times and count compression methods being different, but that has no effect on the particle flux measurements. The EPEAD/EPS channel responses are given in Table 3-8, which is from the GOESN-ENG-048 Data and Calibration Report.

Table 3-8. Constants for EPEAD Proton and Alpha Channel Data Reduction

EPEAD Channel Pi, Ai	Accumulation Time (seconds)	Energy Range E1 – E2 (MeV)	Average Energy (MeV)	Gf(Ei) x DEi (cm^2 sr MeV)
P1	8.192	0.74 – 4.2	2.5	0.194
P2	32.768	4.2 – 8.7	6.5	0.252
P3	32.768	8.7 – 14.5	11.6	0.325
P4	32.768	15 – 40	30.6	5.21
P5	32.768	38 – 82	63.1	14.5
P6	32.768	84 – 200	165.	129.
P7	32.768	110 – 900	433.	839.
A1	32.768	3.8 – 9.9	6.9	0.342
A2	32.768	9.9 – 21.3	16.1	0.638
A3	32.768	21.3 – 61.	41.2	2.22
A4	32.768	60 – 160	120.	21.
A5	32.768	160 – 260	210.	36.
A6	32.768	330 – (500)	435.	176.

3.8.2 HEPAD Data Channel Properties

The GOES-NOP spacecraft have one (1) HEPAD sensor. The HEPADs are identical to the HEPADs on the GOES-I to –M spacecraft. All energy channels are the same, with accumulation times and count compression methods being different, but that has no effect on the particle flux measurements. The HEPAD channel responses are given in Table 3-9, which is from the GOESN-ENG-048 Data and Calibration Report. For the P11 channel, which is an integral channel >700 MeV, an upper energy limit of 1500 MeV has been used to calculate differential fluxes for comparison with the other proton channels. This gives P11 an average energy of 1100 MeV, and a Gf x DE factor of 584 cm2 sr MeV. For GOES-NOP the HEPAD particle channels in Table 3-9 all have an accumulation time of 32.768 seconds, or 32 spacecraft telemetry minor frames.

In-orbit gain changes for the GOES-I to –M HEPADs is not known to ATC, since no detailed in-orbit data on PMT HV stepping was provided to Panametrics after launch.

Table 3-9. HEPAD Energy Channels and Geometric Factor

HEPAD Channel	Particle Energy Range (MeV)	Geometric Factor, Gf(Ei) (cm^2 sr)	Average Energy, Ei (MeV)	Gf(Ei) x DEi (cm^2 sr MeV)
P8	330 – 420	0.73	375	65.7
P9	420 – 510	0.73	465	65.7
P10	510 – 700	0.73	605	138.7
P11	>700	0.73	(1100)	(584)
A7	2560 – 3400	0.73	2980	613.2
A8	>3400	0.73	-	-

3.8.3 GOES-NOP HEPAD PMT Gain Variation with HV Step

The GOES-NOP HEPAD PMT gain varies with HV step by a factor of 1.023 for every step increase of 1. The alpha lamp pulse height as measured by a Multichannel Analyzer (MCA) is shown for several PMT HV steps for the F2 HEPAD in Table 3-4. The PMT gain increase per HV step is fitted with the power law results listed. Note that e0.02271 = 1.023, which is the PMT gain increase per HV step. This should be reasonably constant for all GOES-NOP HEPADs, which operate at about the same HV value. The fit is used to calculate proton energy changes for PMT HV changes, as described below.

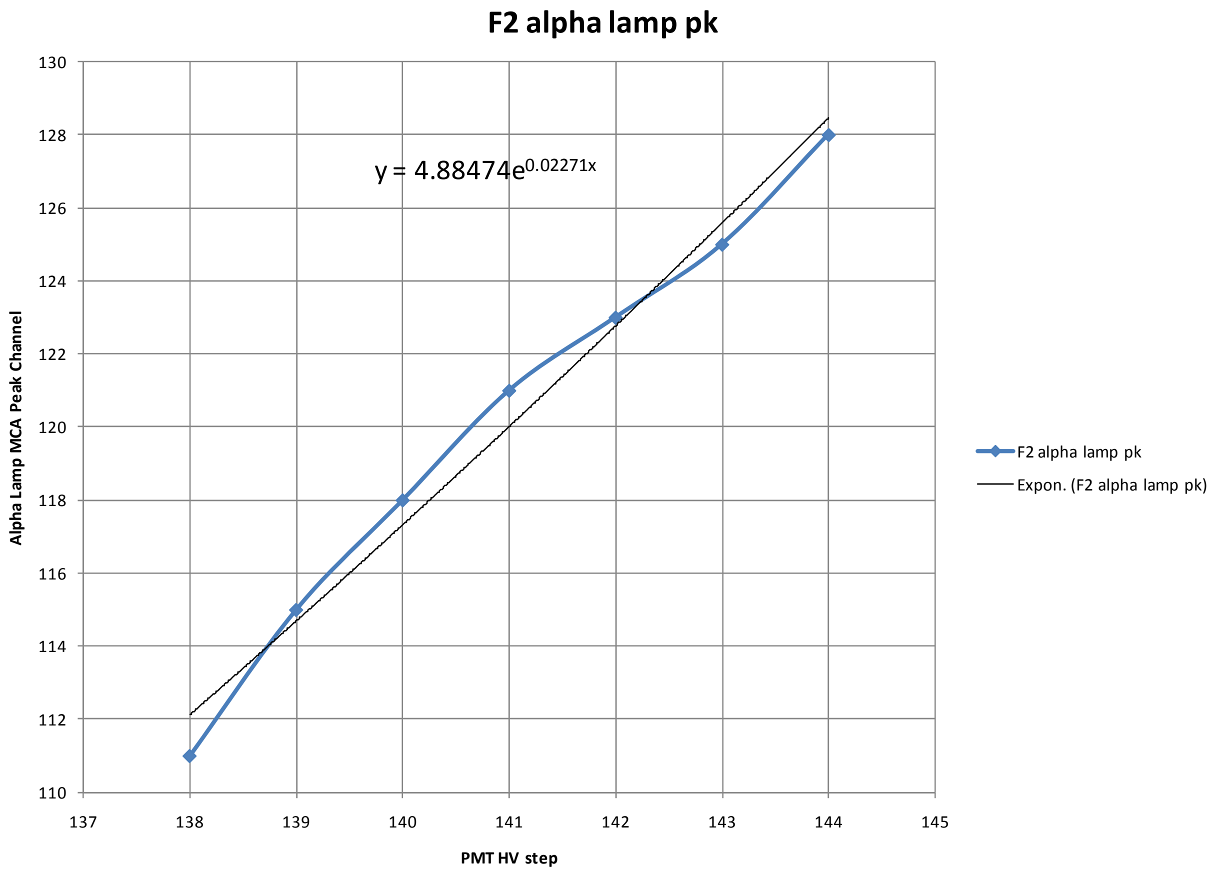

Figure 3-4. HEPAD PMT Gain Change per HV Step

When the HEPAD PMT is operating at an incorrect HV step, the proton energy channels are different. The nominal PMT proton thresholds are 13.5, 69, 114, and 164 pe (photo-electrons), and these will change by the PMT gain factor. Figure 3-5 show the PMT threshold curve for the nominal response, with a polynomial fit. For a PMT effective threshold of (pe) the proton energy is given by

$$Ep(MeV) = 0.0001\,(pe)^3 - 0.0161\,(pe)^2 + 2.3539\,(pe) + 300.9 \qquad (3.1)$$

For the GOES-NOP HEPADs a PMT HV decrease of n steps produces an increase of the proton pe thresholds by a factor of

$$pe(factor) = 1.023^n \qquad (3.2)$$

which is then used in eq. (3.1) to obtain the new, shifted proton thresholds. The shifted proton thresholds are then used to get the new channel average energies and Gf x DE factors.

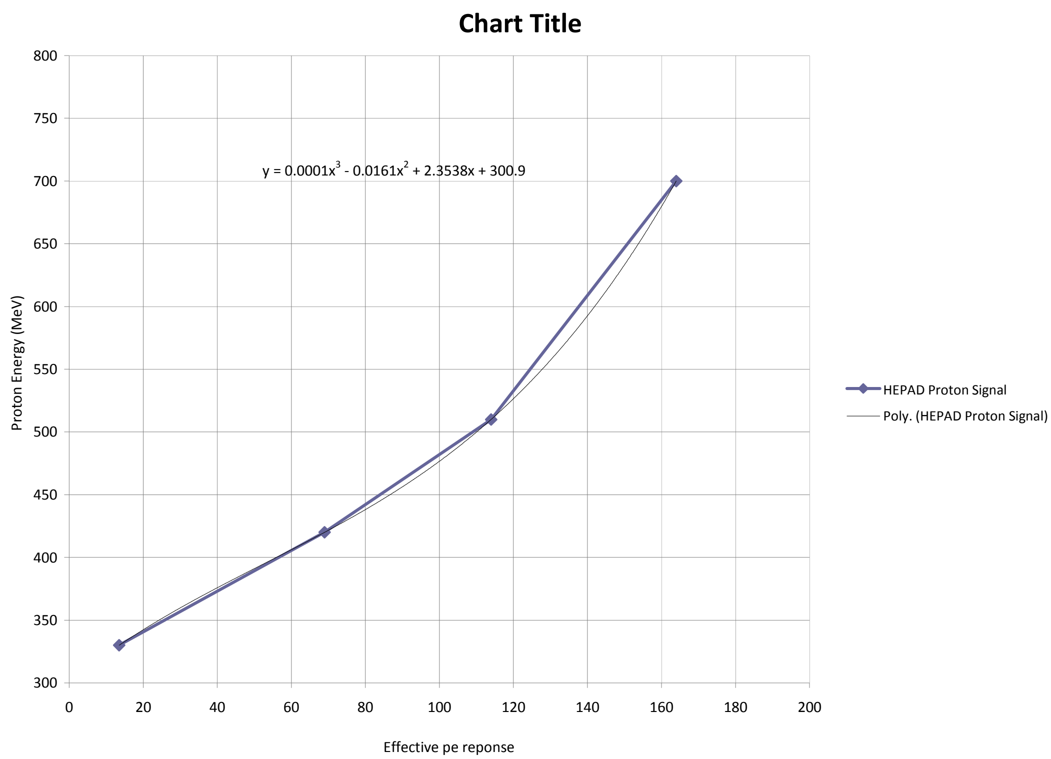

Figure 3-5. HEPAD PMT Proton Energy vs. Threshold

3.8.4 EPEAD/EPS and HEPAD Particle Flux Calculation

The GOES-NOP and –I to –M EPEAD/EPS and HEPAD data channel fluxes are calculated from the measured channel counts divided by the channel accumulation time and by the energy-geometric factor (Gf(Ei) x Dei). The resulting particle fluxes are nominally for the average channel energy, although wide Dei channels may require a slope correction for non-flat energy spectra. The uncorrected particle flux is thus given by

j(Ei) = (Channel Ei count)/[(Channel Ei count time) x (Gf(Ei) x DEi)]..............................(3.3)

where the flux is in particles/(cm2 sr s MeV). Since the HEPAD P11 channel is an integral channel for Ep > 700 MeV, for the present discussion the P11 channel is assumed to be a 700 MeV to 1500 MeV channel, with an average energy of 1100 MeV and a (Gf(Ei) x DEi) of 584 (cm2 sr MeV).

The EPEAD/EPS P7 channel is very broad, and thus will usually have a large slope correction factor. To first order, the spectral shape can be taken to be a power law in energy, with

j(E) = j0 x E-g ....(3.4)

A correction for a channel Ei, with a flat G(E) from Eilow to Eihigh can be calculated from the true flux at Ei jt(Ei) = j0 x Ei-g ....(3.5)

and the approximate flat-spectrum flux, which is given by

jap(Ei) = Int(Eilow, Eihigh)(j0 x E-g)/(Eihigh - Eilow)
= j0 (Eilow1-g - Eihigh1-g)/((Eihigh - Eilow) x (g-1)) ....(3.6)

The correction factor for a given power law value g is given by

Cf(g) = jap(Ei)/jt(Ei)...(3.7)

The flux calculated from eq. (3.3) is divided by the value from eq. (3.7) to get an approximate true differential flux at the channel center energy of Ei. The power law value g is approximated from the uncorrected spectrum, using the decrease in flux over energy to calculate the value of g. This correction is used in the proton spectra from the EPEAD/EPS for channel P7, which is very broad in energy. As shown in Section 4, this correction brings the EPEAD/EPS P7 channel measured flux into good agreement with the HEPAD measured proton spectrum.

4.0 HEPAD IN-ORBIT DATA

4.1 GOES-13 (-N)

4.1.1 PMT HV Stepping Data

The GOES-13 HEPAD PMT HV stepping test was performed on day 262, 2006. A data file was obtained covering the period 0000 UTC through 0400 UTC with PMT HV stepping occurring from 0037:30 UTC through 0305:00 UTC. A second data file was obtained, listing the HV step, the UTC of the step, the S3 count average, the S4 count average, and the S4/S3 ratio. The HV step data are shown in Table 4-1, with the periods of the S3 and S4 plateaus shown, and the S4 count increase from the plateau to the required increase of 102.2 counts/readout. This gives an in-orbit PMT operating HV step of 154, which is a 4 step increase, and corresponds to a gain that is low by a factor of 1.0234 = 1.095. All PMT thresholds are thus higher by this factor.

A plot of the S3 and S4 counts/readout is shown in Figure 4-1, which uses the first data set and plots each available S3 and S4 telemetry count. The S3 and S4 counts/readout both show the plateau discussed above. Section 5 contains additional discussion of the method for PMT gain measurement.

Table 4-1. GOES-13 HEPAD PMT HV Stepping Data – Day 262, 2006

Level	GMT-hrs	S4	S3	S4/S3	S3 Plateau	S4 Plateau
100	0:41	54.6	713.1	0.0766		
110	0:47	73.2	829.1	0.0885		
120	0:51	95.7	889.1	0.1076		
130	0:54	122.7	941.9	0.1303		
140	0:57	146.8	971.5	0.1513		
141	1:01	157.1	1011.5	0.1555	Start	Start
142	1:04	158.7	1001.9	0.1549		Average
143	1:08	174.7	1017.9	0.1717	Average	5 values
144	1:11	168.3	989.9	0.1699	10 values	165.1
145	1:14	166.7	1001.1	0.1663	1007.3	End
146	1:17	183.5	1022.7	0.1795		
147	1:21	188.3	990.7	0.1902		OPHV S4
148	1:24	199.7	990.7	0.2015		165.1+102.2
149	1:27	207.7	1022.7	0.203		= 267.3
150	1:31	212.5	1023.5	0.2073	End	
151	1:35	223.3	1045.1	0.2139		
152	1:38	240.9	1050.7	0.229		
153	1:42	247.7	1087.5	0.2279		
154	1:46	263.9	1093.9	0.2413		~OPHV
155	1:50	279.7	1093.9	0.2556	Pre-launch	
156	1:53	295.7	1106.7	0.2671	Plateau	
157	1:57	316.3	1106.7	0.2858	= 693.4	
158	2:01	324.3	1119.5	0.2901		

Table 4-1. GOES-13 HEPAD PMT HV Stepping Data – Day 262, 2006

Level	GMT-hrs	S4	S3	S4/S3		S3 Plateau	S4 Plateau
159	2:05	357.9	1157.9	0.3091		In-orbit	
160	2:09	364.3	1138.7	0.3199		Increase	
161	2:12	401.9	1145.1	0.3514		= 313.9	
162	2:16	422.7	1170.7	0.3611			
163	2:20	443.1	1196.3	0.3703			
164	2:24	454.3	1170.7	0.3882			
165	2:27	504.3	1234.7	0.4085			
166	2:31	518.3	1215.5	0.4262			
167	2:35	544.7	1260.3	0.432			
168	2:39	565.9	1273.1	0.4447			
169	2:42	581.9	1266.7	0.4597			
170	2:46	597.9	1279.5	0.4673			
171	2:50	613.9	1228.3	0.4998			
172	2:53	645.9	1330.7	0.4855			
173	2:57	665.1	1337.1	0.4974			
174	3:01	690.7	1311.5	0.5268			
175	3:05	709.9	1324.3	0.5362			
150	3:08	213.9	1069.9	0.2002			

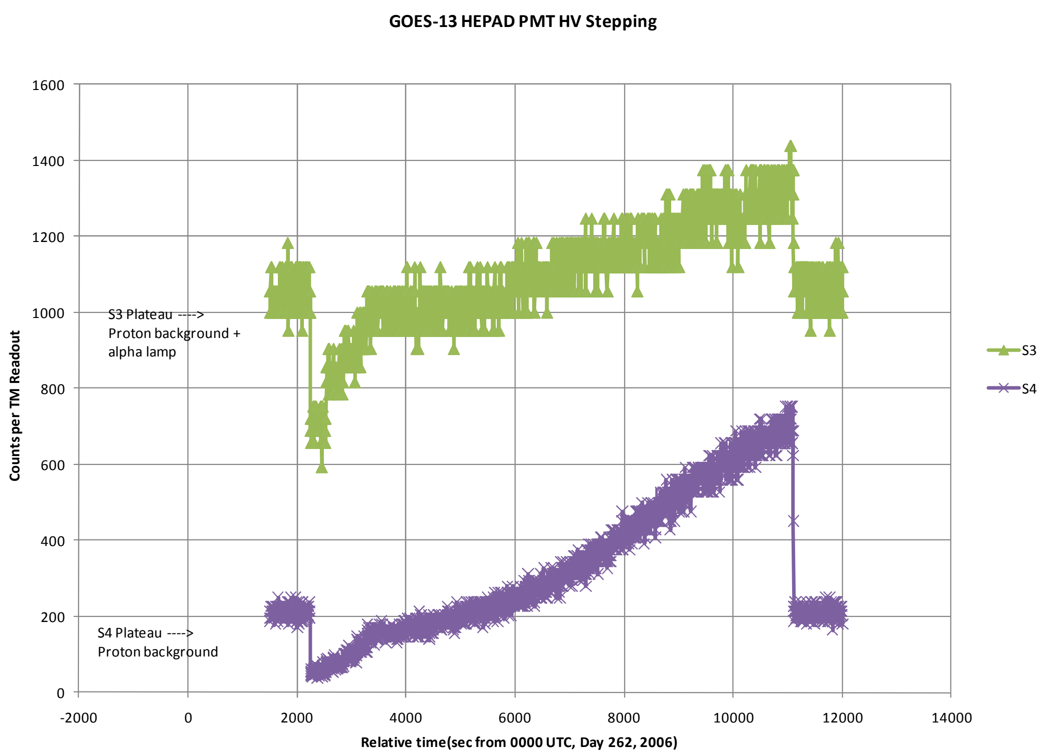

Figure 4-1. GOES-13 HEPAD PMT HV Stepping S3 and S4 Plots

4.1.2 4.1.2 Background Proton Spectrum

The EPEAD-East, EPEAD-West, and HEPAD proton spectra for GOES-13 for a 500 second data average from before the PMT HV stepping is shown in Figure 4-2. The plot show proton channels P4 through P11, with the HEPAD PMT at HV step 150, which gives a gain low by 9.5%. The two EPEAD spectra are in good agreement, with some deviation for the P4 channel, which is most likely due to east/west asymmetry from the earth's magnetic field effects. The higher energy protons are less influenced by the earth's magnetic field, and thus show little difference. The HEPAD spectrum is close to that from the EPEADs, but is for a low gain which means that the true proton energies are higher than the nominal values used. This HEPAD channel energy shift is discussed in more detail below. For this period the proton spectrum is the Cosmic Ray background proton flux, for near solar minimum conditions (see spectral plots in PANA-SEM-3 and PANA-SEM-5).

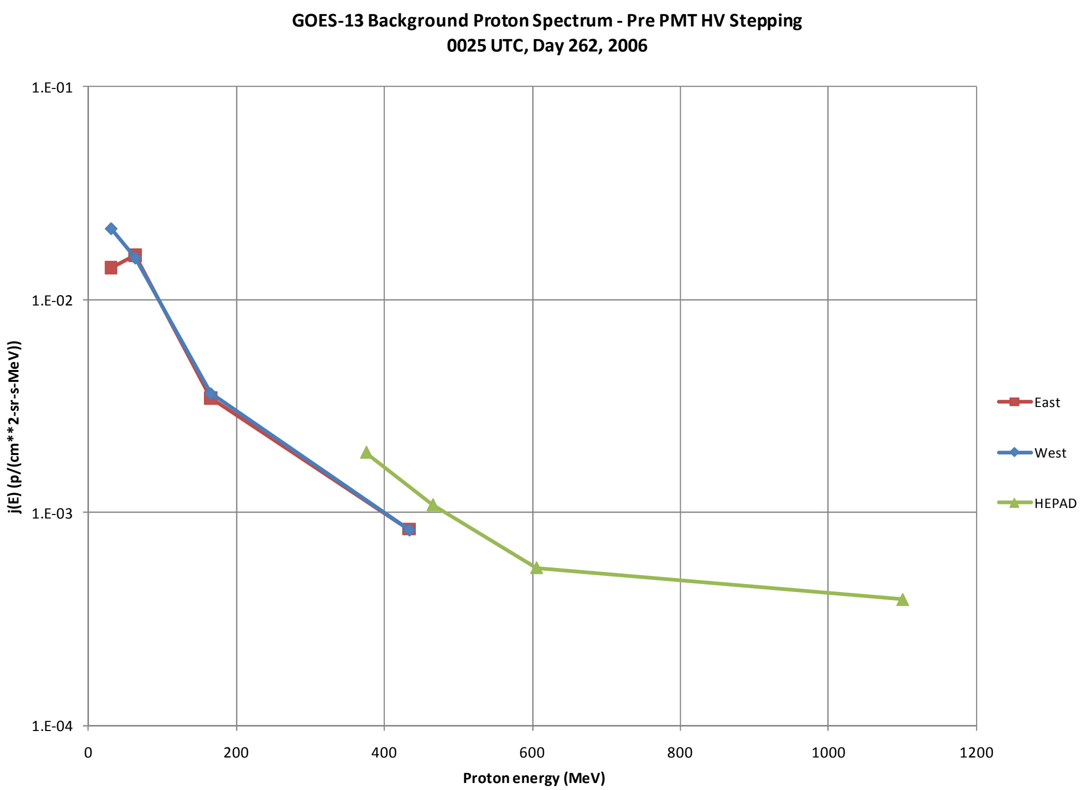

Figure 4-2. GOES-13 Measured Proton Spectra for Day 262, 2006

For comparison, the proton spectra measured by the EPS and HEPAD on GOES-11, GOES-10, and GOES-12 are shown in Figure 4-3, Figure 4-4, and Figure 4-5. Note that the GOES-12 EPS D5 Dome SSDs are noisy, so no good P6 or P7 data are available for Figure 4-5.

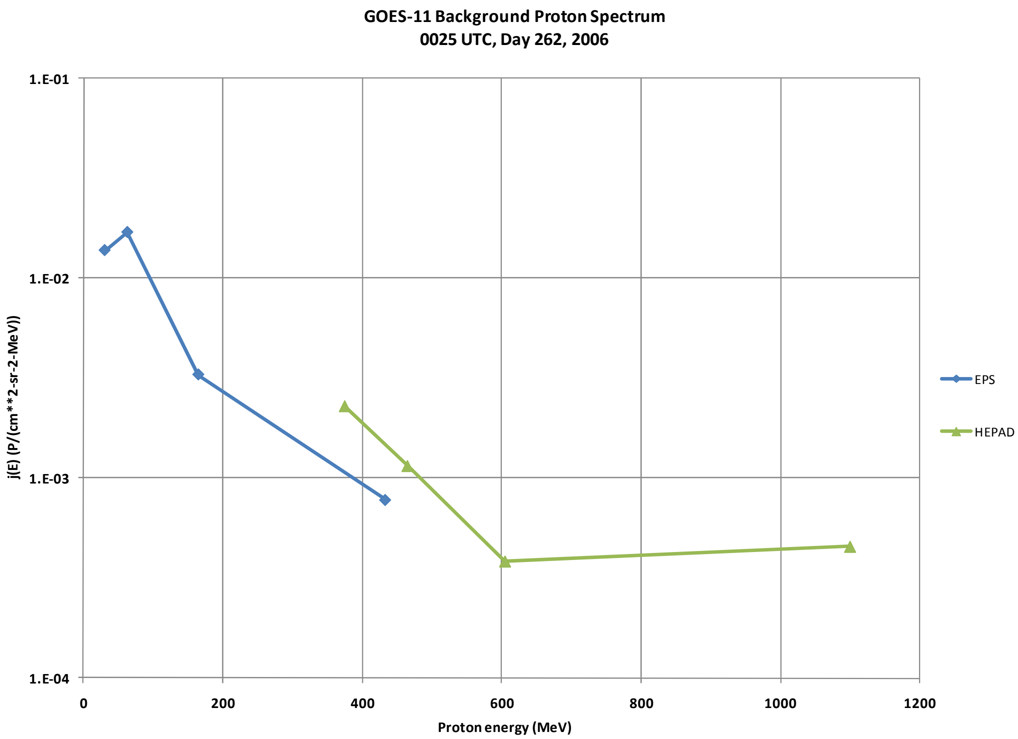

Figure 4-3. GOES-11 Measured Proton Spectra for Day 262, 2006

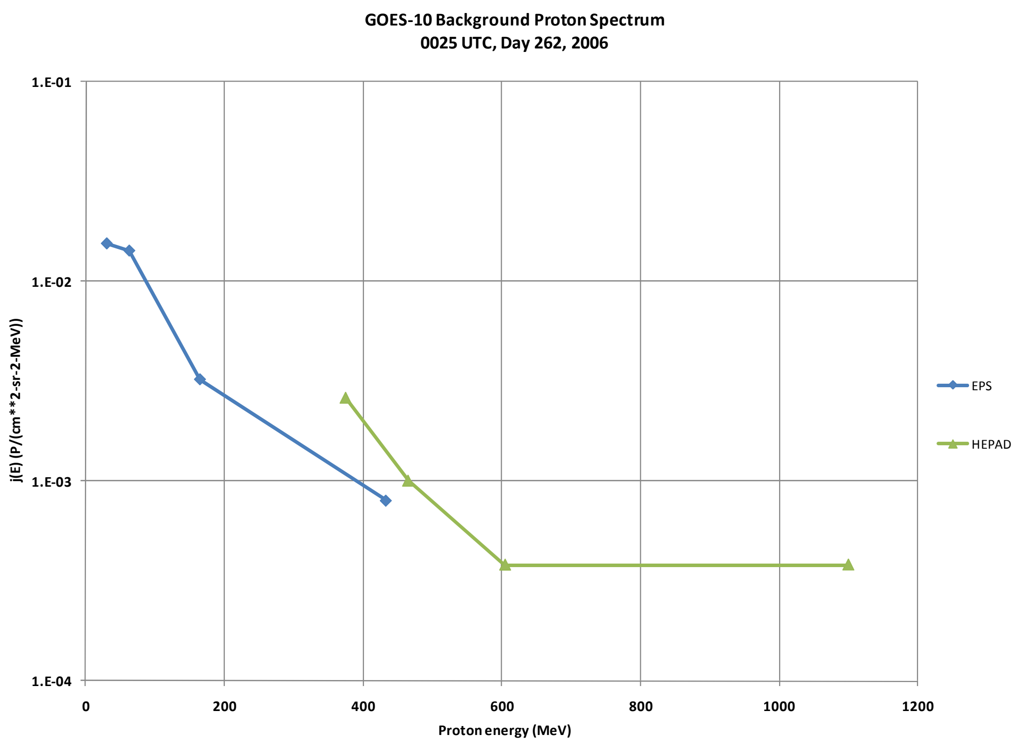

Figure 4-4. GOES-10 Measured Proton Spectra for Day 262, 2006

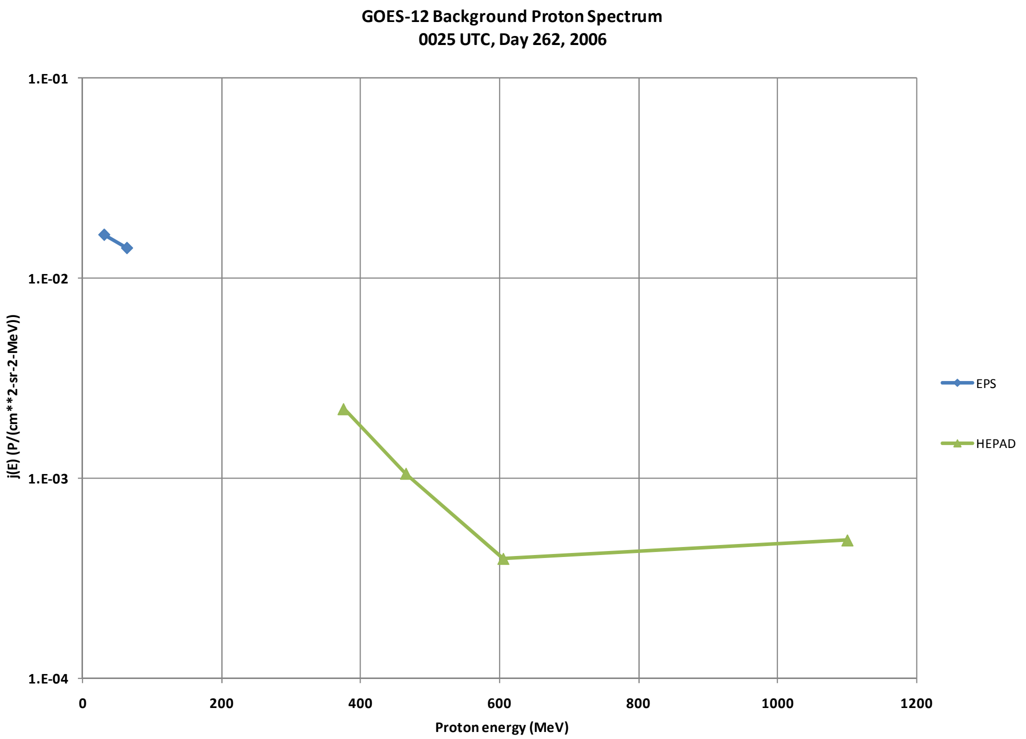

Figure 4-5. GOES-12 Measured Proton Spectra for Day 262, 2006

More detail of the GOES-13 HEPAD proton spectrum is given in Figure 4-6, where the uncorrected pre-step spectrum, the pre-step spectrum corrected for the low PMT gain (9.5%), and the correct proton spectrum for the optimum HV step of 154, are all shown, along with the 1-sigma errors from count statistics. The listed optimum HV step spectrum is actually for an HV step range of 151 to 157 to improve count statistics, but this should have only a minor effect on the proton spectrum. Details of the fluxes and ratios are given in Table 4-2, Table 4-3, and Table 4-4.

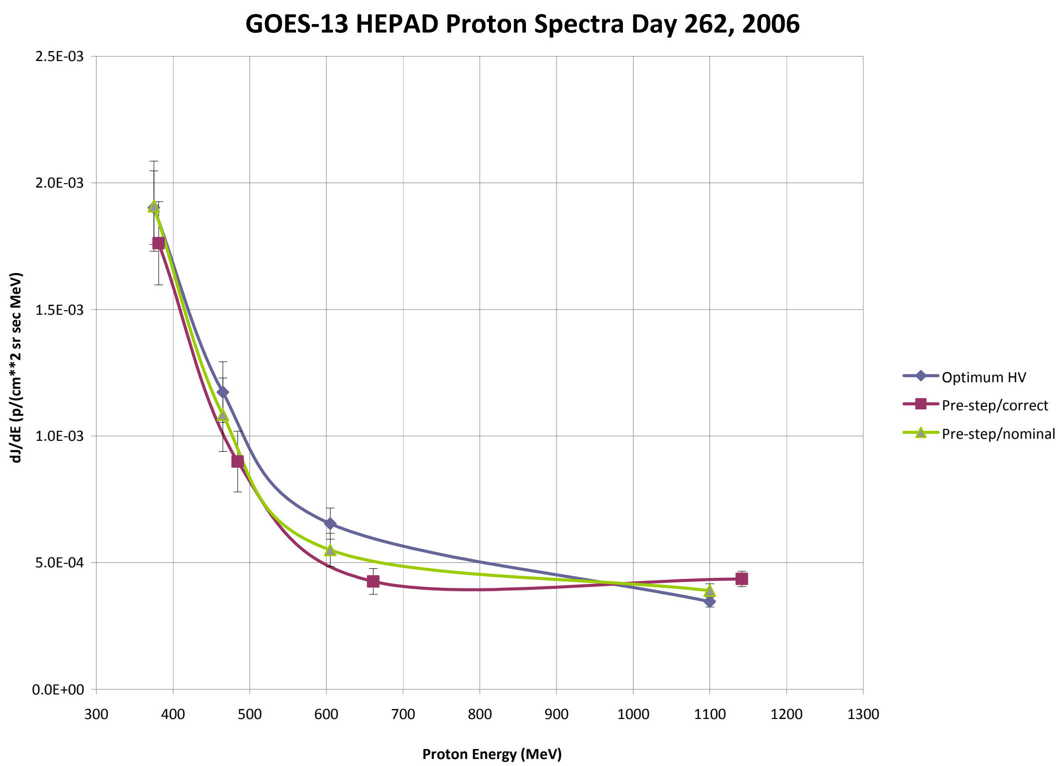

Figure 4-6. GOES-13 Proton Spectra for Day 262, 2006 Compared

Table 4-2. GOES-13 HEPAD Proton Spectra – Pre-Step Nominal and Optimum HV Step

HEPAD Proton Channel	Nominal Energy (MeV)	Pre-HV Step (150)		Optimum HV Step (154 +/- 3)	
		Nominal dJ/dE	Error	dJ/dE (#/(cm^2 sr s MeV))	Error
P8	375	1.908E-03	1.779E-04	1.902E-03	1.450E-04
P9	465	1.084E-03	1.448E-04	1.173E-03	1.198E-04
P10	605	5.501E-04	6.575E-05	6.543E-04	6.155E-05
P11	1100	3.901E-04	2.698E-05	3.462E-04	2.127E-05

Table 4-3. GOES-13 HEPAD Proton Spectra – Pre-Step Corrected and Interpolated

HEPAD Proton Channel	Corrected Channel Energies (MeV)	Average Channel Energy (MeV)	Corrected Pre-HV Step		Interpolated to Nominal Channel Energies	
			dJ/dE (#/(cm^2 sr s MeV))	Error	dJ/dE (#/(cm^2 sr s MeV))	Error
P8	333 - 430	381	1.761E-03	1.642E-04	1.814E-03	1.691E-04
P9	430 - 538	484	8.994E-04	1.202E-04	9.509E-04	1.271E-04
P10	538 – 784	661	4.261E-04	5.092E-05	4.249E-04	5.079E-05
P11	784 - 1500	1142	4.357E-04	3.014E-05	4.348E-04	3.008E-05

Table 4-4. GOES-13 HEPAD Proton Spectra Ratios

HEPAD Proton Channel	Nominal Energy (MeV)	Uncorrected Pre-HV Step		Corrected Pre-HV Step Interpolated to Nominal Channel Energies	
		Ratio to OPHV	Error	Ratio to OPHV	Error
P8	375	1.0029	0.0935	0.9534	0.1148
P9	465	0.9236	0.1234	0.8103	0.1363
P10	605	0.8407	0.1005	0.6495	0.0988
P11	1100	1.1267	0.0779	1.2560	0.1162

The ratios in Table 4-4 show that the uncorrected spectrum, using the nominal energy channel values, fits better than the corrected spectrum interpolated to the nominal energies. The P10 channel shows the largest deviation, but this channel is near the sharp change in proton spectrum slope, and this may be having a significant effect on the corrected, interpolated spectrum. One conclusion is that using the nominal energy channels with the PMT HV step low by 4 steps dose not cause more than about a 16% shift in the proton fluxes. Note that count statistics put about a 10% uncertainty on the proton flux ratios, so the differences are just marginally supported.

HEPAD proton spectra from GOES-11, GOES-10, and GOES-12 are given in Table 4-5. The values are in reasonable agreement with the GOES-13 values in Table 4-2, although there are some differences. Note that the spacecraft are all in different Magnetospheric locations, and this may explain some of the differences.

Table 4-5. GOES-11, -10, and-12 HEPAD Proton Spectra – Day 262, 2006

HEPAD Proton Channel	Nominal Energy (MeV)	GOES-11 HEPAD Flux	GOES-10 HEPAD Flux	GOES-12 HEPAD Flux
P8	375	2.281E-03	2.615E-03	2.221E-03
P9	465	1.147E-03	1.004E-03	1.056E-03
P10	605	3.834E-04	3.803E-04	3.964E-04
P11	1100	4.542E-04	3.806E-04	4.898E-04

The background proton spectra for the EPEAD/EPS and HEPAD on GOES-10, GOES-11, GOES-12, and GOES-13 all agree reasonably well. A similar comparison has been made using data from a solar proton event, using a 800 second data average centered on 1320 UTC, day 341, 2006. The GOES-13 proton spectra are shown in Figure 4-7, while the GOES-11, GOES-10, and GOES-12 proton spectra are shown in Figure 4-8, Figure 4-9, and Figure 4-10. The flux values are listed in Table 4-6, with flux errors (1-sigma uncertainty from counting statistics) being given only for GOES-13, since the other spacecraft data only provided count-rates, not the input counts.. All four GOES proton spectra are in reasonable agreement, considering that the spacecraft are all in different Magnetospheric locations.

The GOES-13 EPEAD P7 channels have been given an approximate slope correction, using the procedure in Section 3.8.3. Using the HEPAD data, which are from significantly narrower energy channels, the power law spectrum has an exponent g ~ 3.32, and this gives a correction factor of 7.8. The East and West P7 channel average, corrected for the slope, is also plotted in Figure 4-7. The corrected P7 channel is in much better agreement with the HEPAD spectrum, and shows that the HEPAD and EPEAD/EPS spectra are consistent.

Table 4-6. GOES-13, -11, -10, and-12 HEPAD Proton Spectra – Day 341, 2006

HEPAD Proton Channel	Nominal Energy (MeV)	GOES-13 HEPAD		GOES-11 HEPAD Flux	GOES-10 HEPAD Flux	GOES-12 HEPAD Flux
		Flux	Error			
P8	375	5.332E-03	3.281E-04	7.069E-03	6.782E-03	6.850E-03
P9	465	2.504E-03	2.249E-04	2.019E-03	2.186E-03	1.644E-03
P10	605	9.101E-04	9.541E-05	7.284E-04	7.559E-04	6.573E-04
P11	1100	3.825E-04	2.828E-05	5.517E-04	4.477E-04	5.008E-04

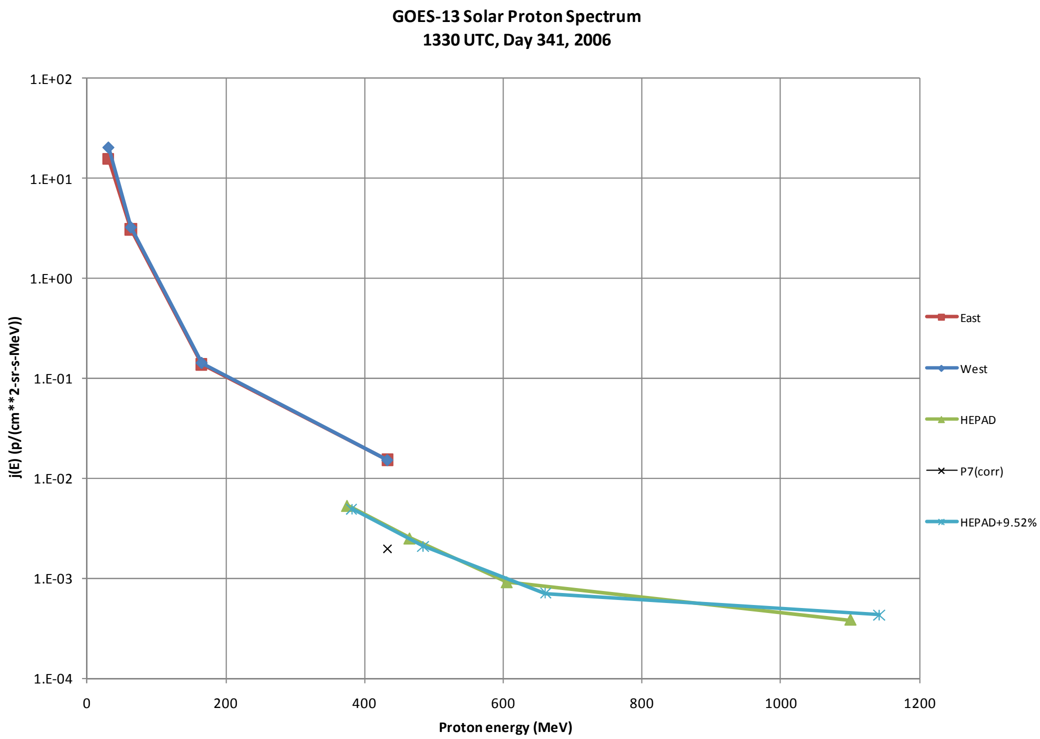

Figure 4-7. GOES-13 Measured Proton Spectra for Day 341, 2006

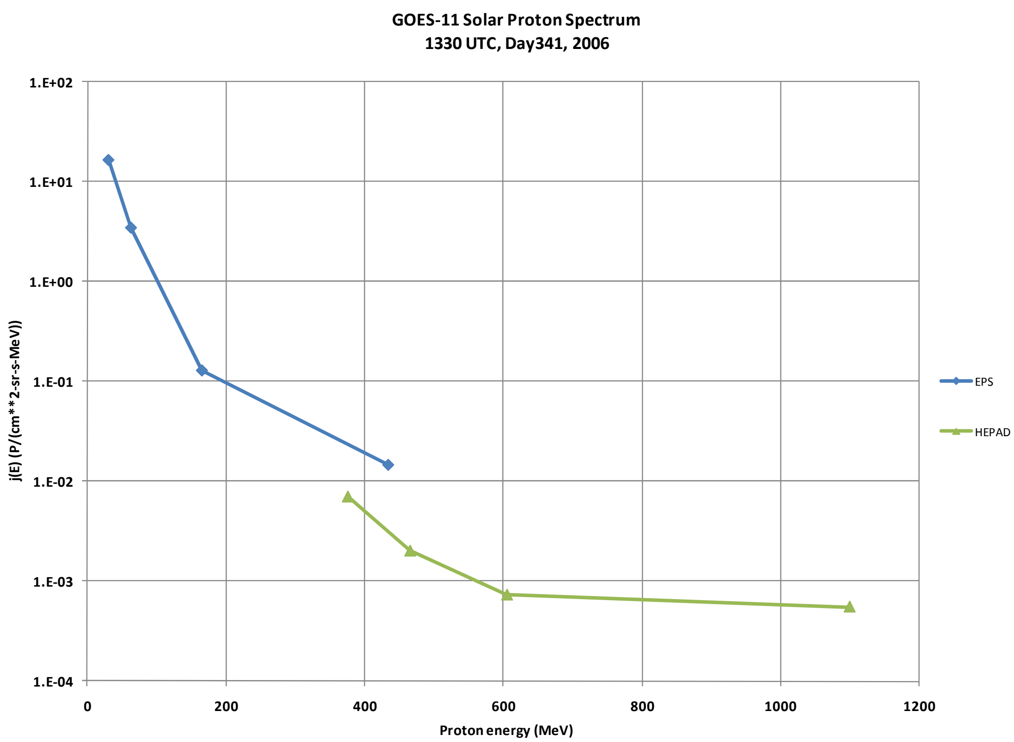

Figure 4-8. GOES-11 Measured Proton Spectra for Day 341, 2006

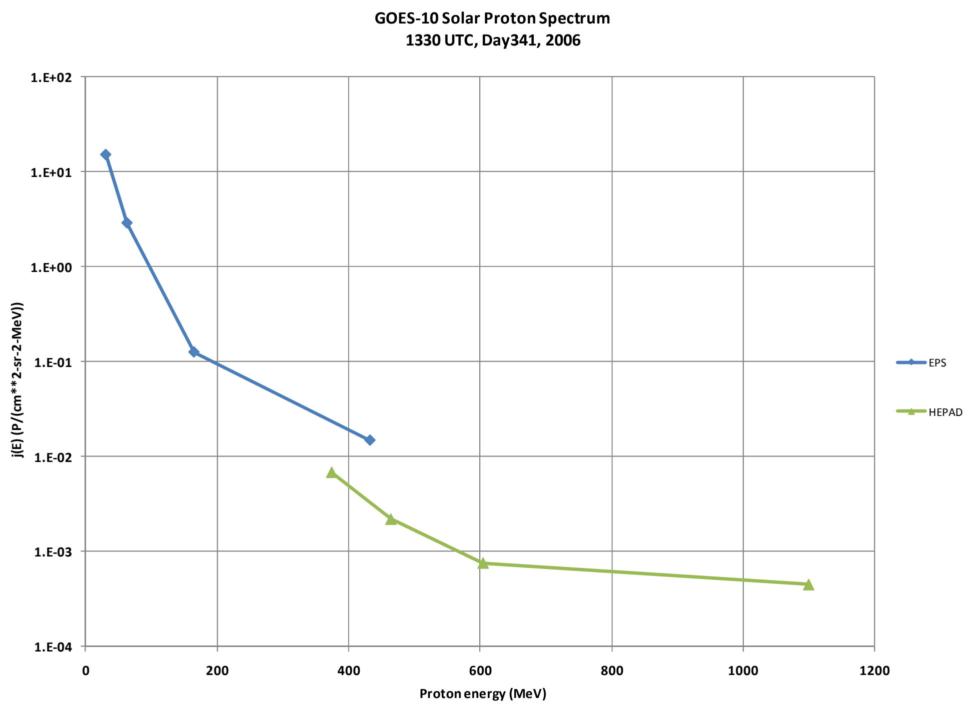

Figure 4-9. GOES-10 Measured Proton Spectra for Day 341, 2006

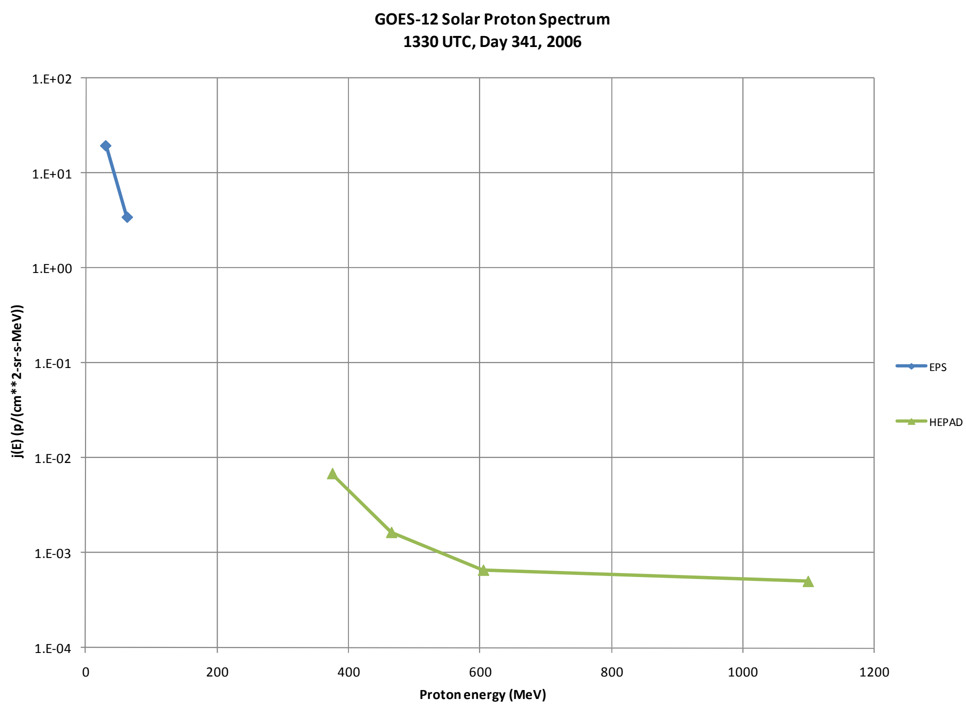

Figure 4-10. GOES-12 Measured Proton Spectra for Day 341, 2006

4.2 GOES-14 (-O)

4.2.1 PMT HV Stepping Data

The GOES-14 HEPAD PMT HV stepping test was performed on day 210, 2009. A data file was obtained covering the period 1630 UTC through 2030 UTC with PMT HV stepping occurring from 1656:40 UTC through 1926:40 UTC. A second data file was obtained, listing the HV step, the S3 count average, the S4 count average, and the S4/S3 ratio. The HV step data are shown in Table 4-7, with the periods of the S3 and S4 plateaus shown, and the S4 count increase from the plateau to the required increase of 36.1 counts/readout. This gives an in-orbit PMT operating HV step of 142, which is a 4 step increase, and corresponds to a gain that is low by a factor of 1.0234 = 1.095. All PMT thresholds are thus higher by this factor.

A plot of the S3 and S4 counts/readout is shown in Figure 4-11, which uses the first data set and plots each available S3 and S4 telemetry count. The S3 and S4 counts/readout both show the plateau discussed above. Section 5 contains additional discussion of the method for PMT gain measurement.

4.2.2 Background Proton Spectrum

The EPEAD-East, EPEAD-West, and HEPAD proton spectra for GOES-14 for a 1000 second data average from before the PMT HV stepping are shown in Figure 4-11. The plot shows proton channels P4 through P11, with the HEPAD PMT at HV step 138, which gives a gain low by 9.5%. The two EPEAD spectra are in good agreement, with some minor deviations for the P4 and P5 channels, which are most likely due to east/west asymmetry from the earth's magnetic field effects. The higher energy protons are less influenced by the earth's magnetic field, and thus show little difference. Note that the geosynchronous proton spectra are influenced by geomagnetic and solar activity, and can be different for different local times. The HEPAD spectrum is close to that from the EPEADs, but is for a low gain which means that the true proton energies are higher than the nominal values used. This HEPAD channel energy shift is discussed in more detail below. For this period the proton spectrum is the Cosmic Ray background proton flux, for near solar minimum conditions (see spectral plots in PANA-SEM-3 and PANA-SEM-5).

Table 4-7. GOES-14 HEPAD PMT HV Stepping Data – Day 210, 2009

Level	S4	S3	S4/S3		S3 Plateau	S4 Plateau
100	105.9	893.9	0.1185			
110	144.3	1087.5	0.1327			
120	161.9	1420.3	0.1142			
130	192.1	1751.5	0.1098			
131	196.3	1778.7	0.1103			
132	197.9	1817.1	0.1090			
133	202.1	1836.3	0.1102		Start	Start
134	211.7	1913.1	0.1106			Average
135	215.5	1893.9	0.1138		Average	5 values
136	211.9	1941.9	0.1091		8 values	212.2
137	219.9	1983.5	0.1110		1958.1	End
138	229.1	2068.3	0.1108			
138	224.3	2044.3	0.1098			
138	226.9	1983.5	0.1145		End	OPHV S4
139	230.6	2124.3	0.1086			212.2+36.1
140	236.5	2137.1	0.1107			= 248.3
141	242.9	2162.7	0.1124			
142	243.5	2213.9	0.1100			~OPHV
143	264.3	2265.1	0.1168			
144	269.1	2341.9	0.1150		Pre-launch	
145	275.1	2431.5	0.1132		Plateau	
146	282.7	2444.3	0.1157		= 735	
147	295.5	2495.5	0.1185			
148	327.5	2623.5	0.1248		In-orbit	
149	306.7	2610.7	0.1175		Increase	
150	324.3	2674.7	0.1214		= 1223	
151	340.3	2777.1	0.1227			
152	372.3	2777.1	0.1341			
153	375.5	2802.7	0.1342			
154	396.7	2943.5	0.1348			
155	426.7	2994.7	0.1425			
156	444.3	3084.3	0.1440			
157	477.9	3173.9	0.1507			
158	500.3	3215.5	0.1556			
159	534.3	3305.1	0.1618			
160	559.5	3346.7	0.1672			

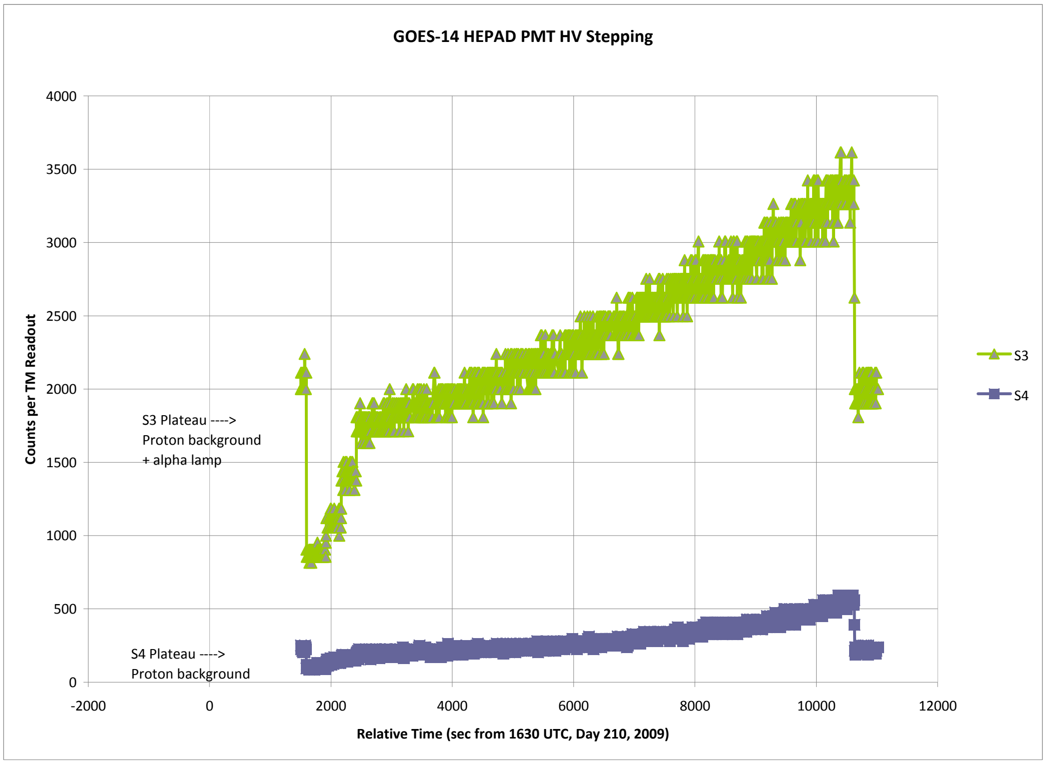

Figure 4-11. GOES-14 HEPAD PMT HV Stepping S3 and S4 Plots

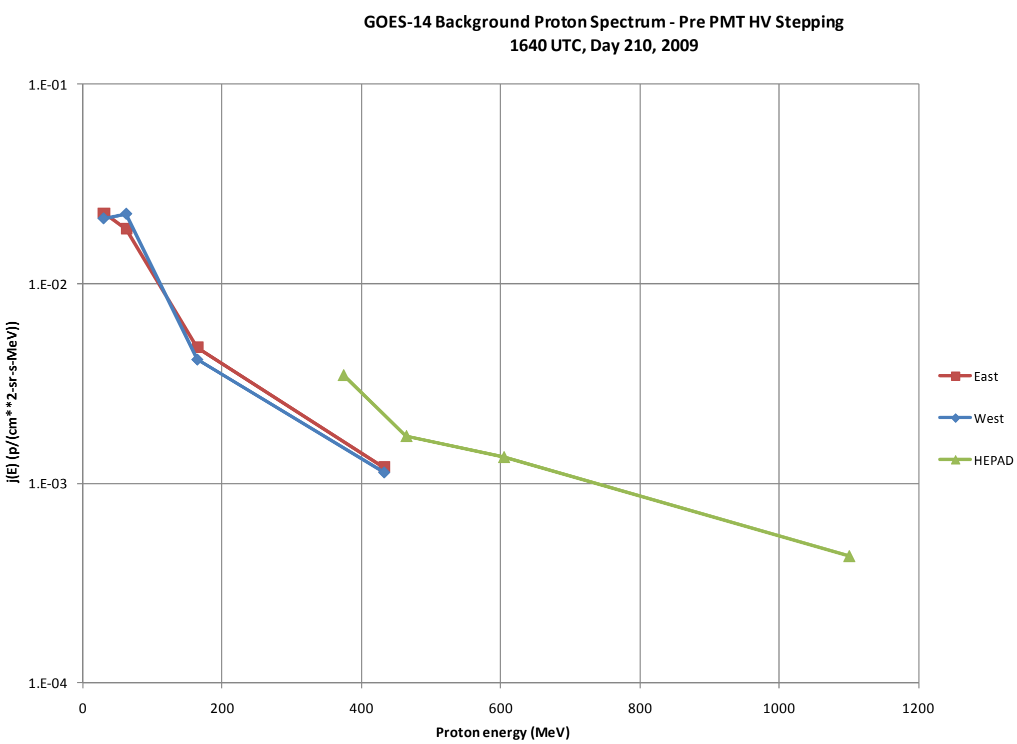

Figure 4-12. GOES-14 Measured Proton Spectra for Day 210, 2009

More detail of the GOES-14 HEPAD proton spectrum is given in Figure 4-13, where the uncorrected pre-step spectrum, the pre-step spectrum corrected for the low PMT gain (9.5%), and the correct proton spectrum for the optimum HV step of 142, are all shown, along with the 1-sigma errors from count statistics. The listed optimum HV step spectrum is actually for an HV step range of 140 to 144 to improve count statistics, but this should have only a minor effect on the proton spectrum. Details of the fluxes and ratios are given in Table 4-8, Table 4-9, and Table 4-10.

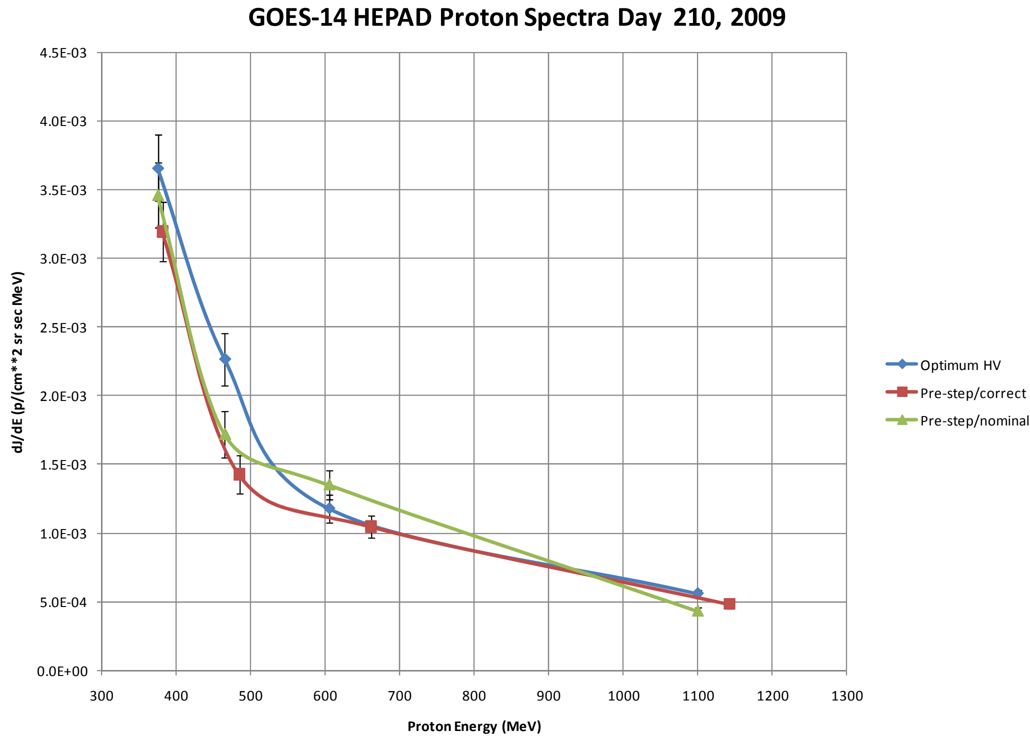

Figure 4-13. GOES-14 HEPAD Proton Spectra for Day 210, 2009 Compared

Table 4-8. GOES-14 HEPAD Proton Spectra – Pre-Step Nominal and Optimum HV Step

HEPAD Proton Channel	Nominal Energy (MeV)	Pre-HV Step (138)		Optimum HV Step (142 +/- 2)	
		Nominal dJ/dE	Error	dJ/dE (#/(cm^2 sr s MeV))	Error
P8	375	3.460E-03	2.354E-04	3.658E-03	2.304E-04
P9	465	1.720E-03	1.720E-04	2.267E-03	2.052E-04
P10	605	1.353E-03	1.050E-04	1.179E-03	9.624E-05
P11	1100	4.337E-04	2.749E-05	5.587E-04	3.351E-05

Table 4-9. GOES-14 HEPAD Proton Spectra – Pre-Step Corrected and Interpolated

HEPAD Proton Channel	Corrected Channel Energies (MeV)	Average Channel Energy (MeV)	Corrected Pre-HV Step		Interpolated to Nominal Channel Energies	
			dJ/dE (#/(cm^2 sr s MeV))	Error	dJ/dE (#/(cm^2 sr s MeV))	Error
P8	333 - 430	381	3.194E-03	2.173E-04	3.301E-03	2.246E-04
P9	430 - 538	484	1.428E-03	1.428E-04	1.469E-03	1.469E-04
P10	538 – 784	661	1.048E-03	8.132E-05	1.113E-03	8.642E-05
P11	784 - 1500	1142	4.844E-04	3.070E-05	5.335E-04	3.381E-05

Table 4-10. GOES-14 HEPAD Proton Spectra Ratios

HEPAD Proton Channel	Nominal Energy (MeV)	Uncorrected Pre-HV Step		Corrected Pre-HV Step Interpolated to Nominal Channel Energies	
		Ratio to OPHV	Error	Ratio to OPHV	Error
P8	375	0.9458	0.0877	0.9025	0.0837
P9	465	0.7590	0.1024	0.6480	0.0874
P10	605	1.1477	0.1293	0.9447	0.1064
P11	1100	0.7763	0.0677	0.9548	0.0833

The ratios in Table 4-10 show that the corrected spectrum interpolated to the nominal energies fits better than the uncorrected spectrum. The P9 channel shows the largest deviation, but this channel is near the sharp change in proton spectrum slope, and this may be having a significant effect on the corrected, interpolated spectrum. One conclusion is that using the nominal energy channels with the PMT HV step low by 4 steps dose not cause more than about a 25% shift in the proton fluxes. Note that count statistics put about a 10% to 15% uncertainty on the proton flux ratios, so the differences are just marginally supported.

4.3 GOES-15 (-P)

4.3.1 PMT HV Stepping Data

The GOES-15 HEPAD PMT HV stepping test was performed on day 92, 2010. A data file was obtained covering the period 1230 UTC through 1610 UTC with PMT HV stepping occurring from 1330:10 UTC through 1520:00 UTC. A second data file was obtained, listing the HV step, the S3 count average, the S4 count average, and the S4/S3 ratio. The HV step data are shown in Table 4-11, with the periods of the S3 and S4 plateaus shown, and the S4 count increase from the plateau to the required increase of 232.7 counts/readout. This gives an in-orbit PMT operating HV step of 166, which is a 12 step increase, and corresponds to a gain that is low by a factor of 1.02312 = 1.314. All PMT thresholds are thus higher by this factor.

A plot of the S3 and S4 counts/readout is shown in Figure 4-14, which uses the first data set and plots each available S3 and S4 telemetry count. The S3 and S4 counts/readout both show the plateau discussed above. Section 5 contains additional discussion of the method for PMT gain measurement.

Table 4-11. GOES-15 HEPAD PMT HV Stepping Data – Day 92, 2010

Level	S4	S3	S4/S3		S3 Plateau	S4 Plateau
100	60.3	642.7	0.0937			
110	88.0	774.7	0.1136			
120	118.1	845.9	0.1396			
130	141.2	889.1	0.1588			
140	177.1	970.7	0.1824			
145	198.5	1001.1	0.1983		Start	Start
146	205.1	1008.3	0.2034			Average
147	213.5	1011.5	0.2111		Average	4 values
148	208.5	1021.9	0.2040		9 values	206.4/End
149	218.9	1012.3	0.2162		1020.4	
150	225.9	1016.3	0.2223			
151	230.3	1022.7	0.2252			OPHV S4
152	246.7	1049.9	0.2350			206.4+232.7
153	251.3	1039.5	0.2418		End	= 439.1
154	267.3	1083.5	0.2467			
154	269.1	1074.7	0.2504			
154	255.9	1074.7	0.2381			
155	270.5	1081.1	0.2502			
156	284.3	1069.1	0.2659			
157	301.9	1100.3	0.2744		Pre-launch	
158	306.7	1113.1	0.2755		Plateau	
159	325.9	1119.5	0.2911		= 613.9	
160	325.9	1100.3	0.2962			
161	341.9	1132.3	0.3020		In-orbit	
162	348.3	1132.3	0.3076		Increase	
163	372.7	1177.1	0.3166		= 406.5	
164	391.5	1164.3	0.3363			
165	395.9	1170.7	0.3382			
166	426.7	1189.9	0.3586			~OPHV
167	451.5	1228.3	0.3676			
168	453.9	1209.1	0.3754			
169	470.7	1234.7	0.3812			
170	480.3	1266.7	0.3792			
171	522.3	1311.5	0.3982			
172	513.9	1305.1	0.3938			
173	549.9	1324.3	0.4152			
174	562.7	1356.3	0.4149			

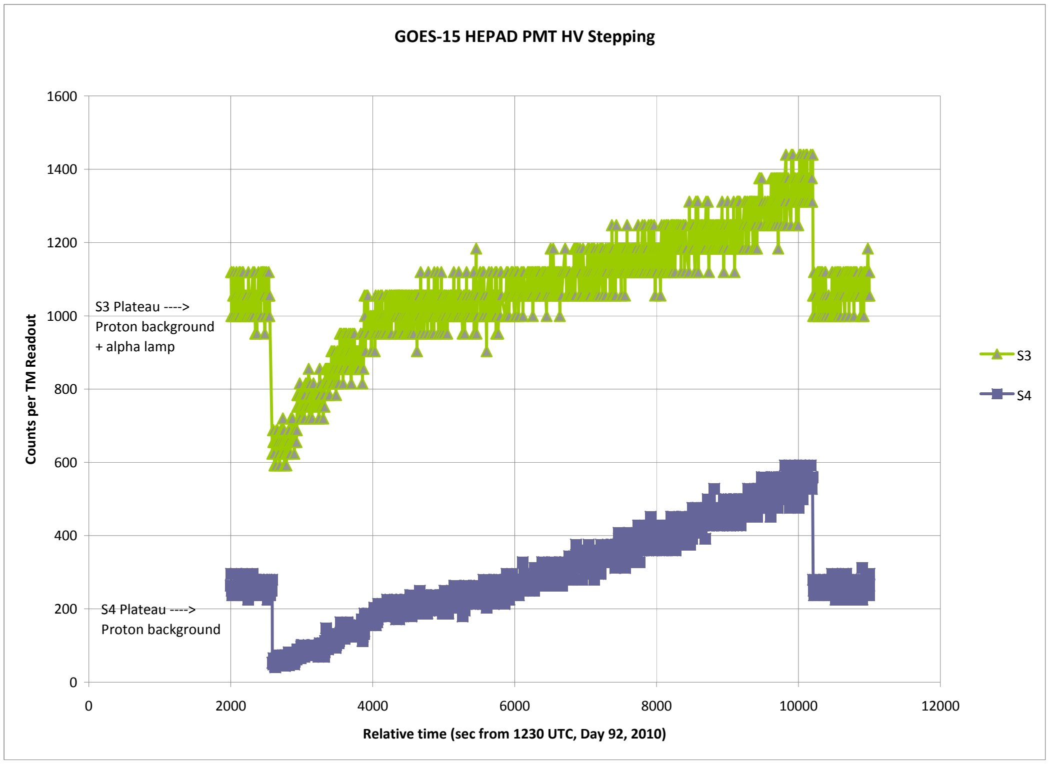

Figure 4-14. GOES-15 HEPAD PMT HV Stepping S3 and S4 Plots, Day 92

A second GOES-15 HEPAD PMT HV stepping test was performed on day 113, 2010. A data file was obtained covering the period 1800 UTC through 2140 UTC with PMT HV stepping occurring from 1859:20 UTC through 2096:40 UTC. A second data file was obtained, listing the HV step, the S3 count average, the S4 count average, and the S4/S3 ratio. The HV step data are shown in Table 4-12, with the periods of the S3 and S4 plateaus shown, and the S4 count increase from the plateau to the required increase of 232.7 counts/readout. This gives an in-orbit PMT operating HV step of 166, which is a 12 step increase, and corresponds to a PMT gain increase of 31.4% (x1.341). A plot of the S3 and S4 counts/readout is shown in Figure 4-15. The S3 and S4 counts/readout both show the plateau discussed above. Section 5 contains additional discussion of the method for PMT gain measurement.

Table 4-12. GOES-15 HEPAD PMT HV Stepping Data – Day 113, 2010

Level	S4	S3	S4/S3		S3 Plateau	S4 Plateau
100	59.7	687.5	0.0868			
110	94.7	786.7	0.1204			
120	117.4	861.1	0.1363			
130	130.6	908.3	0.1438			
140	172.3	937.1	0.1839			
145	196.5	961.1	0.2045		Start	Start
146	202.1	980.3	0.2062			Average
147	206.1	971.5	0.2121		Average	5 values
148	217.5	970.7	0.2241		10 values	207.5
149	215.1	956.3	0.2249		941.8	End
150	231.5	961.1	0.2409			
151	240.3	961.1	0.2500			OPHV S4
152	241.1	976.3	0.2470			207.5+232.7
153	250.9	986.7	0.2543			= 440.2
154	265.9	993.1	0.2677		End	
154	273.5	997.1	0.2743			
154	261.1	981.1	0.2661			
155	279.5	990.7	0.2821			
156	287.5	985.1	0.2918			
157	295.5	975.5	0.3029		Pre-launch	
158	314.7	971.5	0.3239		Plateau	
159	330.7	991.5	0.3335		= 613.9	
160	340.3	1016.3	0.3348			
161	348.3	996.3	0.3496		In-orbit	
162	367.9	1006.7	0.3655		Increase	
163	383.5	1000.3	0.3834		= 327.9	
164	395.5	1023.5	0.3864			
165	419.9	1033.9	0.4061			
166	425.9	1016.3	0.4191			~OPHV
167	439.9	1021.9	0.4305			
168	475.9	1039.5	0.4578			
169	490.7	1056.3	0.4645			
170	503.9	1056.3	0.4770			
171	505.9	1045.1	0.4841			
172	513.9	1045.1	0.4917			
173	537.1	1062.7	0.5054			
174	559.5	1056.3	0.5297			

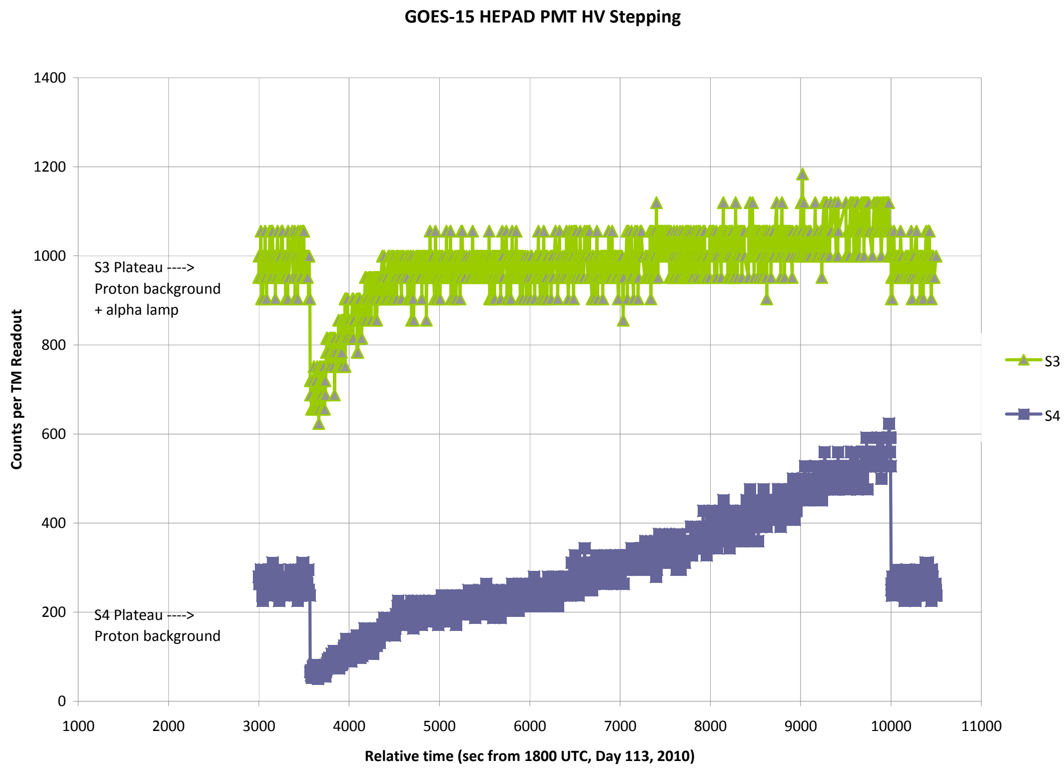

Figure 4-15. GOES-15 HEPAD PMT HV Stepping S3 and S4 Plots, Day 113

4.3.2 Background Proton Spectrum

The EPEAD-East, EPEAD-West, and HEPAD proton spectra for GOES-15 for a 1000 second data average from before the PMT HV stepping on day 92, 2010 are shown in Figure 4-16. The plot shows proton channels P4 through P11. The two EPEAD spectra are in good agreement. The HEPAD spectrum is close to that from the EPEADs. For this period the proton spectrum is the Cosmic Ray background proton flux, for solar minimum conditions (see spectral plots in PANA-SEM-3 and PANA-SEM-5).

A second set of EPEAD-East, EPEAD-West, and HEPAD proton spectra for GOES-17 for a 1000 second data average from before the second PMT HV stepping on day 113 are shown in Figure 4-17. The plot shows proton channels P4 through P11. The two EPEAD spectra are in good agreement. The HEPAD spectrum is close to that from the EPEADs. The proton spectra are in good agreement with the day 92 measurements.

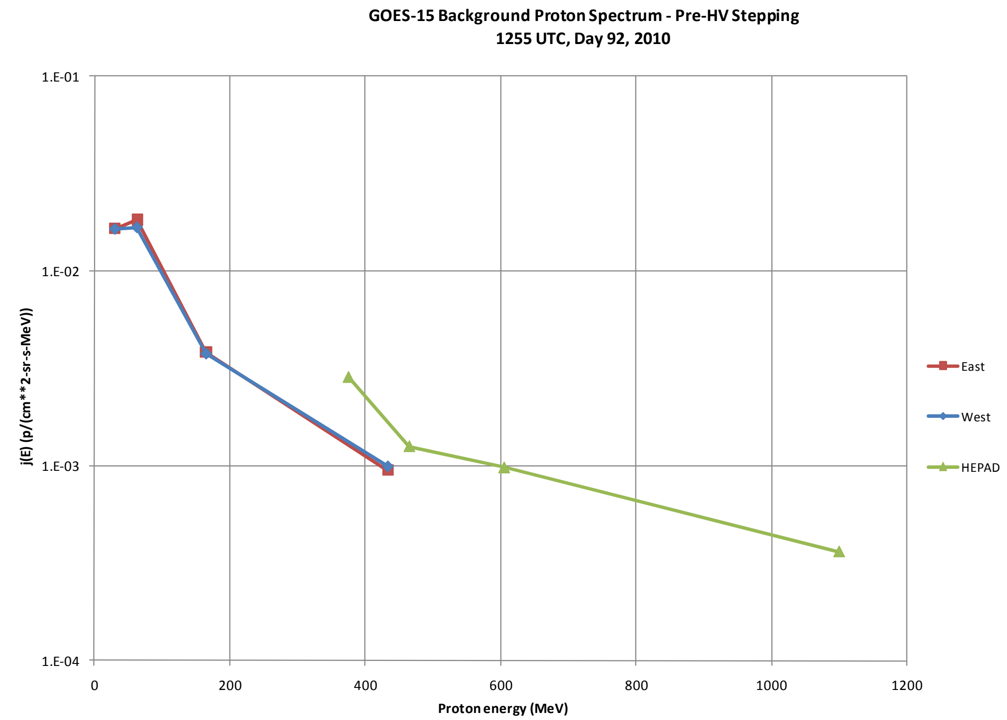

Figure 4-16. GOES-15 Measured Proton Spectra for Day 92, 2010

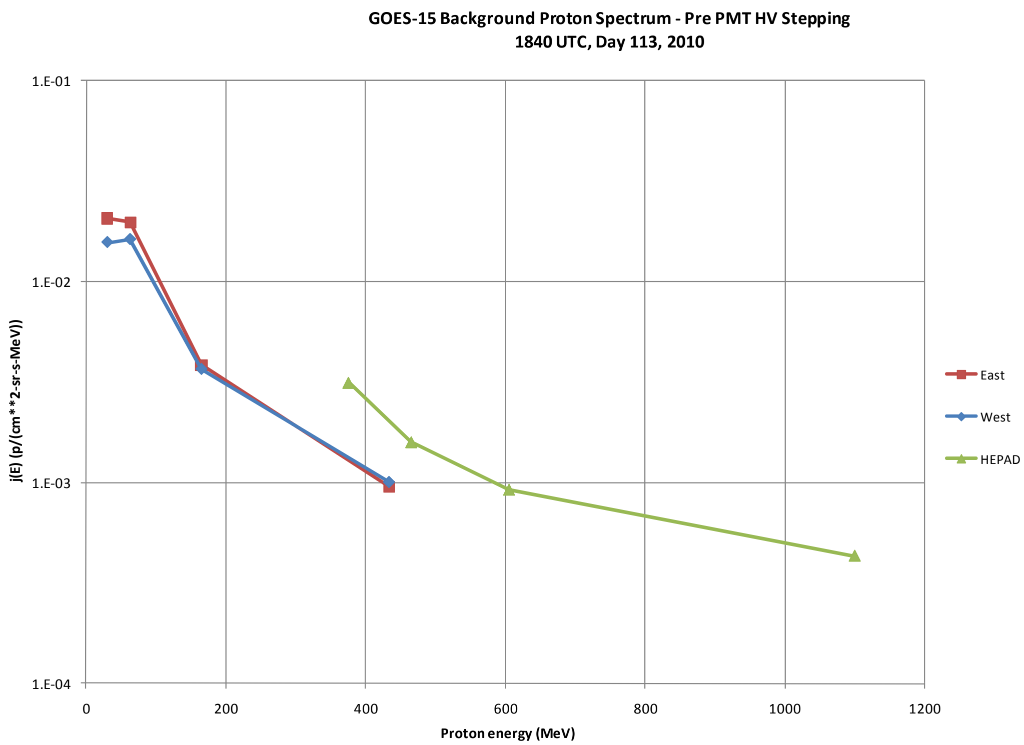

Figure 4-17. GOES-15 Measured Proton Spectra for Day 113, 2010

More detail of the GOES-15 HEPAD proton spectrum is given in Figure 4-18 for Day 92, 2010, where the uncorrected pre-step spectrum, the pre-step spectrum corrected for the low PMT gain (31.4%), and the correct proton spectrum for near the optimum HV step of 166, are all shown, along with the 1-sigma errors from count statistics. The listed near-optimum HV step spectrum is actually for an HV step range of 165 to 171 to improve count statistics, but this should have only a minor effect on the proton spectrum. The shift of +2 steps for an average of 168 should also not have a significant effect on the proton spectrum. Details of the fluxes and ratios are given in Table 4-13, Table 4-14, and Table 4-15.

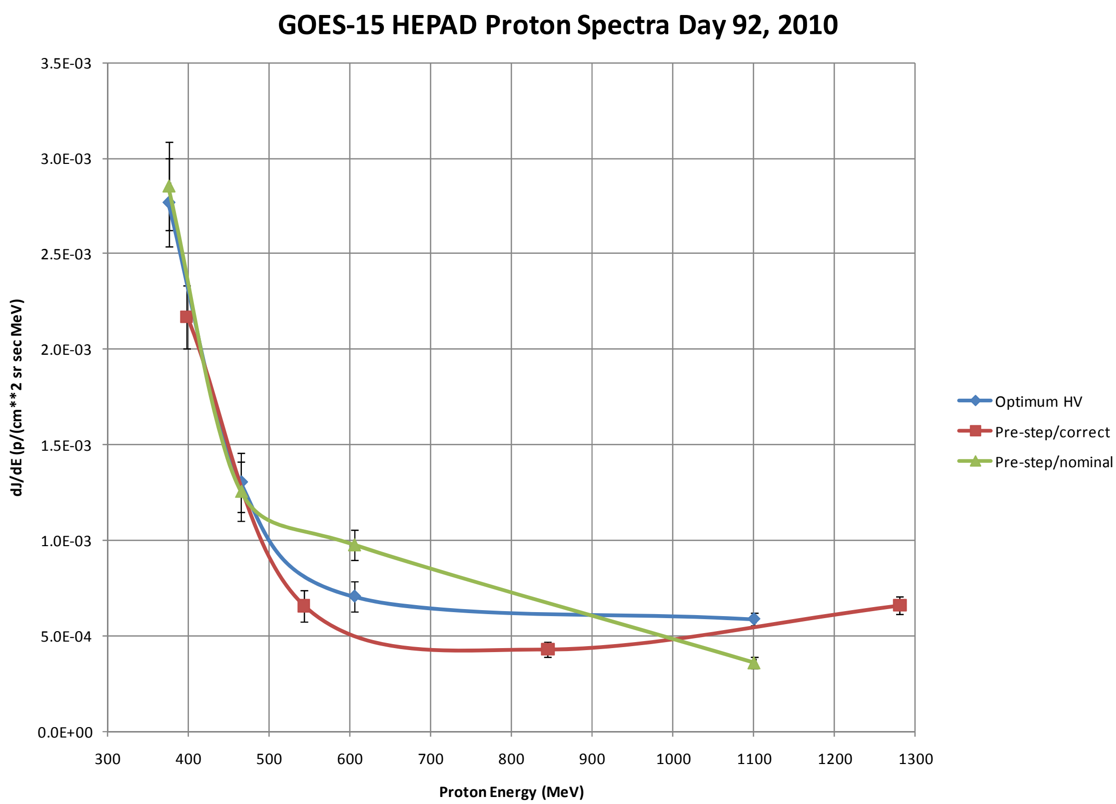

Figure 4-18. GOES-15 HEPAD Proton Spectra for Day 92, 2010 Compared

Table 4-13. GOES-15 HEPAD Spectra – Pre-Step Nominal and Optimum HV Step – Day 92, 2010

HEPAD Proton Channel	Nominal Energy (MeV)	Pre-HV Step (154)		Optimum HV Step (168 +/- 3)	
		Nominal dJ/dE	Error	dJ/dE (#/(cm^2 sr s MeV))	Error
P8	375	2.853E-03	2.176E-04	2.768E-03	2.314E-04
P9	465	1.258E-03	1.560E-04	1.304E-03	1.526E-04
P10	605	9.787E-04	8.617E-05	7.059E-04	8.045E-05
P11	1100	3.621E-04	2.599E-05	5.874E-04	3.253E-05

Table 4-14. GOES-15 HEPAD Spectra – Pre-Step Corrected and Interpolated – Day 92, 2010

HEPAD Proton Channel	Corrected Channel Energies (MeV)	Average Channel Energy (MeV)	Corrected Pre-HV Step		Interpolated to Nominal Channel Energies	
			dJ/dE (#/(cm^2 sr s MeV))	Error	dJ/dE (#/(cm^2 sr s MeV))	Error
P8	338 – 456	397	2.170E-03	1.655E-04	2.403E-03	1.832E-04
P9	456 – 628	542	6.592E-04	8.176E-05	1.465E-03	1.817E-04
P10	628 – 1161	844	4.299E-04	3.785E-05	6.116E-04	5.385E-05
P11	1061 - 1500	1280	6.595E-04	4.735E-05	5.645E-04	4.053E-05

Table 4-15. GOES-15 HEPAD Proton Spectra Ratios – Day 92, 2010

HEPAD Proton Channel	Nominal Energy (MeV)	Uncorrected Pre-HV Step		Corrected Pre-HV Step Interpolated to Nominal Channel Energies	
		Ratio to OPHV	Error	Ratio to OPHV	Error
P8	375	1.0310	0.1167	0.8682	0.0982
P9	465	0.9646	0.1645	1.1233	0.1916
P10	605	1.3865	0.1997	0.8664	0.1248
P11	1100	0.6163	0.0559	0.9609	0.0871

The ratios in Table 4-15 show that the corrected spectrum interpolated to the nominal energies fits better than the uncorrected spectrum. The P8 and P9 channels show the largest deviation, but the P9 channel is near the sharp change in proton spectrum slope, and this may be having a significant effect on the corrected, interpolated spectrum. One conclusion is that using the nominal energy channels with the PMT HV step low by 12 steps can lead to errors of about 40% shift in the proton fluxes at P10 and P11. The interpolated spectra have errors of about 13% or less. Note that count statistics put about a 10% to 20% uncertainty on the proton flux ratios, so the latter differences are just marginally supported.

More detail of the GOES-15 HEPAD proton spectrum for Day 113, 2010 is given in Figure 4-19, where the uncorrected pre-step spectrum, the pre-step spectrum corrected for the low PMT gain (31.4%), and the correct proton spectrum for the optimum HV step of 166, are all shown, along with the 1-sigma errors from count statistics. The listed near-optimum HV step spectrum is actually for an HV step range of 164 to 170 to improve count statistics, but this should have only a minor effect on the proton spectrum. The shift of +1 step for an average of 167 should also not have a significant effect on the proton spectrum. Details of the fluxes and ratios are given in Table 4-16, Table 4-17, and Table 4-18.

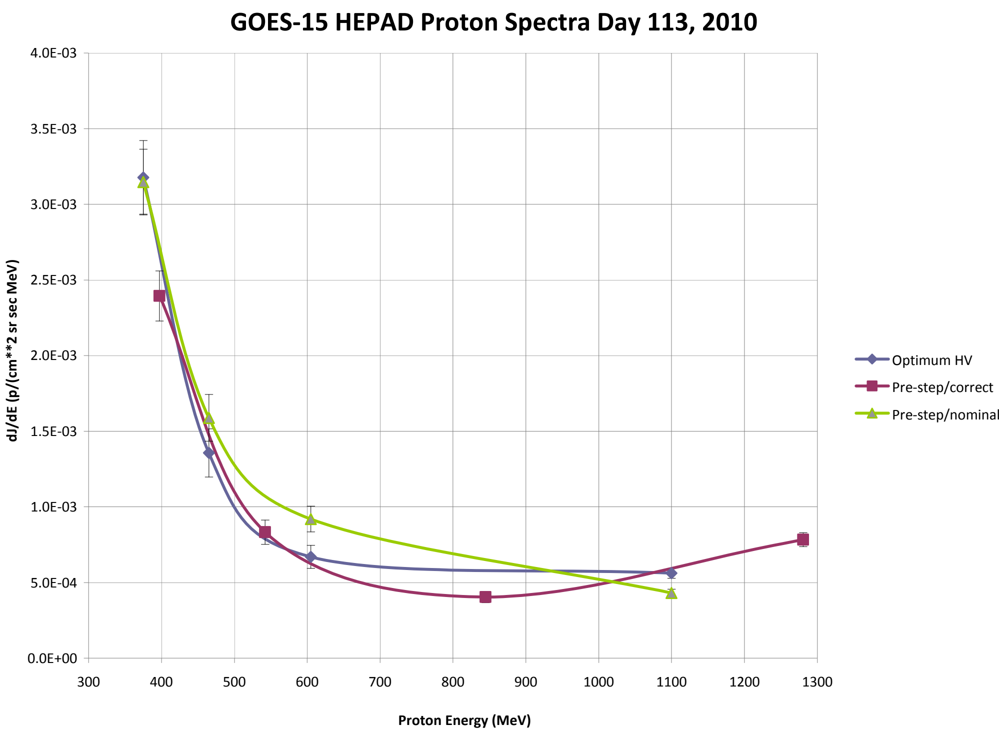

Figure 4-19. GOES-15 HEPAD Proton Spectra for Day 113, 2010 Compared

Table 4-16. GOES-15 HEPAD Spectra – Pre-Step Nominal and Optimum HV Step – Day 113, 2010

HEPAD Proton Channel	Nominal Energy (MeV)	Pre-HV Step (154)		Optimum HV Step (167 +/- 3)	
		Nominal dJ/dE	Error	dJ/dE (#/(cm^2 sr s MeV))	Error
P8	375	3.147E-03	2.171E-04	3.177E-03	2.430E-04
P9	465	1.588E-03	1.543E-04	1.356E-03	1.587E-04
P10	605	9.194E-04	8.500E-05	6.689E-04	7.673E-05
P11	1100	4.300E-04	2.534E-05	5.607E-04	3.357E-05

Table 4-17. GOES-15 HEPAD Spectra – Pre-Step Corrected and Interpolated – Day 113, 2010

HEPAD Proton Channel	Corrected Channel Energies (MeV)	Average Channel Energy (MeV)	Corrected Pre-HV Step		Interpolated to Nominal Channel Energies	
			dJ/dE (#/(cm^2 sr s MeV))	Error	dJ/dE (#/(cm^2 sr s MeV))	Error
P8	338 – 456	397	2.393E-03	1.652E-04	2.634E-03	1.817E-04
P9	456 – 628	542	8.322E-04	8.083E-05	1.665E-03	1.617E-04
P10	628 – 1161	844	4.038E-04	3.733E-05	7.434E-04	6.873E-05
P11	1061 - 1500	1280	7.832E-04	4.615E-05	6.262E-04	3.690E-05

Table 4-18. GOES-15 HEPAD Proton Spectra Ratios – Day 113, 2010

HEPAD Proton Channel	Nominal Energy (MeV)	Uncorrected Pre-HV Step		Corrected Pre-HV Step Interpolated to Nominal Channel Energies	
		Ratio to OPHV	Error	Ratio to OPHV	Error
P8	375	0.9904	0.1020	0.8289	0.0854
P9	465	1.1710	0.1781	1.2274	0.1867
P10	605	1.3745	0.2025	1.1114	0.1637
P11	1100	0.7668	0.0644	1.1167	0.0938

The ratios in Table 4-18 show that the corrected spectrum interpolated to the nominal energies fits better than the uncorrected spectrum. The P8 and P9 channels show the largest deviation, but the P9 channel is near the sharp change in proton spectrum slope, and this may be having a significant effect on the corrected, interpolated spectrum. One conclusion is that using the nominal energy channels with the PMT HV step low by 12 steps can lead to errors of about 40% shift in the proton fluxes at P10 and P11. The interpolated spectra have errors of about 23% or less. Note that count statistics put about a 10% to 20% uncertainty on the proton flux ratios, so the latter differences are just marginally supported.

4.4 GOES-13 (-N) Electron Fluxes and Effects

The GOES-13 HEPAD PMT HV stepping performed on day 262, 2006 was during a period of moderately high electron fluxes, with variations of about a factor of 4 over the data period. The electron flux data for this period are shown in Figure 4-20. A plot of the S3, S4, E2E, and E2W data are shown in Figure 4-21, and shows no significant effect of the electron flux at that level on the S3 and S4 counts. A plot of the S1, S2, and S5 counts along with the E2E and E2W counts is shown in Figure 4-22, and shows that the S1 and S2 SSD singles counts have a moderate effect from the high energy electron flux, with a very low effect in the S5 SSD coincidence count.

Figure 4-20. GOES-13 Electron Flux Data for Day 262, 2006

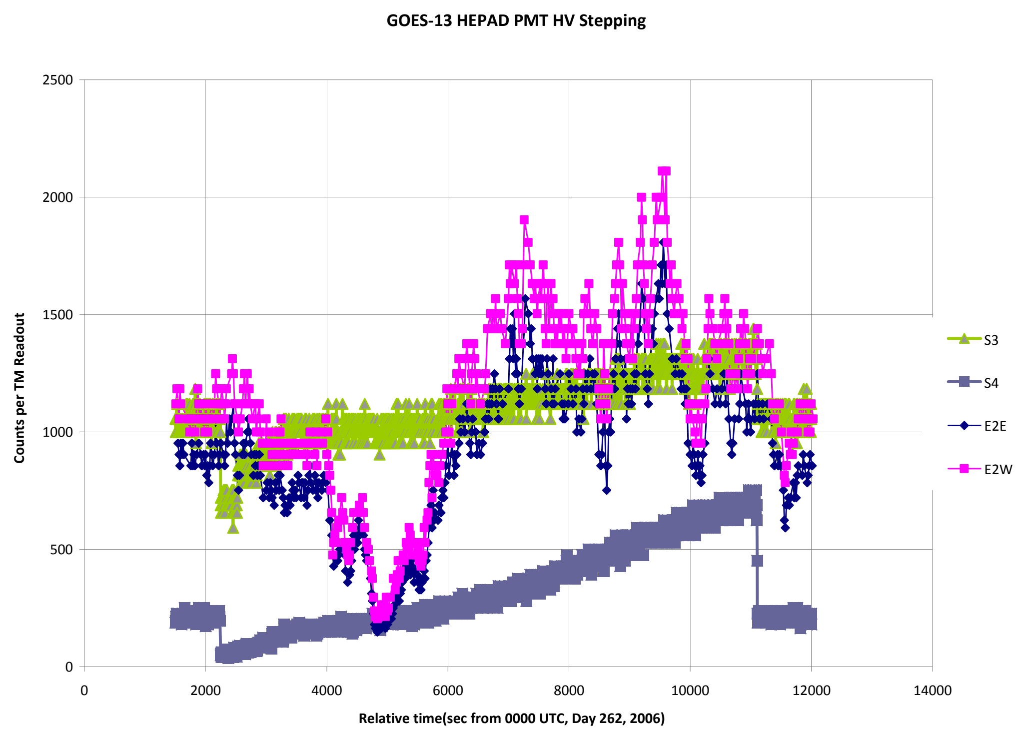

Figure 4-21. GOES-13 HEPAD S3 and S4, and Electron E2E and E2W Data for Day 262, 2006

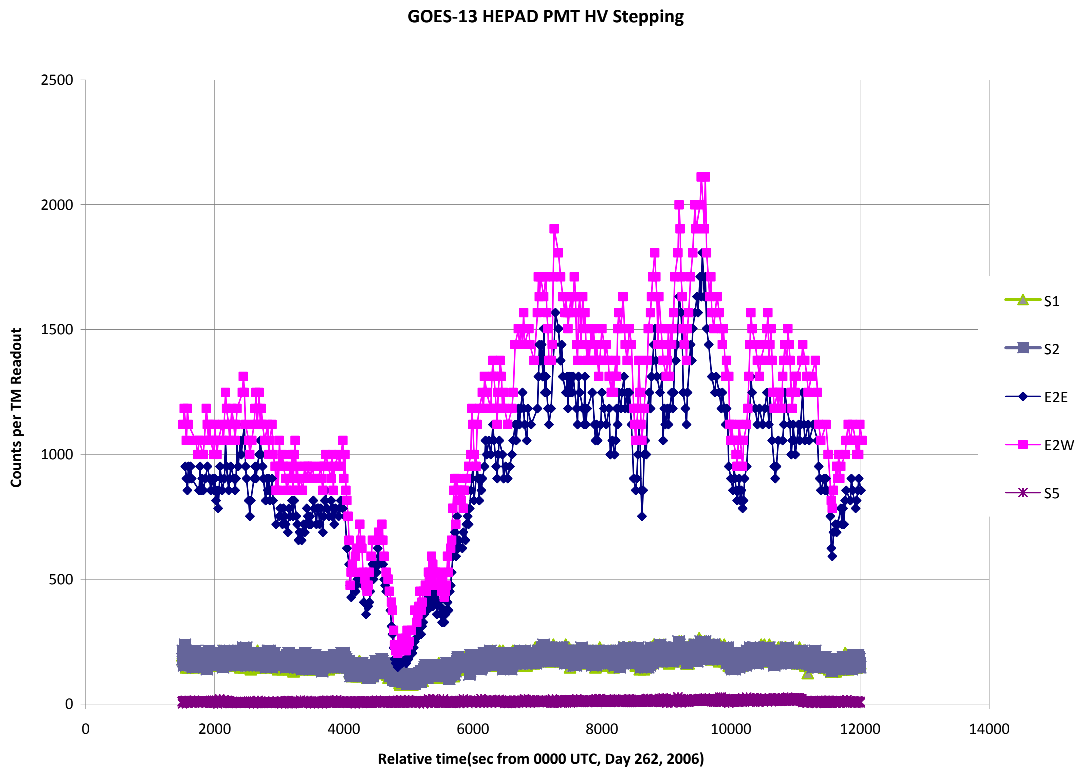

Figure 4-22. GOES-13 HEPAD S1, S2 and S5, and Electron E2E and E2W Data for Day 262, 2006

4.5 Discussion of GOES Background Proton Measurements

The background proton spectra shown in Figures 4-2 through 4-5, 4-12, 4-16, and 4-17 all show the P7 flux as about a factor of 2 below the HEPAD P8 and P9 fluxes. This difference can arise in two ways, which are discussed below.

The background Cosmic Ray (CR) proton spectra generally peak in the few hundred MeV region, with a minimum below 100 MeV before a rise towards lower energies. CR proton and helium spectra are shown in Figure 4-23, which is taken from the “Handbook of Geophysics and the Space Environment”, Figure 6-2. The proton fluxes plotted are a factor of 5 high to avoid overlap with the helium spectra. The range of spectra are for solar minimum (highest flux values) and solar maximum (lowest flux values) conditions.

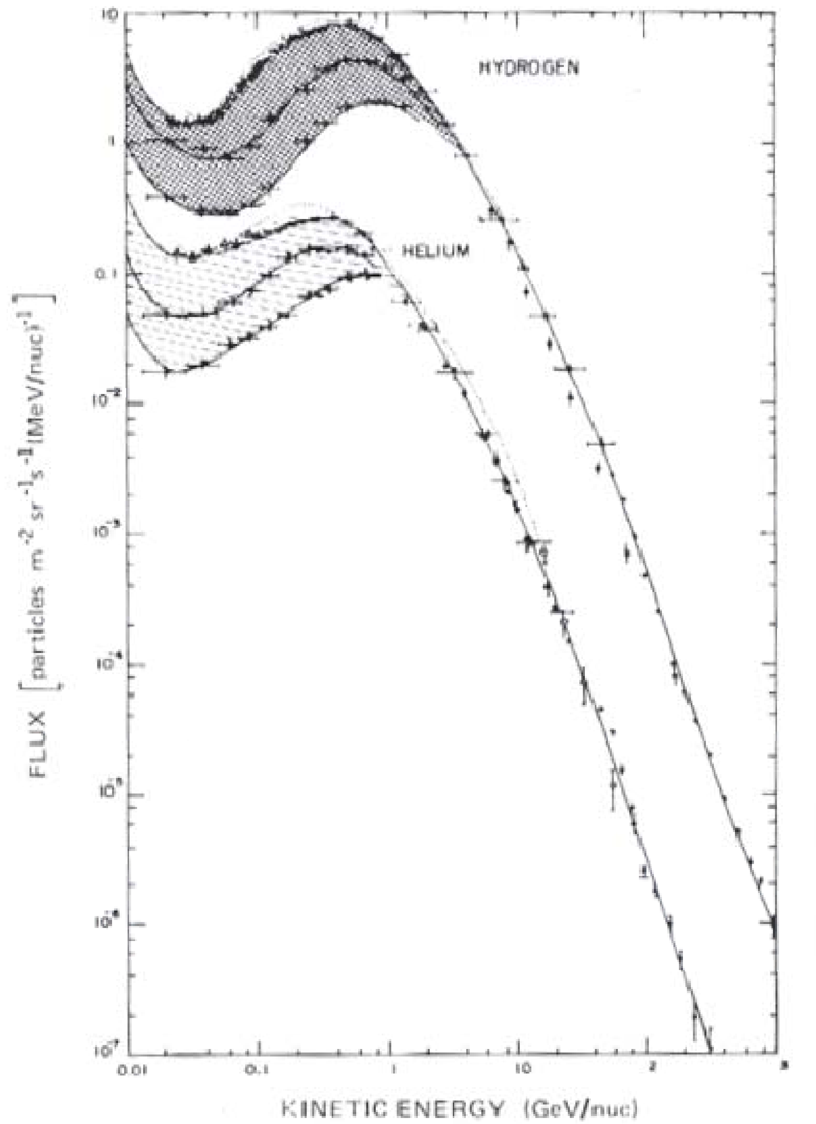

Figure 4-23. Background Cosmic Ray Proton and Helium Spectra

Note that the spectral range shown in Figure 4-23 is for the approximately average solar minimum and maximum conditions. The just passed solar minimum was extended in time, and was unusually low. Thus the CR background proton spectrum for some of the measurements presented in this report may be larger than shown in Figure 4-23. Geomagnetic activity also affects the CR proton spectrum at geosynchronous orbit, as does local time (local noon is near the front magnetopause, while local midnight is near the tail field).

The low P7 fluxes can be explained by at least two effects. The broad energy channel (110 MeV to 900 MeV) can cause a change because of the proton spectrum slope, as discussed in Section 3.8.4. If the proton spectrum is rising with an E^2 variation, then the correction from eq. (3.7), using g = -2, gives a factor of 1.64. This would raise the P7 flux close to the HEPAD fluxes. However, the HEPAD fluxes do not show a significant increase in flux with energy, so this correction may not apply, even though the CR proton spectra do show a rise in the few hundred MeV region.

A second possible explanation is the different FOVs of the HEPAD and P7 channel. The HEPAD has a 30 degree half angle detection cone, aimed in the anti-earth direction. The P7 channel is from the EPEAD (EPS) D5 dome, and is essentially omni-directional in response. If the CR proton spectrum has a significant angular variation, then this could explain the difference between the nominal (uncorrected) P7, and the HEPAD P8 and P9 fluxes. If the CR proton flux is primarily arriving from the anti-earth direction, with a significantly weaker flux from the toward-earth direction, then this would reduce the P7 flux measurement by about a factor of 2. Since geomagnetic and solar activity affect the CR proton flux, the exact angular distribution and intensity may vary with time.

The HEPAD and EPEAD (EPS) background CR proton spectra are in good agreement, when the preceding discussion is taken into account. Note that the solar proton event spectra in Figure 4-6 through Figure 4-10 show the opposite effect, with P7 being larger than P8 and P9, but this is for a steeply falling proton spectrum, and the P7 correction from eq. (3.7) reduces the flux by a large factor.

5.0 HEPAD PMT IN-ORBIT GAIN MEASUREMENT

The HEPAD PMT HV stepping data in Section 3 show a plateau in both S3 and S4. The plateau counts are elevated above the ground-based plateaus from the alpha lamp, since there is a high energy cosmic ray proton background present. The suggested PMT gain measurement method of GOESN-ENG-048 is to measure the in-orbit S3 count plateau increase, and then subtract this increase from both S3 and S4 to obtain corrected counts to use to calculate the S4/S3 ratio. This has worked for past HEPADs, but it shows some problems when used during an extended, very weak solar minimum. Under such conditions the low energy proton flux is enhanced, and the background is more complicated.

A second method to measure the PMT gain is to observe the increase in S4 counts above the stepping plateau. This increase should be equal to that measured on the ground for the S4 count at the desired PMT HV step. The measured in-orbit S4 count increase above the plateau can be used to estimate the actual PMT gain by comparison with the pre-launch ground based data. This method was illustrated in detail for the GOES-NOP HEPADs in Section 4.0.

The GOES-NOP HEPADs have a gain increase of x1.023 per PMT HV step, so a 4 step increase means the PMT gain is 9.5% low (GOES-13 and GOES-14), while a 12 step increase means that the PMT gain is 31.4% low (GOES-15). Note that the GOES-4, -5, and -6 HEPADs had a gain change of x1.045 per PMT HV step.

5.1 GOES-13 HEPAD PMT Gain Measurement

The GOES-13 HEPAD PMT stepping data from Section 4.1.1 shows an S3 plateau of 1007.3 counts/readout, and an S4 plateau of 165.1 counts per readout. The S3 alpha lamp plateau for before launch is 693.4 counts per readout, so the CR proton background contributes 327.9 counts/readout. Since one readout corresponds to 4.096 seconds, the CR proton background in S3 is 76.6 cps. This compares with the GOES-5 and GOES-6 measured increases in S3 of 32 cps and 34.4 cps. Since the just past solar minimum is a very low, and extended, minimum, the background cosmic ray proton countrate in the HEPAD S3 channel is expected to be higher.

The S4 counts per readout should increase by 102.2 for the correct PMT gain, and the in-orbit data give an increase above the S4 plateau of 47.4 counts per readout at HV step 150. The S3 and S4 counts per readout listed in Table 3-3 indicate that the in-orbit gain is about 4 HV steps low, as shown in Table 4-1. The GOES-NOP HEPADs have a gain increase of x1.023 per PMT HV step, so a 4 step increase means the PMT gain is 9.5% low. Note that the GOES-5 HEPAD required a 2 step PMT HV increase in-orbit (PANA-SEM-5), and for this HEPAD that corresponds to a 9.2% low gain (x1.045 for 1 PMT HV step). The GOES-13 HEPAD PMT in-orbit gain shift is thus consistent with previous HEPADs.

A 9.5% low HEPAD PMT gain shifts the proton energy bands to higher energies, as described in Sections 3.8.3 and 3.8.4, so the nominal energy bands in Table 3-9 become those listed in Table 5-1. Only the proton channels are shown, and the P11 channel is considered to be differential to 1500 MeV. The P11 spectrum point is thus a crude approximation, and would require a correction for proton spectrum shape to give a more accurate result. The HEPAD proton spectrum calculated using the correct energy channels in Table 5-1 were shown in Figure 4-13. This is the solar proton event spectrum previously shown in Figure 4-12 with only the uncorrected HEPAD proton spectrum. As discussed in Section 3.8.4, the HEPAD spectral shape and differential flux intensity are not significantly dependent on the precise HEPAD gain, within about 14%.

Table 5-1. HEPAD Energy Channels and Geometric Factor for 9.5% Gain Change

HEPAD Channel	Particle Energy Range (MeV)	Geometric Factor, Gf(Ei) (cm^2 sr)	Average Energy, Ei (MeV)	Gf(Ei) x DEi (cm^2 sr MeV)
P8	332.5 – 430.0	0.73	381.3	71.16
P9	430.0 – 538.4	0.73	484.2	79.17
P10	538.4 – 783.7	0.73	661.1	179.07
P11	>783.7 (- 1500)	0.73	1141.9	522.87

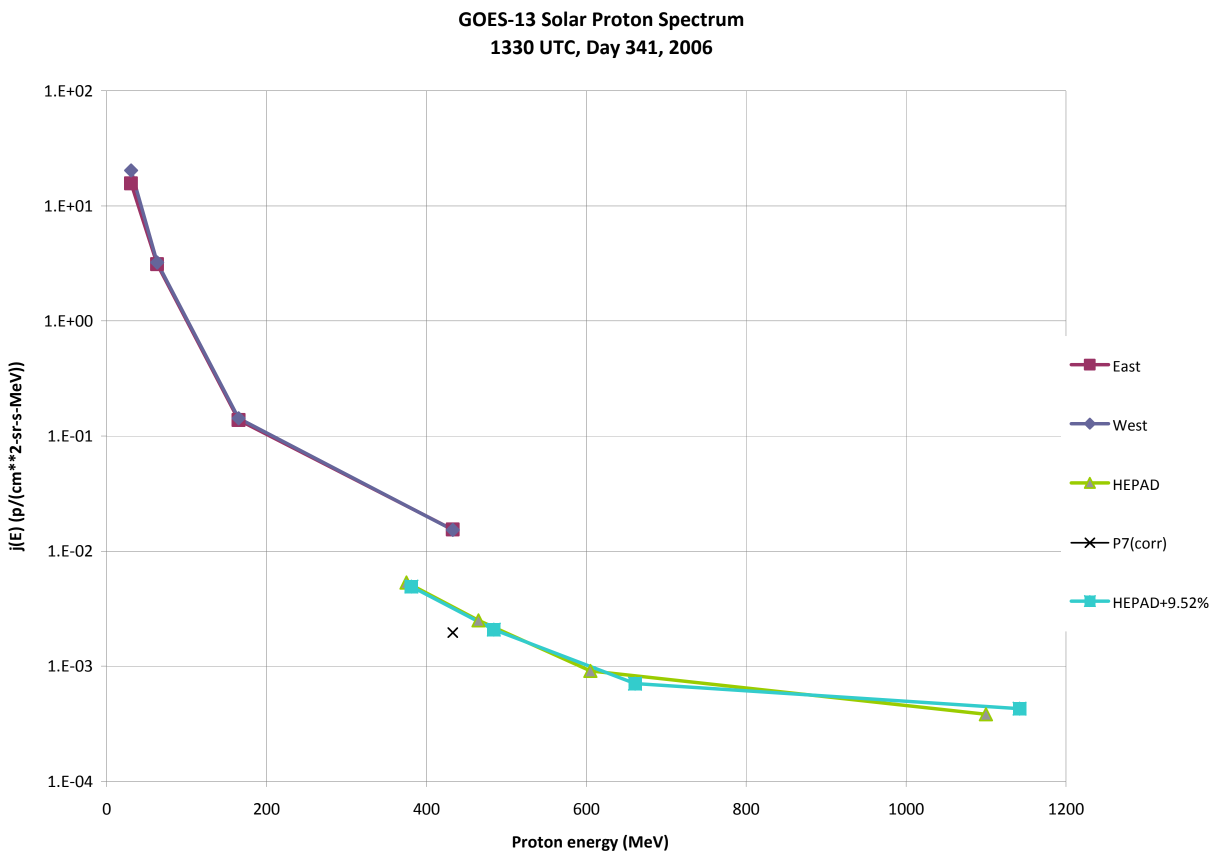

Figure 5-1. GOES-13 Measured Proton Spectra for Day 341, 2006

5.2 GOES-14 HEPAD PMT Gain Measurement

The GOES-14 HEPAD PMT stepping data from Table 4-7 and Figure 4-11 show an S3 plateau of 1958.1 counts/readout, and an S4 plateau of 212.2 counts per readout. The S3 alpha lamp plateau for before launch is 735 counts per readout, so the CR proton background contributes 1223.1 counts/readout. Since one readout corresponds to 4.096 seconds, the CR proton background in S3 is 298.6 cps. This is almost 4 times the GOES-13 S3 count rate increase in 2006, but is consistent with a higher CR proton background because of the extended and very low solar minimum.

The S4 counts per readout should increase by 36.1 for the correct HV step of 138, and the in-orbit data give an increase above the S4 plateau of 16.9 counts per readout. The S3 and S4 counts per readout listed in Table 3-5 indicate that the in-orbit gain is about 4 HV steps low, and corresponds to a PMT gain that is low by about 9.5%. This gain shift is the same as for the GOES-13 HEPAD, and should not have a significant impact on the HEPAD proton spectrum shape or intensity within about 12%. The GOES-14 HEPAD PMT in-orbit gain shift is consistent with that observed in other HEPADs.

5.3 GOES-15 HEPAD PMT Gain Measurement

The GOES-15 HEPAD PMT stepping data from Table 4-11 and Figure 4-14 for Day 92, 2010 show an S3 plateau of 1020.4 counts/readout, and an S4 plateau of 206.4 counts per readout. The S3 alpha lamp plateau for before launch is 613.9 counts per readout, so the CR proton background contributes 406.5 counts/readout. Since one readout corresponds to 4.096 seconds, the CR proton background in S3 is 99.2 cps. This is higher than the GOES-13 S3 count per readout increase in 2006, but lower than the GOES-14 increase in 2009. This is consistent with a higher CR proton background because of the extended and very low solar minimum, but the difference with GOES-14 may be caused by some weak solar proton source present at the time of the GOES-14 PMT HV stepping measurements, or by the solar minimum having ended.

The S4 counts per readout should increase to 439.1 for the correct PMT gain, and the in-orbit data give an increase above the S4 plateau of 62.7 counts per readout for the pre-launch HV step 154. The S3 and S4 counts per readout listed in Table 3-7 indicate that the in-orbit gain is 12 HV steps low. This corresponds to a PMT gain that is low by 31.4%. This gain shift is larger than that for the GOES-13 and GOES-14 HEPADs, and produces changes in the HEPAD proton spectrum intensity of close to 40% for the uncorrected spectrum (Section 4.3.2). The GOES-15 HEPAD PMT in-orbit gain shift is larger than that observed in most other HEPADs, but is not inconsistent with possible PMT and/or HV supply changes associated with launch and the space environment.

The GOES-15 HEPAD PMT stepping data from Table 4-12 and Figure 4-15 for Day 113, 2010 show an S3 plateau of 941.8 counts/readout, and an S4 plateau of 207.5 counts per readout. The S3 alpha lamp plateau for before launch is 613.9 counts per readout, so the CR proton background contributes 327.9 counts/readout. Since one readout corresponds to 4.096 seconds, the CR proton background in S3 is 80.1 cps. This is higher than the GOES-13 S3 count per readout increase in 2006, but lower than the GOES-14 increase in 2009 and the GOES-15 increase for day 92, 2010. This is consistent with a higher CR proton background because of the extended and very low solar minimum, but the difference is decreasing as the solar minimum ends.

The S4 counts per readout should increase to 440.2 for the correct PMT gain, and the in-orbit data give an increase above the S4 plateau of 53.6 counts per readout for the pre-launch HV step 154. The S3 and S4 counts per readout listed in Table 3-7 indicate that the in-orbit gain is 12, possibly 13, HV steps low. For 12 steps low this corresponds to a PMT gain that is low by 31.4%. This gain shift is larger than that for the GOES-13 and GOES-14 HEPADs, and produces changes in the HEPAD proton spectrum intensity of close to 40% for the uncorrected spectrum (Section 4.3.2). The GOES-15 HEPAD PMT in-orbit gain shift is larger than that observed in most other HEPADs, but is not inconsistent with possible PMT and/or HV supply changes associated with launch and the space environment.

5.4 GOES-NOP HEPAD PMT S3 and S4 responses to Protons

The GOES-NOP HEPAD PMT S3 and S4 channel responses to protons, generally CR background protons, is not calculable to a high degree of accuracy. The data from the HEPAD PMT HV stepping for these three spacecraft show significant differences in the CR proton background for different times, so calculating the S3 and S4 CR background responses would require very accurate proton flux measurements at the same time and location of the spacecraft in question. A brief consideration of the S3 and S4 responses to protons indicates that precise calculation of the response is not likely to be accurate. The HEPAD PMT response to protons was measured over the angular response range of the triple coincidence, as described in GOESN-ENG-048, but the S3 and S4 responses in singles mode were not measured outside the triple coincidence range, and thus are not calibrated to any accuracy. Approximate response calculation is not likely to be sufficiently accurate to allow the response to off-axis protons to be obtained reliably.

The best method to measure the HEPAD PMT gain in-orbit is to observe the S4 plateau, and measure the increase in the S4 counts/readout above this plateau. The increase should be the same as for the ground-based S4 increase for the desired operating HV step (correct PMT gain).

HEPAD PMT gain measurements made with HV stepping should only be done during periods of stable background CR proton fluxes. Solar proton event data are very likely to be unreliable, since the S3 and S4 responses to the proton fluxes may vary significantly with time, thus making a plateau difficult to see, and the S4 increase may contain a component from the proton flux variation. Added S3 and S4 counts from the increased proton flux will also make the count statistics worse, thus giving a less accurate gain measurement. Periods of magnetic field changes, such as solar activity and geomagnetic variations, should also be avoided, since there may be variations in the proton background that mask the true S3 and S4 counts from the alpha lamp. The S3 and S4 counts from before and after the PMT HV stepping period should not be different by more than a few percent if the data are to be considered a valid PMT gain measurement.

Strong fluxes of high energy electrons may also affect the S3 and S4 counts because of bremsstrahlung, so periods of intense electron fluxes should also be avoided for HEPAD PMT gain measurements. The S3 count will be affected more strongly than the S4 count.

The HEPAD spectral and intensity response is not significantly dependent on the precise HEPAD PMT gain. The spectral points may be shifted, but the spectral intensity and shape will not change significantly for PMT gain changes up to +/- 20%. For larger PMT gain changes, there will be some significant changes in calculated proton flux, possibly changes of 40% for gain changes near 30%.

6.0 CONCLUSIONS

A study of the GOES-NOP HEPAD in-orbit data shows that the three HEPADs are operating properly. The main conclusions are as follows.

1. The GOES-NOP HEPAD proton responses are close to the HEPADs on GOES-10, -11, and -12.
2. The GOES-13 HEPAD PMT is currently being operated 4 HV steps low (9.5% low gain).
3. The GOES-14 HEPAD PMT is currently being operated 4 HV steps low (9.5% low gain).
4. The GOES-15 HEPAD PMT is currently being operated 12 HV steps low (31.4% low gain).
5. The GOES-13 and GOES-14 HEPAD PMT gain changes are reasonably consistent with changes observed for the HEPAD PMTs on GOES-4, -5, and -6.
6. The GOES-15 HEPAD PMT gain changes are larger than seen in most other HEPADs, but the change is stable. The energy channel values should be changed, or the PMT HV step increased, to avoid significant errors in the proton fluxes.
7. The calculated HEPAD proton spectra do not depend strongly on the PMT gain. A change of +/-20% will still give the correct spectral shape and intensity within about 15%.
8. The calculated HEPAD proton spectra for gain changes near 30% may have some proton flux errors up to 40%.
9. The best method to measure the PMT gain is to measure the S4 count increase above the in-orbit plateau, and compare this to the ground-based S4 increase.
10. PMT gain measurements should only be made (or used) when there are no solar proton events, or solar or geomagnetic variations in magnetic field. Periods of intense high energy electron fluxes should also be avoided. The S3 and S4 counts from before and after the PMT HV stepping period should not be different by more than a few percent.
11. HEPAD sensitivity to high energy electrons is mostly in the SSD singles channels, S1 and S2. The PMT has very low sensitivity to electron fluxes.