The Proton Electron Telescope (PET) on SAMPEX

Users Document

Compiled by
Richard Mewaldt
Caltech
(RMewaldt@SRL.caltech.edu)
(626-395-6612)

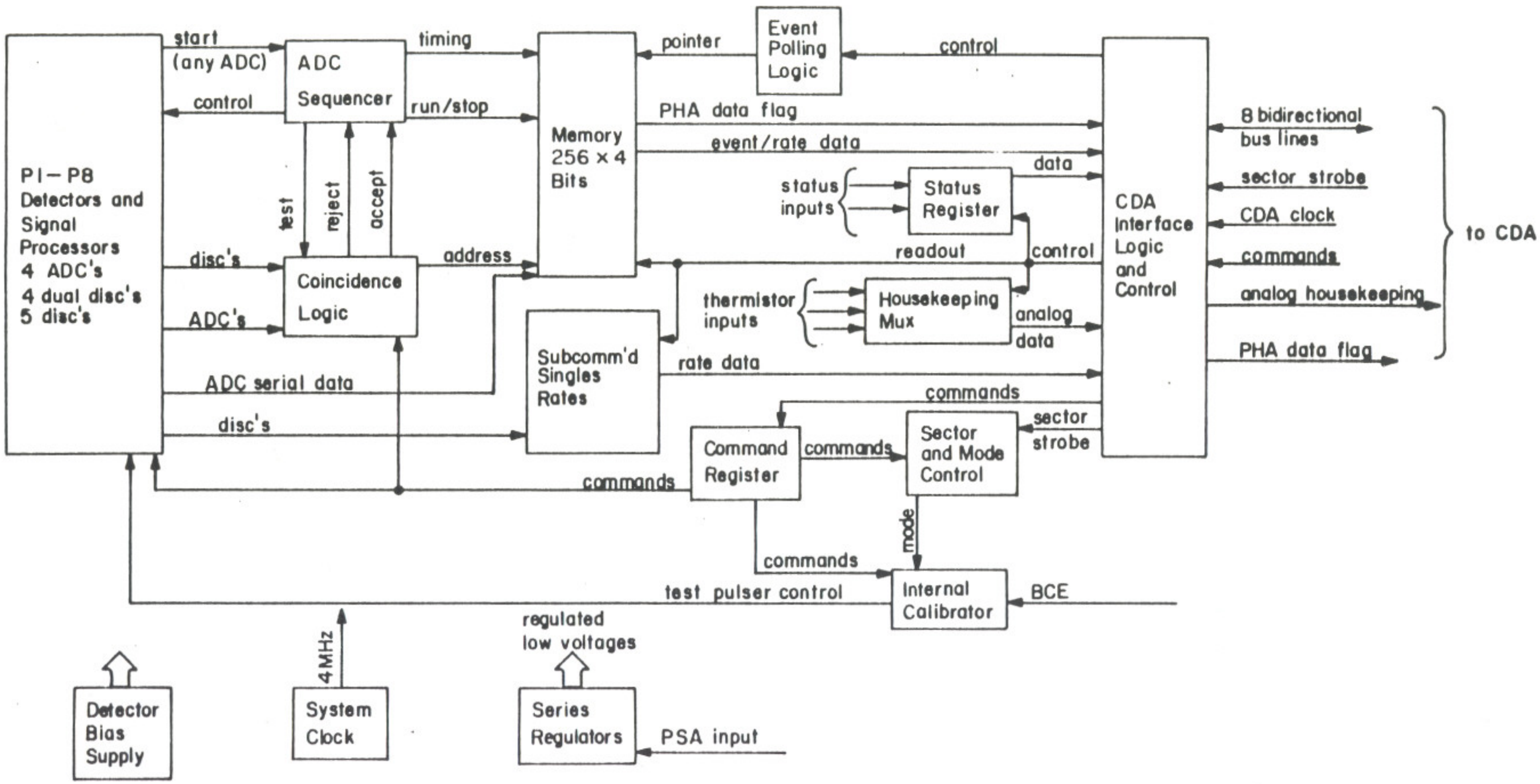
August, 1993

return to R. Mewaldt

3. PROTON/ELECTRON TELESCOPE (PET)

3.1 Block Diagram

PET BLOCK DIAGRAM



3.1.1

3.2 Telescope

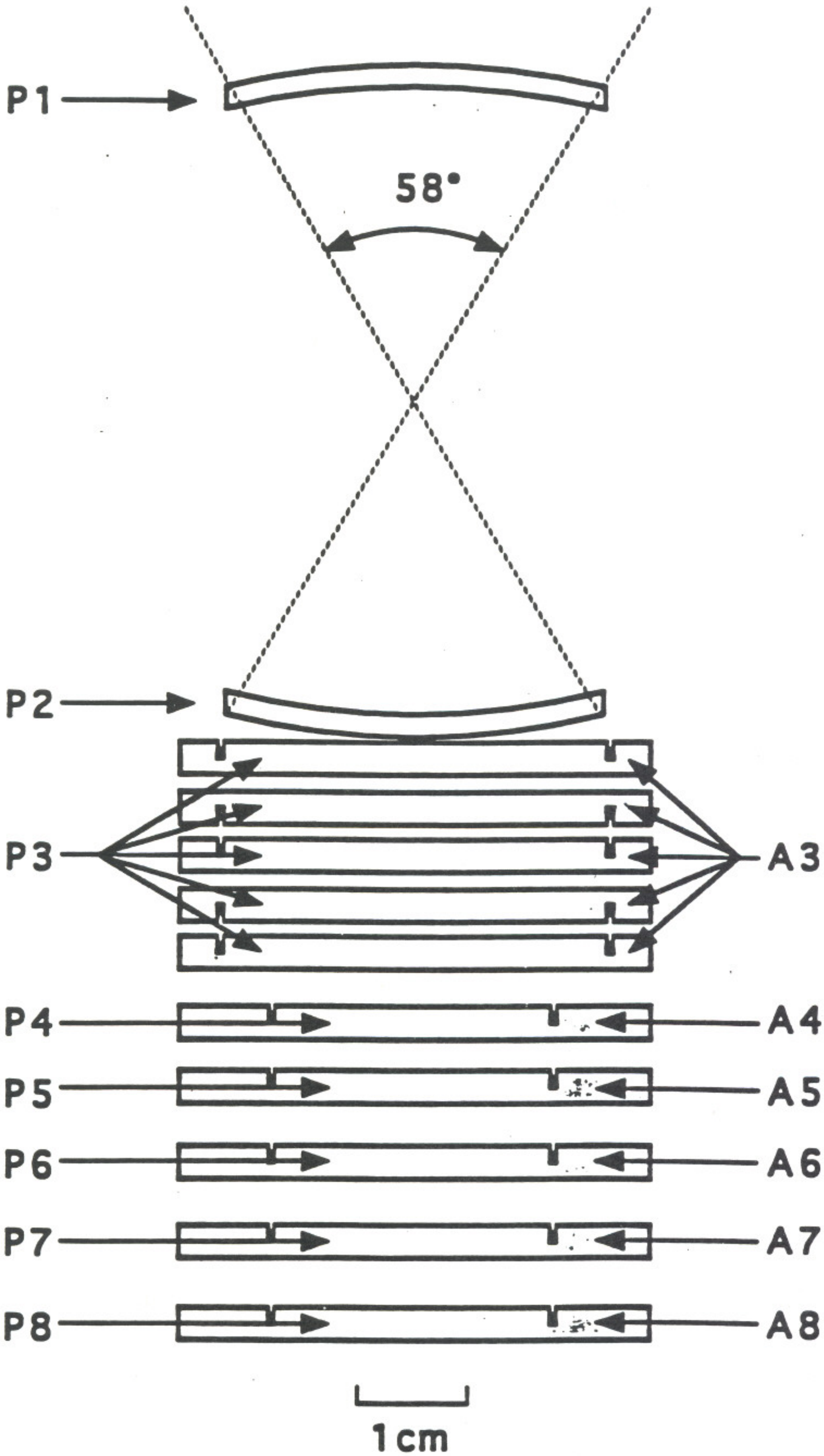
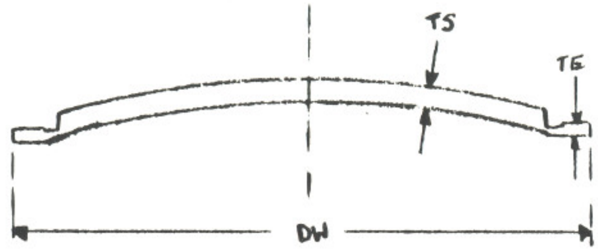


Figure 4

2.1.2 PET Detector Characteristics

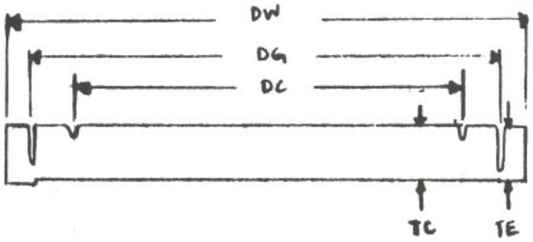
P1, P2 Lithium Drifted Detectors (curved)



Parameter	P1,P2	UNITS
Thickness of spherical shell (TS)	2.00	mm
Thickness of peripheral area (TE)	1.52	mm
Radius of curvature to centerline of active thickness	61.6	mm
Detection area, grooved side	8.00	cm**2
Wafer diameter (DW)	37.7	mm
Width of groove	1.0	mm
Estimated detector capacitance	42.	pF
Estimated leakage current - typ @ room temp	2.5	microamps
- max @ 35 deg C	9.	microamps
Bias voltage	-400.	volts
Mass of silicon	4.6	grams

PET Detector Characteristics (continued)

P3 - P8 Lithium Drifted Detectors



PARAMETER	P3A[a]	P4 - P8	UNITS
Thickness of central area (TC)	3.06	3.06	mm
Thickness of peripheral area (TE)	3.20	3.20	mm
Wafer diameter (DW)	47.9	47.9	mm
Center area	9.2	4.5	cm**2
Outer area	3.5	8.0	cm**2
Diameter of inner groove (DC)	34.8	24.5	mm
Diameter of outer groove (DG)	42.2	40.5	mm
Width of inner groove	0.5	0.5	mm
Width of outer groove	1.0	1.0	mm
Detector capacitance - center	32.	15.	pF
- guard	12.	27.	pF
- center to guard	10.	10.	pF
Leakage current, guard + center - @ room temp	6.(typ)	10.(max)	microamps
- max @ 35 deg C	20.	25.	microamps
Bias voltage	-500.	-500.	volts
Mass of silicon	12.9	13.5	grams

NOTE : a) P3 consists of 5 3-mm detectors (like P3A) connected in parallel

Detector Measurements and Tests

The following pages summarize the results of detector inspection, measurement, and testing carried on in the SRL Detector Testing Laboratory after receipt of the devices from the supplier.

PET 2MM SPHERICAL SHELL DETECTOR TESTING 12/21/81

TEST	SPEC	2284	2726	2294	2329	2491
1) ACTIVE AREA (SQCM)	MIN=8.1 TYP=8.1 MAX=8.3	* 7.9260	* 7.5170	* 8.0136	* 7.8941	* 7.4906
2) RADIUS OF CURVATURE: (INCHES) ALUMINUM GOLD	MIN=2.423 TYP 2.425 MAX=2.427					
3) DISTANCE BETWEEN GROOVE AND GOLD CONTACT (MM)	MAX=.25	.19	* .54	* .55	* .55	* .40
4) CONCENTRICITY OF ACTIVE AREA AND WAFER (MM)	MAX=.5	.02	.19	.098	.170	NO DIMPLE
5) GROOVE WIDTH (MM)	MAX=1.0	.62	.95	.50	.65	.92
6) WAFER DIAMETER (INCHES)	MIN=1.483 TYP=1.486 MAX=1.489					
7) THICKNESS OF PERIPHERAL AREA (INCHES)	MIN=.057 TYP=.059 MAX=.061					
8) DEPLETION DEPTH OF ACTIVE AREA (MM)	MIN=2.00 MAX=2.10					
9) THICKNESS UNIFORMITY OF ACTIVE AREA (MICRONS)	MAX=20					
10)UNGROOVED DEADLAYER (MICROGRAMS/SQCM)	MAX=100					
11)GROOVED DEADLAYER (MICRONS)	MAX=100	91	* 581			
12)UNIFORMITY OF GROOVED DEADLAYER (MICRONS)	MAX=5					
13)DEPLETION AT 200V BIAS	MAX SHIFT = -.1%	* -.17% @ 200V -.04% @ 300V	* -.923% @ 200V -.148% @ 300V	* -.13% @ 200V -.094% @ 300V	* -.19% @ 200V -.04% @ 300V	-.085% @ 200V -.075% @ 300V
14)BETA ENERGY RESOLUTION (KEV FWHM)	MAX=80	23	30			
15)ALPHA ENERGY RESOLUTION (KEV FWHM)	MAX=95	40	50			
16)THERMAL VACUUM: LEAKAGE CURRENT @ 20C NOISE @ 20C (SIGMA) LEAKAGE CURRENT @ 35C NOISE @ 35C (SIGMA)	 MAX=4 MICROAMPS MAX=10 MICROAMPS	GOOD 008 2.6 18.5 5.3 22.8	GOOD 009 2.8 22.6 8.5 55.6			
17)COMMENTS		SURFACE IN GOOD CONDITION	GOLD SIDE HEAVILY PITTED	GOLD SURFACE THIN AL SURFACE QUITE DISCOLORED	GOLD VERY THIN MASSIVE SILICON SHOWS THROUGH CIRCULAR SCRATCH FROM CONTACT	TOUCHED BY 'SCOPE GOLD SIDE LOOKS NEW,THICK; AL LOOKS GOLD; BOTH SIDES VERY CLEAN

C-7-7-C

PET 3MM 12.5 450 X 800 SQCM DOUBLE CONCENTRIC LID 12/21/81

TEST	SPEC	2668	2669A	2670	2671	2684	2685
1) DIAMETER OF CENTER ACTIVE AREA (MM)	MIN=23.90 TYP=24.00 MAX=24.10	* 23.598 23.616	* 23.151 23.517	* 23.768 23.741	* 23.706 23.702	* 23.782 23.844	* 23.824 23.762
2) DIAMETER OF TOTAL ACTIVE AREA (MM)	MIN=40.00	* 39.686 39.663	* 38.512 38.520	* 39.504 39.555	* 39.472 39.401	* 39.364 39.389	* 39.480 39.565
3) DISTANCE BETWEEN GROOVE AND GOLD CONTACT (MM)	MAX=0.25	* .85	* .70	* .78	* .67	* .57	* .48
4) CONCENTRICITY OF INNER AND OUTER AREAS (MM)	MAX=0.5	.246	.0423	.046	.193	.071	.1984
5) INNER GROOVE WIDTH (MM)	TYP=0.5 MAX=1.0	1.003	* 1.635	0.835	* 1.063	.8638	.8623
6) WAFER DIAMETER (MM)	MIN=47.80 TYP=47.88 MAX=47.96	47.879	47.879	47.879	47.879	47.879	47.879
7) THICKNESS OF PERIPHERAL AREA (MM)	MIN=3.15 TYP=3.20 MAX=3.25	3.226	3.226	3.226	* 3.251	3.213	3.200
8) DEPLETION DEPTH OF ACTIVE AREA (MM)	TYP=3.00						
9) THICKNESS UNIFORMITY OF ACTIVE AREA (MICRONS)	MAX=30						
10) UNGROOVED DEADLAYER (MICROGRAMS/SQCM)	MAX=150						
11) GROOVED DEADLAYER (MICRONS)	TYP=200	56	120	183	67	89	67
12) UNIFORMITY OF GROOVED DEADLAYER (MICRONS)	MAX=5						
13) DEPLETION AT 300V BIAS	MAX SHIFT= -.1%	-.11% @ 300V -.09% @ 400V	-.11% @ 300V -.08% @ 400V	-.08% @ 300V -.32% @ 200V	-.07% @ 250V +.02% @ 375V	-.10% @ 300 V -.28% @ 200 V	-.09% @ 300V -.39% @ 200V
14) BETA ENERGY RESOLUTION (KEV FWHM) CENTER GUARD	MAX=80 MAX=80	18 25	14 30	15 24	15 23	12 22	10 25
15) ALPHA ENERGY RESOLUTION (KEV FWHM) CENTER GUARD	MAX=95 MAX=95	40 40	40 50	40 40	40 40	40 80	40 RAW DATA ONLY
16) THERMAL VACUUM: LEAKAGE CURRENT @ RMT NOISE @ RMT (SIGMA) LEAKAGE CURRENT @ 35C NOISE @ 35C (SIGMA)	 MAX=10 MICROAMPS MAX=25 MICROAMPS 	UNCLASS 006 4.00 9.7 12.36 16.7	GOOD 009 3.20 11.7 9.60 16.6	GOOD 006 4.31 8.2 13.98 15.5	GOOD 005 2.54 8.3 8.98 15.5	GOOD 005 4.35 7.7 14.79 14.4	GOOD 005 4.58 11.0 16.11 22.7
17) COMMENTS		SMALL BLEMISHES ON GOLD SIDE AL SIDE CLEAN	SOME BLEMISHES ON AL; MACHINE SCRATCHES ON AU	BOTH SIDES FAIRLY AVERAGE	LONG SCRATCH ON GOLD	FINE SCRATCHES ON BOTH SIDES	MANY PARTICLES, BOTH SIDES

PET 3MM 900 X 350 SQCM DETECTOR TESTING 12/21/81

TEST	SPEC	2672	2673	2727	2730	2731
1) DIAMETER OF CENTER ACTIVE AREA (MM)	MIN=33.79 TYP=34.29 MAX=34.54	34.023 33.958	* 34.823 * 33.749	* 33.553 33.562	* 33.635 33.654	* 33.535 33.560
2) DIAMETER OF TOTAL ACTIVE AREA (MM)	MIN=41.21	* 40.740 40.723	* 40.749 40.725	* 40.387 40.382	* 40.564 40.544	* 40.327 40.383
3) DISTANCE BETWEEN GROOVE AND GOLD CONTACT (MM)	MAX=0.25	* .668	* .390	* 1.00	* .40	* .45
4) CONCENTRICITY OF INNER AND OUTER AREAS (MM)	MAX=0.5	.056	* .547	.247	.175	.169
5) INNER GROOVE WIDTH (MM)	TYP=0.5 MAX=1.0	.807	.729	* 1.198	* 1.227	* 1.249
6) WAFER DIAMETER (MM)	MIN=47.80 TYP=47.88 MAX=47.96	47.879	47.879	47.879	47.879	47.879
7) THICKNESS OF PERIPHERAL AREA (MM)	MIN=3.15 TYP=3.20 MAX=3.25	3.175	3.226	* 3.2766	3.2004	3.213
8) DEPLETION DEPTH OF ACTIVE AREA (MM)	TYP=3.00					
9) THICKNESS UNIFORMITY OF ACTIVE AREA (MICRONS)	MAX=30					
10)UNGROOVED DEADLAYER (MICROGRAMS/SQCM)	MAX=100					
11)GROOVED DEADLAYER (MICRONS)	TYP=60 MAX=100	70	95	73	86	67
12)UNIFORMITY OF GROOVED DEADLAYER (MICRONS)	MAX=5					
13)DEPLETION AT 300V BIAS	MAX SHIFT= -.1%	-.10% @ 300V -.29% @ 200V	-.03% @ 300V -.25% @ 200V	-.10% @ 300V -.30% @ 200V	-.09% @ 300V	* -.14% @ 300V
14)BETA ENERGY RESOLUTION (KEV FWHM) CENTER GUARD	MAX=80 MAX=100	24 40	29 40	18 40	14 35	15 30
15)ALPHA ENERGY RESOLUTION (KEV FWHM) CENTER GUARD	MAX=95 MAX=125	40 55	40 50	40 40	40 55	40 60
16)THERMAL VACUUM: LEAKAGE CURRENT @ 20C NOISE @ 20C (SIGMA) LEAKAGE CURRENT @ 35C NOISE @ 35C (SIGMA)	 TYP=6 MICROAMPS MAX=20 MICROAMPS	GOOD 006 6.41 18.1 * 20.06 32.5	GOOD 006 15.07 17.0 * 27.76 23.8	UNCLASS 009 3.0 12.3 8.4 19.2	GOOD 008 2.8 9.6 8.6 16.7	GOOD 008 5.8 15.0 11.7 15.6
17)COMMENTS		AL SIDE VERY DIRTY	GOLD DISCOLORED AL DIRTY	BOTH SIDES DISCOLORED	VERY CLEAN	VERY CLEAN

2.1.3 PET Telescope Window

The PET telescope is protected by an aluminized-Mylar window of TBD thickness (Mylar side out). The principal purposes of the window are to provide an electrical shield and protect the solid state detectors from sunlight. The thickness of the window is TBD. The choice of window thickness should take into account the following considerations (see also MAST Section 1.1.3):

1) Accoustic Testing - Necessary for any thickness, but especially for thinner windows than used in the past (0.75 mil on IMP).

2) Radiation Damage - For Jovian Flybys, a thicker window can help protect against radiation damage from trapped H, O, and S nuclei with ~1 MeV/nucleon. One Voyager I HET B1 detector (same design as PET P1) experienced a degradation of performance during Jovian encounter (fluence of $\sim 5 \times 10^9$ protons and $\sim 10^5$ $Z \geq 8$ ions). Thus the PET window should be thicker than HET's window of 3.5 mil Mylar. A 10 mil window would decrease the proton fluence (at the outside surface) by about only a factor of 3, while the $Z \geq 8$ fluence would decrease by more than a factor of ~10. The Solar Polar trajectory by Jupiter should be folded into these estimates, as well as the P1 deadlayer thickness.

3) Effect on Energy Intervals - Negligible effect on PET since all particles must go through at least 2 mm of silicon to be registered.

4) Solar Flare Studies - A thicker window would help allow PET to operate at higher flux levels in flares, but this is perhaps not an important consideration since PET is not designed for solar flare studies.

5) Window Produced Background - Not as important a consideration as in MAST since the threshold for ^2H and ^3He is ~20 MeV/nucleon, and the background levels from other sources are higher. Should be looked at however.

6) Electron Scattering - The mean scattering angle of a 3 MeV electron in 10 mil Mylar is $\sim 7^\circ$, proportional to the square root of the thickness. This will tend to smear out the electron angular response. Thus a window of the proper thickness should be included in any electron calibrations.

3.3 ADC/Discriminator Characteristics

PET ADC Characteristics[a]

I. LO-Z MODE

ADC Name	Dynamic Range	Full Scale (MeV)	Thresh. (MeV)	Channel Width (MeV)	DISC A (MeV)	DISC A Nom Ch.[c]	DISC B (MeV)	DISC B Nom Ch.[c]
P1	450:1	157	.350	.153[b]	$3.1^{+.2}_{-.2}$	26	----	---
P2	450:1	157	.350	.153[b]	----	---	----	---
P3	450:1	317	.700	.312[b]	$2.8^{+.4}_{-.2}$	15	$12.^{+5.}_{-1.}$	44
P47	923:1	337	$.365^{+.015}_{-.015}$	.333[d]	----	---	----	---

II. HI-Z Mode

ADC Name	Dynamic Range	Full Scale (MeV)	Thresh. (MeV)	Channel Width (MeV)	DISC A (MeV)	DISC A Nom Ch.[c]	DISC B (MeV)	DISC B Nom Ch.[c]
P1	450:1	4800	10.7	4.72[b]	$95.^{+6.}_{-6.}$	26	----	---
P2	450:1	4800	10.7	4.72[b]	----	---	----	---
P3	450:1	15500	34.4	15.2[b]	137.	15	587.	44
P47	923:1	337	$.365^{+.015}_{-.015}$	.333[d]	----	---	----	---

NOTES :

a) 1024 channels
b) cw = fs/(1022.5 - 5.96)
c) N = (delta E)/cw + 5.96
d) cw = fs/(1022.5-10.95)

Note on Calculating ADC Disc Commands

PET :

DISC A goes high when

ADC channel number .GE. 2(CMND DATA A) + 2

DISC B goes high when

ADC channel number .GE. 2(CMND DATA A + CMND DATA B) + 4

2.2.2 PET Discriminator Characteristics

Disc Ref	Disc's Connected	Nominal Value (MeV)	Other Possible Values (MeV)
PA	P4,P5,P6,P7	0.200	.151, .167, .233, .266, .300, .348, .400
PC	P8	0.200	same as above
PB	A3L,A4L,A57L,A68L	0.200	same as above
PD	A4H,A57H,A68H	1.17	1.15, 1.22, 1.26, 1.31, 1.35, 1.42, 1.49
PD	A3H	5.0	4.96, 5.09, 5.18, 5.27, 5.36, 5.49, 5.63

Table 1 - PET Detector, ADC, and Discriminator Characteristics

Detector Name	Nominal Thickness (mm)	Central Active Area (cm2)	Guard Active Area (cm2)	Nominal ADC Threshold (MeV)	Nominal ADC Full Scale (MeV)	Nominal Discriminator Thresholds (MeV)	Guard Discriminator Thresholds (MeV)
P1	2	8.0	-	0.35	157	P1A = 3.1	-
P2	2	8.0	-	0.35	157	-	-
P3	15 (5 x 3 mm)	9.2	4.5	0.7	317	P3A = 2.8 P3B = 12	0.3, 5
P4-P7	3	4.5	8.0	0.36	337	0.23	0.3, 1.2
P8	3	4.5	8.0	-	-	0.3	0.3, 1.2

California Institute of Technology
Space Radiation Laboratory
Pasadena, Ca 91125
26-Feb-1993

To: PET Investigators
From: Daniel Williams

Here is a compilation of the PET channel-to-energy relations, gotten from tests of the instrument in the fall of 1991. Internal capacitances are given for reference only. This is for detectors P1, P2, and P3. Data for P47 will be distributed at a later date.

	Internal Cap. (pf)	Threshold (MeV)	A Thresh (MeV)	B Thresh (MeV)
P1	0.513	0.380	3.16	n/a
P2	0.390	0.380	n/a	n/a
* P3	0.600	0.749	3.23	12.27

PET Guard thresholds (MeV)

A68L	0.207	A68H	1.29
A3L	0.213	A3H	5.6
A4L	0.203	A4H	1.24
A57L	0.210	A57H	1.26

The PET channel-energy relationship is given by: E(MeV)= A*channel - B

Coefficient:	A	B
P1	0.1626	0.8651
P2	0.1704	0.9148
P3	0.3223	1.770

Note: On day 191, at about 9:30am UT, the response of the P3 detector became changed. It would seem that some of the charge on P3(1) is being lost, and possibly spilling over into the guard, causing a shift in the location of the proton track, and causing many of the proton events to be vetoed because they trigger the low-level guard, A3L.
This problem, which is currently under investigation, will affect the P3 calibration for data after 9:30am on day 191.

Accompanying this memo are tables of channels vs. energies for P1, P2, and P3.

* P3 values revised from those distributed on 2/16/93

3.3.4-1

P1 channel-energy table: Note that threshold is about channel 7

6.00000	0.110572
7.00000	0.273178
8.00000	0.435784
9.00000	0.598390
10.0000	0.760996
11.0000	0.923601
12.0000	1.08621
13.0000	1.24881
14.0000	1.41142
15.0000	1.57403
16.0000	1.73663
17.0000	1.89924
18.0000	2.06184
19.0000	2.22445
20.0000	2.38705
21.0000	2.54966
22.0000	2.71227
23.0000	2.87487
24.0000	3.03748
25.0000	3.20008
26.0000	3.36269
27.0000	3.52530
28.0000	3.68790
29.0000	3.85051
30.0000	4.01311
31.0000	4.17572
32.0000	4.33833
33.0000	4.50093
34.0000	4.66354
35.0000	4.82614
36.0000	4.98875
37.0000	5.15135
38.0000	5.31396
39.0000	5.47657
40.0000	5.63917
41.0000	5.80178
42.0000	5.96438
43.0000	6.12699
44.0000	6.28960
45.0000	6.45220
46.0000	6.61481
47.0000	6.77741
48.0000	6.94002
49.0000	7.10263

P2 channel-energy table: Note that threshold is about channel 7

6.00000	0.107322
7.00000	0.277673
8.00000	0.448025
9.00000	0.618377
10.0000	0.788729
11.0000	0.959080
12.0000	1.12943
13.0000	1.29978
14.0000	1.47014
15.0000	1.64049
16.0000	1.81084
17.0000	1.98119
18.0000	2.15154
19.0000	2.32189
20.0000	2.49225
21.0000	2.66260
22.0000	2.83295
23.0000	3.00330
24.0000	3.17365
25.0000	3.34401
26.0000	3.51436
27.0000	3.68471
28.0000	3.85506
29.0000	4.02541
30.0000	4.19576
31.0000	4.36612
32.0000	4.53647
33.0000	4.70682
34.0000	4.87717
35.0000	5.04752
36.0000	5.21787
37.0000	5.38823
38.0000	5.55858
39.0000	5.72893
40.0000	5.89928
41.0000	6.06963
42.0000	6.23998
43.0000	6.41034
44.0000	6.58069
45.0000	6.75104
46.0000	6.92139
47.0000	7.09174
48.0000	7.26210
49.0000	7.43245

P3 channel-energy table: Note that threshold is about channel 7

6.00000	0.164383
7.00000	0.486703
8.00000	0.809023
9.00000	1.13134
10.0000	1.45366
11.0000	1.77598
12.0000	2.09830
13.0000	2.42062
14.0000	2.74294
15.0000	3.06526
16.0000	3.38758
17.0000	3.70990
18.0000	4.03222
19.0000	4.35454
20.0000	4.67686
21.0000	4.99918
22.0000	5.32150
23.0000	5.64382
24.0000	5.96614
25.0000	6.28846
26.0000	6.61078
27.0000	6.93310
28.0000	7.25542
29.0000	7.57774
30.0000	7.90006
31.0000	8.22238
32.0000	8.54470
33.0000	8.86702
34.0000	9.18934
35.0000	9.51166
36.0000	9.83398
37.0000	10.1563
38.0000	10.4786
39.0000	10.8009
40.0000	11.1233
41.0000	11.4456
42.0000	11.7679
43.0000	12.0902
44.0000	12.4125
45.0000	12.7349
46.0000	13.0572
47.0000	13.3795
48.0000	13.7018
49.0000	14.0241

3.3.5

California Institute of Technology
Space Radiation Laboratory
Pasadena, Ca 91125
4/27/93

To: PET Investigators
From: Daniel Williams
Subject: PET P3 problem

On July 9, 1992 (day 191), at approximately 9:21 (UT), the response of the PET P3 detector changed. As seen in figure 1, the instrument appeared to be vetoing valid proton events. It was guessed that this was because these events were triggering the low guard. To check this, the low and high guard vetoes were taken out of the PET event equation during a period lasting from late December, 1992, to mid-January, 1993.

Figures 2 and 3 are of data from this period. Figure 2 shows what is left if events with low guard triggers are taken out. The remaining proton track has the same gap as seen in figure 1. Figure 3 shows the events left if those with high guard triggers are taken out. There is no characteristic gap in the proton track. Thus, it appears that the low guard trigger causes valid PET events to be lost.

This leads one to expect that perhaps some of the signal from the active region of the detector is leaking onto the low guard ring, which should cause a degradation of the PHA signal. In figure 4 the proton track measured in flight is compared to the calculated proton track. The track is indeed off.

Figure 5 is data taken before the problem occurred. The calculated track is in reasonably good agreement with the measured track. (Note: This simulation does not take detector geometry or the active and dead regions of the detectors; the corrections are small compared to the track shift being studied).

If we naively assume that there is a 50% loss of signal in the first detector (P3A) of P3, then we can model the odd track seen in figure 4. However, this model can not reproduce the helium track seen in the detector (see figure 6). Study of the helium track is currently underway, and any ideas or suggestions are welcome.

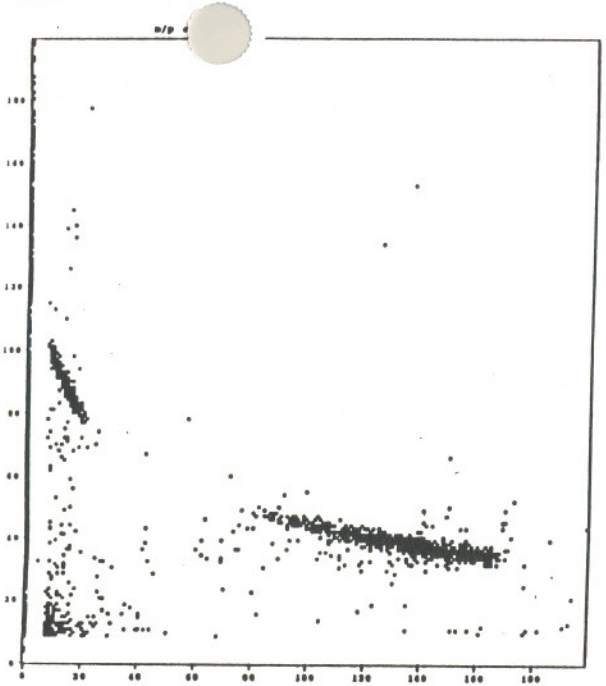


figure 1

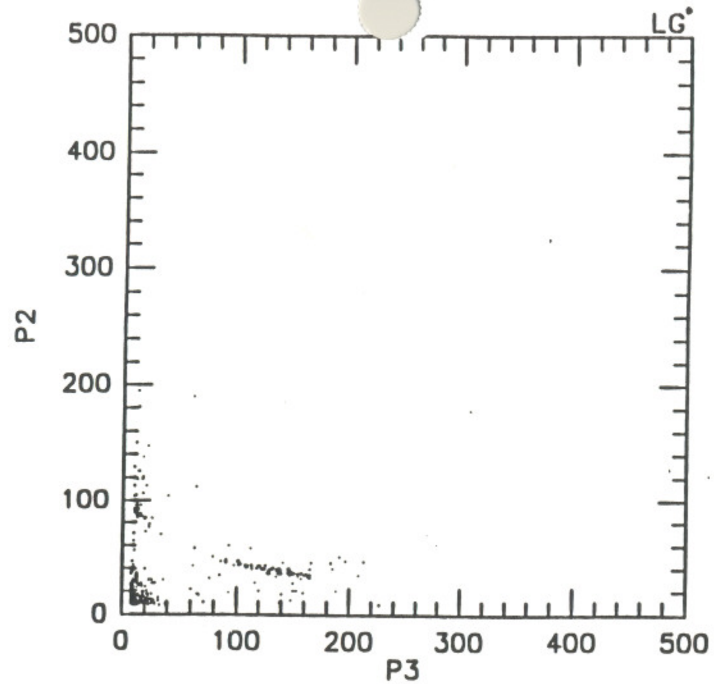


figure 2

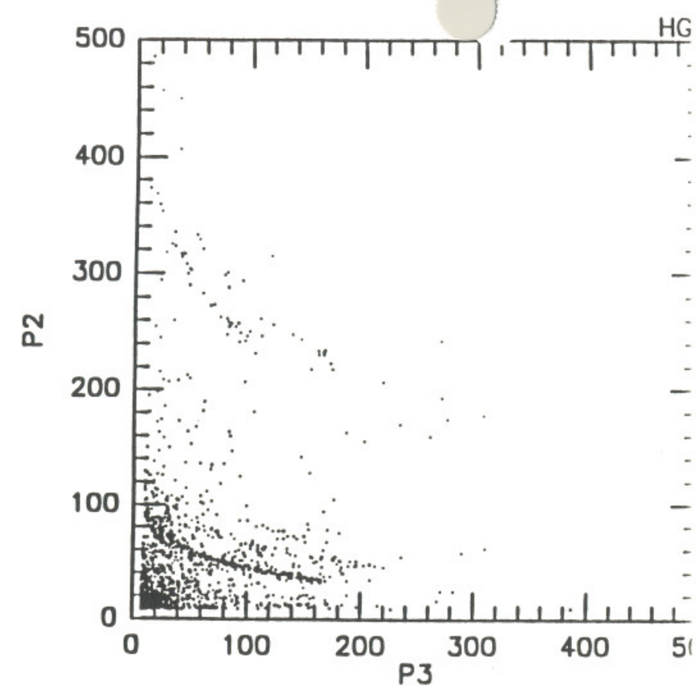


figure 3

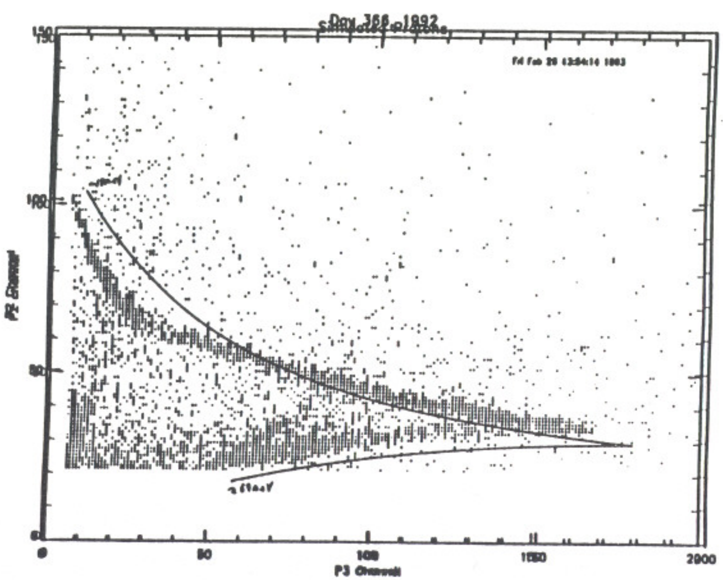


figure 4

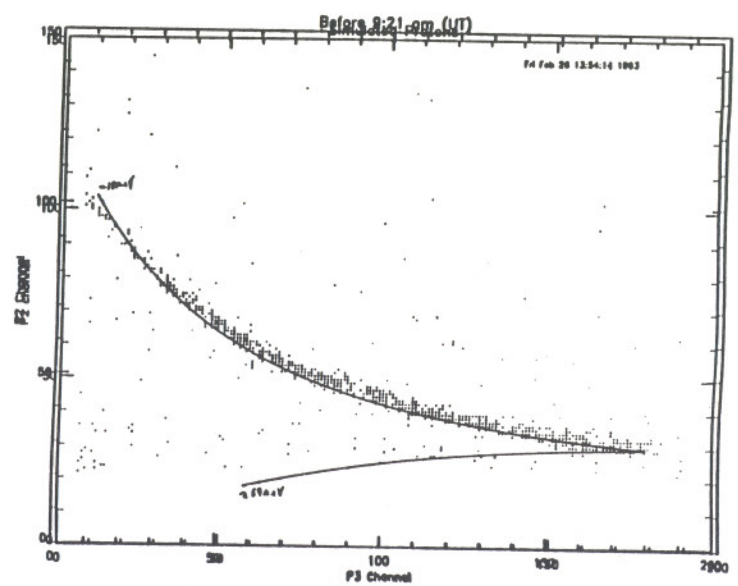


figure 5

3.3.5-1

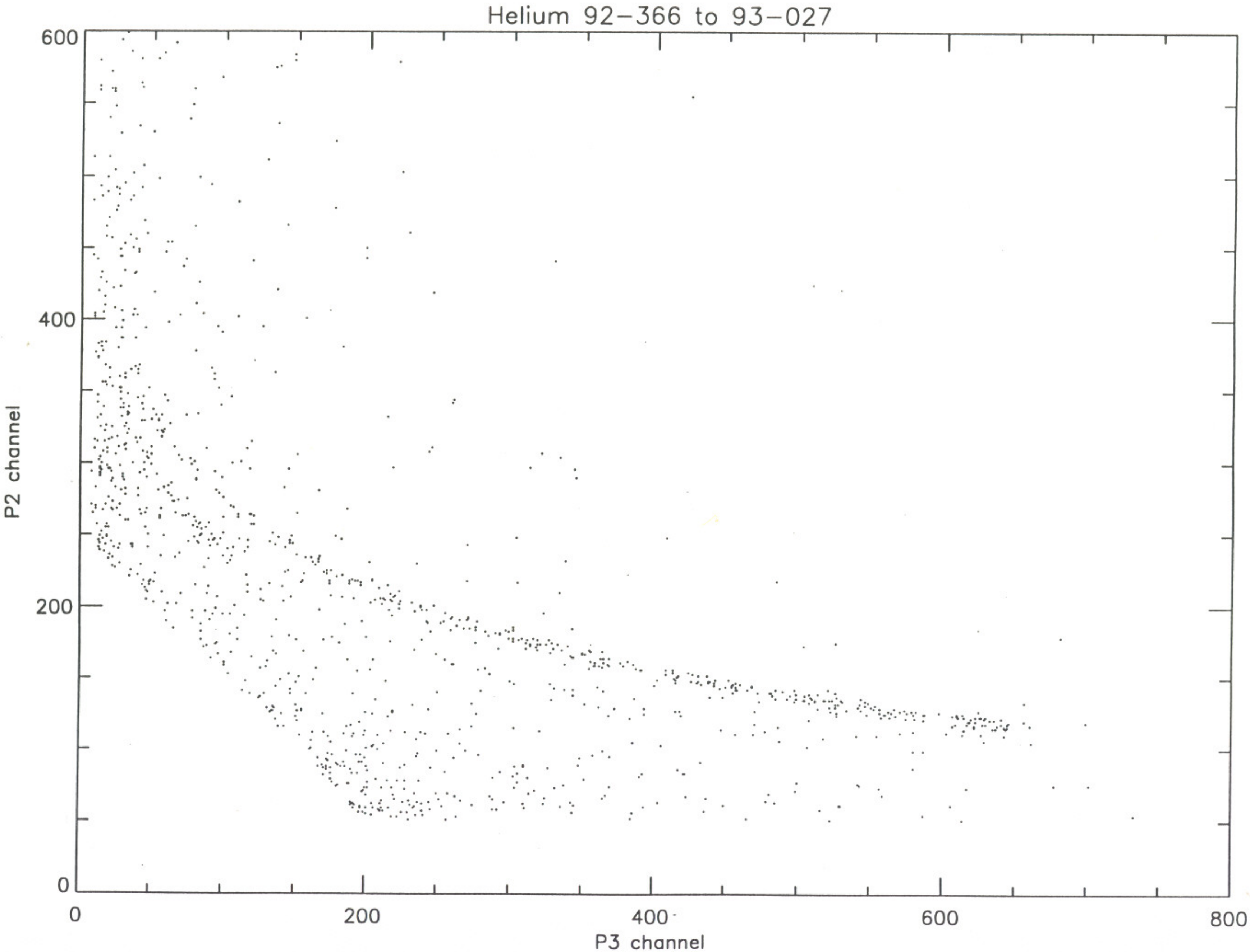


figure 6

3.4 Logic

PET Rate Equations[a,b]

Rate No.	CDA Address	Subcom State	Name	Equation
1	3	-	PLO	[P1] [P1A] [P2] [P3*] [P4*] /P5*/ [AL*] /AH*/
2(sect.)	2	-	PHI	" " " [P3] " " " "
3	3	-	ELO	" [P1A*] " [P3*] " " " "
4(sect.)	2	-	EHI	" " " [P3] /P3AE/ " " " "
5	4	-	RNG[c]	" [P2] [P4] /P5/ /P7*/ [P8R*] [ALR*] /AHR*/
6	3	-	EWG[d]	[P1*] /P2*/ [P2E] /P3A/ [P3B*] [P4] /P5/ /P7*/ [P8*] [ALE*] /AHE*
7	4	-	PEN	[P1] [P2] /P4/ /P7/ [P8] /ALP*/ /AHP*/ LOZMODE
8	3	-	LIVE TIME	
9	4	1	P1 ADC	P1
		2	ADC OR	P1 + P2 + P3 + P47
		3	P2 ADC	P2
		4	AL	A3L + A4L + A57L + A68L
		5	P3 ADC	P3
		6	AH	A3H + A4H + A57H + A68H
		7	P47 ADC	P47
		8	HAZ	HAZ
		9-16	repeat 1-8	
10	4	1-8	singles	P4, P5, P6, P7, P8, A3L,A3H,A4L
		9-16	singles	A4H,A57L,A57H,A68L, A68H,P1A,P3A,P3B

NOTES :

a) [ ] terms are normally included ; / / terms can be added ; * is logical complement

b) The following terms refer to ADC threshold : P1, P2, P2E, P3, P47
The following terms refer to ADC discriminators : P1A, P3A, P3AE, P3B
All other terms refer to discriminator outputs

c) Note that P8R* in this equation is controlled by same bit (c223) that controls P8*

d) Neutral Mode (NMODE) obtained by removing P2E term and including P2* and P3A terms; note that P2* and P2E terms are controlled with the same command bit (c206).

PET Event Equations[a,b]

Buf. No.[c]	Name	Equation										
7	CAL	tbd										
0	P	[P1]	[P1A]	[P2]	/P3*/	/P3P/	[P4*]	/P5*/	[AL*]	/AH*/	[RP]	[HAZ*]
1	E	"	[P1A*]	"	/P3E/	/P3AE/	"	"	"	"	[RE]	"
2	RNGE	RNG [RR] [HAZ*]										
3	EWGE	EWG [REW] [HAZ*]										
4	PENE	PEN [RPN] [HAZ*]										

NOTES :

a) consult sections on PET RATE EQUATIONS and PET LOGIC DEFINITIONS for definition of terms

b) [ ] terms are normally included ; / / terms can be added ; * is logical complement

c) event readout controlled by polling pointer which steps sequentially thru buffers until a filled buffer is encountered; polling sequence is 7,0,1,2,3,4,7,0,1,2,3,4,7...; polling starts at buffer following the one previously readout.

PET Logic Definitions

Name	Definition
cijk	Command word i, bit jk
cijk*	Logical complement of the state of the command bit cijk
*	Logical complement
AH	A3H + A4H + A57H + A68H
/AH*/	AH* + c228
/AHE*/	AH* + c229
/AHP*/	AH* + c231
/AHR*/	AH* + c230
AL	A3L + A4L + A57L + A68L
[AL*]	AL* LOZMODE + AH* HIZMODE + c224
[ALE*]	AL* LOZMODE + AH* HIZMODE + c225
/ALP*/	AL* LOZMODE + AH* HIZMODE + c227
[ALR*]	AL* LOZMODE + AH* HIZMODE + c226
[HAZ*]	HAZ* + c425
HIZ EN	c418
HIZMODE	(HIZ EN) (LOZ EN)*
LOZ EN	c419
LOZMODE	(HIZ EN)* (LOZ EN)
[P1]	P1 + c201
[P1*]	P1* + c202
[P1A]	P1A + c203
[P1A*]	P1A* + c204
[P2]	P2 + c205
/P2*/	P2* + c206
[P2E]	P2 + c206*
[P3]	P3 + c207

Name	Definition
[P3*]	P3* + c208
/P3*/	P3* + c209
/P3A/	P3A + c210
/P3AE/	P3A + c213
[P3B*]	P3B* + c214
/P3E/	P3 + c211
/P3P/	P3 + c212
[P4]	P4 + c215
[P4*]	P4* + c216
/P4/	P4 + c217
/P5/	P5 + c218
/P5*/	P5* + c219
/P7/	P7 + c220
/P7*/	P7* + c221
[P8]	P8 + c222
[P8*]	P8* LOZMODE + HIZMODE + c223
[P8R*]	P8* + c223
[RE]	c410
[REW]	c412
[RP]	c409
[RPN]	c413
[RR]	c411

Event Priority and Polling

PET events are analysed according to a polling system described below. An incoming event is tested against the PET event logic equations (Section 2.3.2) sequentially in the following order: CAL, P, E, RNGE, EWGE,and PENE. If an event buffer is full, it is passed over. Only the highest priority empty buffer that is satisfied is written into. If an event satisfies two or more equations, the buffer used will depend on whether the higher priority buffer(s) is (are) full at the time. An exception to this is CAL events, which write over previous CAL events, and therefore do not pass down to test other event equations.

Event readout is controlled by a polling pointer that steps sequentially through the buffers until a filled buffer is encountered. The polling sequence is 7 (CAL), 0 (P), 1 (E), 2 (RNGE), 3 (EWGE), 4 (PENE), 7, 0, 1, 2, 3, 4, 7, etc. Polling starts at the buffer following the last one read out.

PET rate equations (Section 2.3.1) are tested sequentially in the following order: LIVE TIME, PEN, RNG, PHI, EHI, PLO, ELO, and EWG. Only the first one satisfied is accumulated (unlike MAST).

The live time for a particular event buffer should be calculated in the same fashion as for MAST (Section 1.3.4).

Comments on the PET Logic

The notes below attempt to document the motivation for including various terms in the PET rate and event logic.

EQUATION	TERM(S)	CMD BITS AND INIT STATES	COMMENTS
All rates			PET rates are tested sequentially in the following order: LIVE TIME, PEN, RNG, PHI, EHI, PLO, ELO, EWG. If two or more rate equations are satisfied, only the first encountered will be accumulated (unlike MAST).
All events			PET event equations are tested sequentially in the following order: CAL, P, E, RNG, EWG, PEN. Only the highest priority empty buffer is written into (like MAST). Therefore, if an event satisfies two or more equations, the buffer used will depend on whether the higher priority buffer(s) is (are) full at the time. These rules should be kept in mind in altering the initial command state.
PLO, PHI, P ELO, EHI, E	[P4*] /P5*/	c216=0 c219=1	If P4 fails, P5 can be substituted as the "end of range" detector for the low energy nuclei and electron modes. RNG should also be modified to include P5 to avoid an ambiguity for range 4 events.
" "	[AL*] /AH*/	c224=0 c228=1	If too many "good" events are lost in these modes because they trigger the low guard threshold AL, then AH* can be substituted.
P, E	/P3*/ /P3E/ [P1A] [P1A*]	c209=1 c211=1 c203=0 c204=0	These terms might be useful to reconfigure the HIZ mode, where electrons are no longer measured, and the P1A discriminator is no longer very useful. Setting c209=c211=0 and c203=c204=1 would make the P event buffer represent Range 2 nuclei, and the E buffer Range 3. The rate equations remain as is.
EHI, E	/P3AE/	c213=1	If RTG produced electrons make electron events with E < 3 MeV useless, requiring P3A = 3 MeV in P3 for the EHI rate and E events would give a greater proportion of "good" events. The ELO rate would still monitor electrons with < 3 MeV.
P, E	/P3P/ /P3E/	c212=1 c211=1	If P1 or P2 fails, then P3 should be required to avoid recording single detector events.

EQUATION	TERM(S)	CMD BITS AND INIT STATES	COMMENTS
RNG, RNGE, EWG, EWGE	[P4] /P5/	c215=0 c218=1	If P4 fails, P5 can be required in its place for these modes.
" "	/P7*/ [P8*] [P8R*]	c221=1 c223=0 c223=0	If P8 fails, P7* can be used to define the "end of range". Note that setting c223=1 also removes the P8R* requirement from RNG.
RNGE, RNGE	[ALR*] /AHR*/	c226=0 c230=1	If too many "good" RNG events trigger AL, AH* can be substituted in these equations.
EWG, EWGE	[ALE*] /ALE*/	c225=0 c229=1	If too many "good" EWG events trigger AL, AH* can be substituted in these equations.
EWG, EWGE	/P3A/ [P2E] /P2*/ [P4]	c210=1 c206=1 c206=1 c215=0	It may be useful to periodicly monitor neutral events produced by gamma rays and neutrons. Setting c210=c206=0 and c215=1 converts EWG to a "neutral mode" where events triggering P3A and possibly P4, P5, P6, and P7 are analysed. The P2* term is substituted for the P2E requirement by setting c206=0.
PEN, PENE	/P4/	c217=1	If P1 or P2 fails, it may be useful to require P4 to better define the geometry factor for this mode.
" "	/P7/ [P8]	c220=1 c222=0	If P8 fails, P7 can be substituted as the "penetrating" detector.
" "	/ALP*/ /AHP*/	c227=1 c231=1	The PEN mode nominally does not use guards in anticoincidence because of the unknown degree to which "good" events will be lost due to knockons, etc. Analysis of flight data may show that AH* or AL* should be required. For example, "showers" may dominate the data.
All events	[HAZ*]	c425=0	HAZ events are not nominally read out in order to maximize the return of data unaffected by pulse pileup. They are counted in the rates. Setting c425=1 will allow HAZ events to be read out.

3.5 Commands

PET Command Table

Bit No.	WORD 1 Term	WORD 1 Initial State	WORD 2 Term	WORD 2 Initial State	WORD 4 Term	WORD 4 Initial State	
1	spare	0	[P1]	0	not stored	-	
2	"	0	[P1*]	0	" "	-	
3	"	0	[P1A]	0	" "	-	
4	P4 D EN	1	[P1A*]	0	" "	-	
5	P5 D EN	1	[P2]	0	" "	-	
6	P6 D EN	1	/P2*/,[P2E]	1	" "	-	
7	P7 D EN	1	[P3]	0	" "	-	
8	P8 D EN	1	[P3*]	0	" "	-	
9	A3 LD EN	1	/P3*/	1	[RP]	1	
10	A3 HD EN	1	/P3A/	1	[RE]	1	
11	A4 LD EN	1	/P3E/	1	[RR]	1	
12	A4 HD EN	1	/P3P/	1	[REW]	1	
13	A57 LD EN	1	/P3AE/	1	[RPN]	1	
14	A57 HD EN	1	[P3B*]	0	P1 ADC EN	1	
15	A68 LD EN	1	[P4]	0	P2 ADC EN	1	
16	A68 HD EN	1	[P4*]	0	P3 ADC EN	1	
17	P3B-8	1	/P4/	1	P47 ADC EN	1	
18	" -4	1	/P5/	1	HIZ EN	0	a
19	" -2	0	/P5*/	1	LOZ EN	1	a
20	" -1	1	/P7/	1	LOG CAL DIS	1	b
21	P3A-8	0	/P7*/	1	RMP CAL DIS	1	b
22	" -4	1	[P8]	0	ADC CAL DIS	1	b
23	" -2	1	[P8*],[P8R*]	0	CMND CAL TRIG	0	
24	" -1	1	[AL*]	0	ACE EN	0	
25	P1B-8	0	[ALE*]	0	[HAZ*]	0	
26	" -4	0	[ALR*]	0	spare	0	
27	" -2	0	/ALP*/	1	"	0	
28	" -1	0	/AH*/	1	"	0	
29	P1A-8	1	/AHE*/	1	"	0	
30	" -4	1	/AHR*/	1	"	0	
31	" -2	0	/AHP*/	1	CALIBRATE OFF	1	b
32	" -1	0	NDW-A	0	NDW-B	0	

NOTE :
a) Auto-gain cycle (12.8 min in HIZ, 3.2 min in LOZ) selected if both bits have same value
b) In-flight set these bits low to start auto calibrate mode (see Section 2.7.2)

PET Command Cross Reference Table

CMD BIT	COMMAND	P (EVENTS)	E (EVENTS)	RNGE (EVENTS)	EWGE (EVENTS)	PENE (EVENTS)	CAL (EVENTS)	PLO (RATES)	PHI (RATES)	ELO (RATES)	EHI (RATES)	RNG (RATES)	EWG (RATES)	PEN (RATES)	DEFINITION/COMMENTS
101-103	spare														
104	P4 "	X	X	X	X	X	D	L	X	L	X	X	X	X	Enable/disable discriminators
105	P5 "	X	X	X	X	D	D	L	L	L	L	X	X		
106	P6 "	D	D	D	D	D	D								
107	P7 "	D	D	X	X	X	D					X	X	X	
108	P8 "	D	D	X	X	X	D					X	X	X	
109	A3 LD EN	X	X	X	X	X	D	X	X	X	X	X	X	X	enable/disable guard discriminators
110	A3 HD EN	X	X	X	X	X	D	X	X	X	X	X	X	X	
111	A4 LD EN	X	X	X	X	X	D	L	X	L	X	X	X	X	
112	A4 HD EN	X	X	X	X	X	D	L	X	L	X	X	X	X	
113	A57 LD EN	L	L	X	X	X	D	L	L	L	L	X	X	X	
114	A57 HD EN	L	L	X	X	X	D	L	L	L	L	X	X	X	
115	A68 LD EN	L	L	X	X	X	D	L	L	L	L	X	X	X	
116	A68 HD EN	L	L	X	X	X	D	L	L	L	L	X	X	X	
117-120	P3B-n				D		D						D		commandable discriminator levels (n,m = 8,4,2,1)
121-124	P3A-m		D		D		D				D		D		
125-128	P1B-n						D								
129-132	P1A-m	D	D				D	D	D	D	D				

NOTES:
- X = affects logic and also data
- D = affects data, not logic
- L = affects logic, probably not data
- P = affects polling and/or readout of events
- blank = no effect if starting from nominal command state

PET Command Cross Reference (continued)

CMD BIT	COMMAND	EVENTS: P	E	RNGE	EWGE	PENE	CAL	RATES: PLO	PHI	ELO	EHI	RNG	EWG	PEN	DEFINITION/COMMENTS
201	[P1]	X	X	X		X	D	X	X	X	X	X		X	Removes P1 from all except EWGE, EWG
202	[P1*]				X		D						X		Removes P1* from EWGE,EWG
203	[P1A]	X					D	X	X						Removes P1A from P, PLO, PHI
204	[P1A*]		X				D			X	X				Removes P1A* from E, ELO, EHI
205	[P2]	X	X	X	X	X	D	X	X	X	X	X	X	X	Removes P2 from all events, rates
206	/P2*/,[P2E]				X		D						X		Used for EWGE, EWG Neutral Mode
207	[P3]						D		X		X				Removes P3 from PHI, EHI
208	[P3*]						D	X		X					Removes P3* from PLO, ELO
209	/P3*/	X					D								Adds P3*to P for possible HIZ reconfig.
210	/P3A/				X		D						X		Adds P3A to EWG, EWGE for neutral mode
211	/P3E/		X				D								Adds P3 to E for HIZ reconfig. or P2 failure
212	/P3P/	X					D								Adds P3 to P for possible P2 failure
213	/P3AE/		X				D				X				Adds P3A to E, EHI
214	[P3B*]				X		D						X		Removes P3B* from EWG, EWGE
215	[P4]			X	X		D					X	X		Removes P4 from RNG, RNGE, EWG, EWGE
216	[P4*]	X	X				D	X	X	X	X				Removes P4* from P, E, PLO, PHI, ELO, EHI
217	/P4/					L	D							L	Adds P4 to PEN
218	/P5/			X	X		D					X	X		Adds P5 to RNG, RNGE, EWG, EWGE
219	/P5*/	X	X				D	L	L	L	L				Adds P5* to P, E, PLO, PHI, ELO, EHI
220	/P7/					X	D							X	Adds P7 to PEN, PENE
221	/P7*/			X	X		D					X	X		Adds P7* to RNG, RNGE, EWG, EWGE
222	[P8]					X	D							X	Removes P8 from PEN, PENE
223	[P8*],[P8R*]			X	X		D					X	X		Removes P8* from RNG, RNGE, EWG, EWGE
224	[AL*]	X	X				D	X	X	X	X				Removes AL* from P, E, PLO, PHI, ELO, EHI
225	[ALE*]				X		D						X		" " " EWG, EWGE
226	[ALR*]			X			D					X			" " " RNG, RNGE
227	/ALP*/					X	D							X	Adds AL* to PEN, PENE
228	/AH*/	X	X				D	X	X	X	X				Adds AH* to P, E, PLO, PHI, ELO, EHI
229	/AHE*/				X		D						X		" " " EWG, EWGE
230	/AHR*/			X			D					X			" " " RNG, RNGE
231	/AHP*/					X	D							X	" " " PEN, PENE
232	NDW-A	P	P	P	P	P	X								"new data wins" if NDW-A=NDW-B=1

PET Command Cross Reference (continued)

CMD BIT	COMMAND	EVENTS P	E	RNGE	EWGE	PENE	CAL	RATES PLO	PHI	ELO	EHI	RNG	EWG	PEN	DEFINITION/COMMENTS
401-408	Not stored														
409	[RP]	P					D								Controls whether event buffers are read out
410	[RE]		P				D								
411	[RR]			P			D								
412	[REW]				P		D								
413	[RPN]					P	D								
414	P1 ADC EN	X	X	X	X	X	D	X	X	X	X	X	X	X	Disable/enable ADC's
415	P2 ADC EN	X	X	X	X	X	D	X	X	X	X	X	X	X	
416	P3 ADC EN	X	X	D	X	D	D		X		X		X		
417	P47 ADC EN	D	D	D	D	D	D								
418	HIZ EN	X	X	X	X	X	D	X	X	X	X	X	X	X	HIZ enable/disable if =, then
419	LOZ EN	X	X	X	X	X	D	X	X	X	X	X	X	X	LOZ enable/disable auto sequence
420	LOG CAL DIS	P	P	P	P	P	X	D	D	D	D	D	D	D	Disable/enable auto logic calibration
421	RMP CAL DIS	P	P	P	P	P	X	D	D	D	D	D	D	D	Disable/ " " ramp "
422	ADC CAL DIS	P	P	P	P	P	X	D	D	D	D	D	D	D	Disable/ " " ADC "
423	CMD CAL TRG	P	P	P	P	P	X	D	D	D	D	D	D	D	Initiates calibration sequence
424	ACE EN	P	P	P	P	P	X	D	D	D	D	D	D	D	Enable GSE calibration
425	[HAZ*]	X	X	X	X	X	D								Removes HAZ* requirement from all events
426	spare														
427	"														
428	"														
429	"														
430	"														
431	CAL OFF	P	P	P	P	P	X	D	D	D	D	D	D	D	Disable/enable internal calibration
432	NDW-B	P	P	P	P	P	P								"new data wins" if NDW-A=NDW-B=1

3.6 Data

PET Event Data Format[a]

Byte	Bit	Data Bit	Name	Comments
1	7-0	1-8	P1 ADC	MSB first
2	7-6	9-10	"	
2	5-0	11-16	P2 ADC	MSB first
3	7-4	17-20	"	
3	3-0	21-24	P3 ADC	MSB first
4	7-2	25-30	"	
4	1-0	31-32	P47 ADC	MSB first
5	7-0	33-40	"	
6	7-5	41-43	Buffer no.	MSB first
	4	44	NMODE	Identifies neutal mode
	3-1	45-47	Sector	MSB first, 8 sect. per rev.
	0	48	LOZMODE	Identifies gain state
7	7	49	P3	Flag for discriminator
	6	50	P4	" " "
	5	51	P5	" " "
	4	52	P6	" " "
	3	53	P7	" " "
	2	54	P8	" " "
	1	55	AL	Low-level guard
	0	56	AH	High-level guard

NOTE :
a) 7 bytes parallel data from CDA address 1

PET Rate Data Format[a,b]

CDA Address	Name	No. of Bits (msb first)		Memory Device
2	PHI	24	(1st out)	TCC244
	EHI	"	(2nd ")	"
3	PLO	"		"
	ELO	"		"
	EWG	"		"
	LIVE TIME	"		"
4	PEN	"		"
	RNG	"		"
	RATE 9	"		DCR633
	RATE 10	"		"
7	STATUS	8		4014

NOTE :
a) Serial data
b) Readout period is 192 sec

PET Status Byte Format[a]

Byte	Bit	Data Bit	Name	Comments
1	7	1	LOG CAL	
	6	2	RAMP CAL	
	5	3	ADC CAL	
	4	4	CAL EN	
	3	5	ACE EN*	
	2	6	LOZMODE	
	1	7	NMODE*	
	0	8	-	

NOTE :
a) Serial data

PET HOUSEKEEPING PARAMETERS[a]

HSKPG-MUX ADDRESS	NOMINAL RANGE OFF-STATE	NOMINAL RANGE ON-STATE	PARAMETER
0	0 Volts	4.49 V @ -20 deg C 0.89 V @ +30 deg C	P8RT Thermistor
1	"	"	P1RT Thermistor
2	"	"	ANART Thermistor
3	"	"	P8RT Thermistor
4	"	"	P1RT Thermistor
5	"	"	ANART Thermistor
6	"	"	P1RT Thermistor
7	"	"	P8RT Thermistor
8-15	(same as 0-7)		

NOTE: a) source packet byte 22

PET HISTORY PACKET
(30 samples of 192 seconds each)

QTY #	*RATE* #	*DPU* ADDRESS	*SUBCOM* STATE*	NAME
1	1	3		PLO
2	2	2		PHI
3	3	3		ELO
4	4	2		EHI
5	5	4		RNG
6	6	3		EWG
7	7	4		PEN
8	8	3		LIVE TIME
9	9	4	0, 8	P1 ADC
10	9	4	1, 9	ADC OR
11	9	4	2, 10	P2 ADC
12	9	4	3, 11	AL
13	9	4	4, 12	P3 ADC
14	9	4	5, 13	AH
15	9	4	6, 14	P47 ADC
16	9	4	7, 15	HAZ
17	10	4	0	P4
18	10	4	1	P5
19	10	4	2	P6
20	10	4	3	P7
21	10	4	4	P8
22	10	4	5	A3L
23	10	4	7	A4L
24	10	4	9	A57L
25	10	4	11	A68L

*Subcom States run from 0 to 15

QTY #	*HOUSEKEEPING* ADDRESS	PARAMETER
26	0	P8RT Thermistor
27	1	P1RT Thermistor
28	2	ANART Thermistor

(2/14/91, WRC)

Notes on MAST/PET Control and Rate Readout by the DPU

Notes on MAST/PET Control and Rate Readout by the DPU

MAST and PET are electronically separate instruments with nearly identical electrical interface to the DPU (see the MAST/PET to DPU ICD). The similarity of MAST and PET extends further, such that many of the details of their rate accumulation and readout systems are also the same. The MAST rate accumulation scheme is described in detail below, while the section to follow on PET concentrates only on the differences of PET from MAST.

MAST Rate Accumulation and Readout

MAST contains two types of counters: (1) the "RAM" counters which are used to measure various "coincidence" rates which are necessary for the normalization of event data to obtain absolute flux measurements, and (2) the "DCR633" counters which are generally used to measure the rates of individual detector discriminator firings ("singles")and are needed only for engineering assessment and potentially for the optimization of commandable thresholds. Both types of counters are buffered such that previously acquired static data are readout while new count data are being accumulated. Thus the readout process induces essentially zero deadtime for the counters.

The RAM Counters

In MAST a set of N 24 bit counters are implemented using a single four bit adder and 256 bytes of random access memory. Following each trigger of the MAST event processor (which occurs on any ADC trigger), the MAST rate equations are sequentially tested and the corresponding count in RAM is incremented if appropriate. The RAM is divided into two buffers: one containing static data available for readout, and one containing dynamic, current data. The buffers are switched by toggling bit S2E-3 of the control word (see Figure 1) which is periodically downloaded by the DPU. A buffer is cleared by the readout process.

The DCR633 Counters

MAST contains a single "DCR633" custom GSFC counter-register IC. The DCR633 contains two independent 24 bit binary counters, each with an associated 24 bit output register. The transfer of the contents of the counters to the registers and the subsequent clearing of the counters is initiated by a one to zero transition bit S2E-1. Each of the two 24 bit counters is preceeded by a multiplexor which selects one of 16 possible singles rates, based on the four bits S2E04, S2E05, S2E06 and S2E07 of the control word. These bits specify the "subcom" state ranging from 0 through 15.

MAST Rates Readout

The MAST rate readout sequence is illustrated by the timing diagram of Figure 2. The sequence is controlled by the DPU via the periodic sending of control words over the serial command interface and the enabling of the most recently sent control word by the SCTR signal positive transition. The illustrated time pattern of bits S2E-3, and S2E-1 achieves the needed buffering operations for the RAM and DCR633 counters. Meanwhile, the subcom bits repeatedly count 0 through 15. The length of each subcom state is 6 seconds and the 16 state cycle repeats every 96 seconds. During a given subcom state all the count rate data for the previous subcom state should be readout by the DPU.

PET Rates Readout

The PET rates readout (which would otherwise be similar to the MAST readout) is complicated by the desire to obtain high time-resolution sampling of the P1 ADC Rate, which should respond to low energy magnetospheric electrons. The P1 ADC Rate is counted in a DCR633 counter when the subcom state 0 is selected.

The PET readout sequence illustrated in Figure 3 was chosen to provide a sample of the P1 ADC rate once every 0.1 sec, while keeping the readout as close as possible to the simple one for MAST. The subcom state is set to zero and the P1 ADC rate is accumulated during alternate 0.05 sec intervals for a 50% duty cycle. During the intervening 0.05 sec intervals the subcom state is set to its "normal" value which, as in MAST, counts repeatedly from 0 through 15, spending 6 seconds in each state.

To reduce the rate of control words needed to operate PET, we have modified the circuitry such that the process of transfering the DCR633 counter contents to output register and subsequent clearing of the counter is initiated by the SCTR signal rather than by a 1 to 0 transition of bit S2E-1. This automatic reseting of the DCR633's may is disabled by setting bit S2E-4 to 1, such that for normal operation S2E-4 is kept at 0. ?

The PET rates are readout according to the schedule of addresses listed in Figure 4. Note that the P1 ADC rate is readout at address 4, which is thus accessed during every 0.05 sec period.

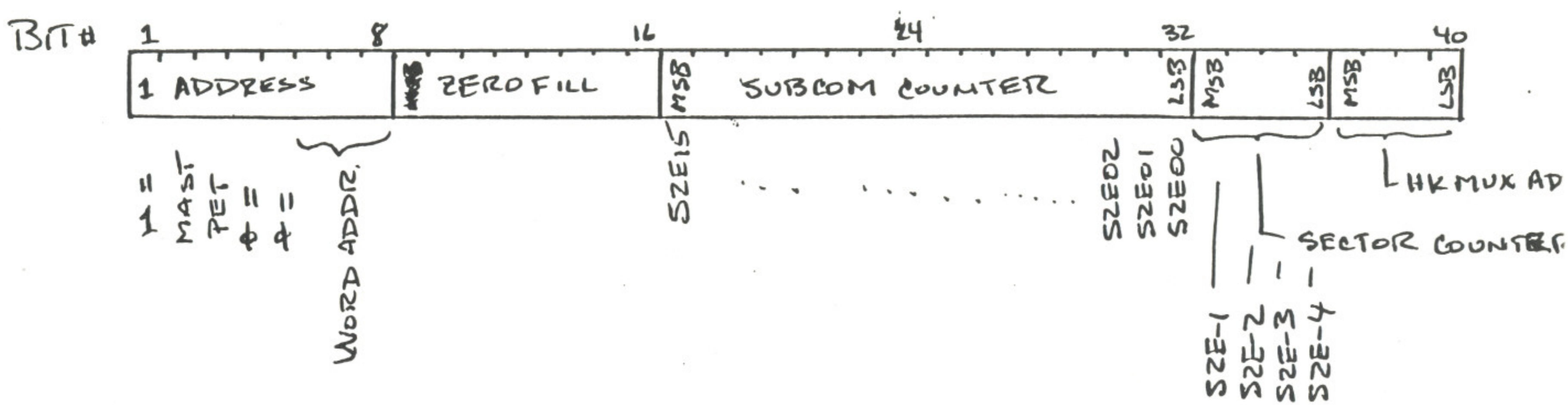
The PET rate readout scheme, since it deviates from that originally intended by the PET logic designer, requires that some additional accumulations be performed by the DPU as follows:

(1) Non-subcommutated rates, excluding those readout at address 4. The desired 6 second samples of these rates are obtained by summing two readouts: one made during the 120th 0.05 sec period of the given 6 sec interval and a second made during the 1st 0.05 sec period of the next 6 sec interval. In this way, counts stored in the two halves of PET's RAM counters are separately readout and then combined.

(2) Non-subcommutated rates readout at address 4. The reading of rate address 4 on every 0.05 sec period causes all the rates accessed by address 4 to be zeroed. Thus, to obtain a complete 6 second sample of the rates ------, the DPU must sum 120 consecutive 0.05 second samples, beginning with the 2nd sample readout during a given 6 sec interval and ending with the 1st sample readout during the following 6 sec interval.

(3) Subcommutated rates. All subcommutated PET rates are readout at address 4, and are thus zeroed each 0.05 sec. The subcommutated rates are accumulated during alternate 0.05 sec periods, when the subcom state is "normal", and are then readout during the following 0.05 sec periods, while the P1 ADC rate is being accumulated. To obtain a 6 second sample of a subcommutated rate the DPU must sum 60 alternate 0.05 second samples, beginning with the data readout during the 2nd 0.05 second period of the given 6 sec interval, and ending with the 120th 0.05 second period of the same 6 sec interval. While the sample spans 6 seconds, the duty cycle for counting is only 50%, such that the livetime is 3 seconds.

FIGURE 1 : CONTROL WORD FORMAT



(FOR CONTROL WORD ; ADDRESS FIELD = 1111111)

FIGURE 2: MAST CONT[illegible] WORD SEQUENCE

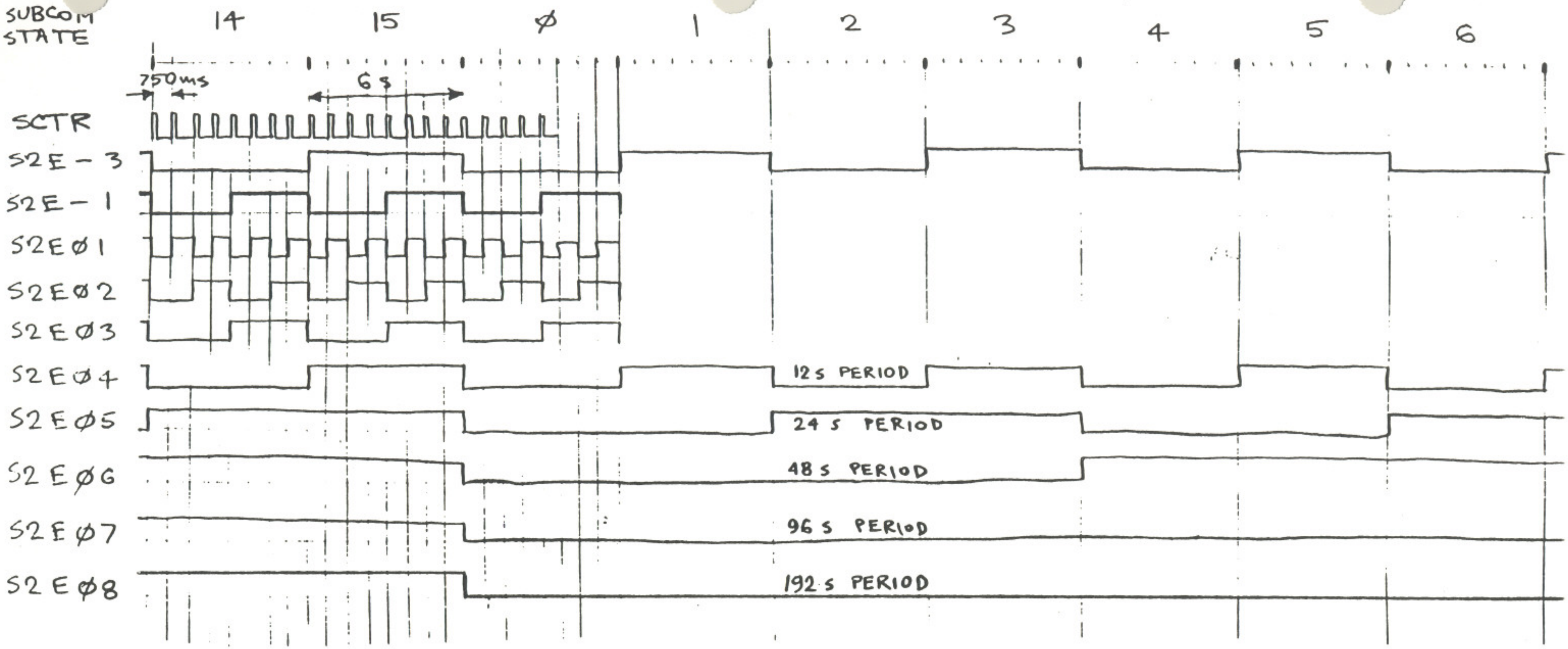
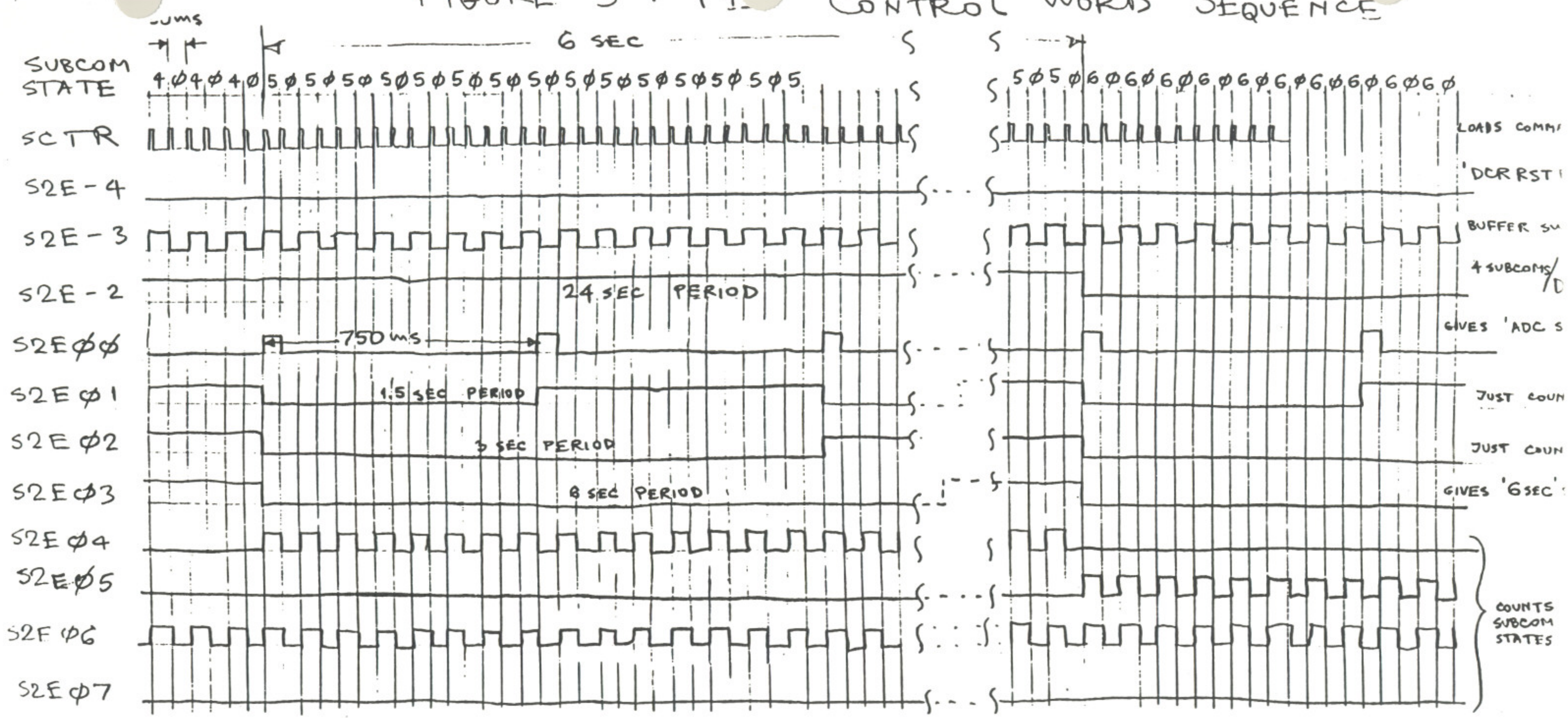


FIGURE 3 : PE CONTROL WORD SEQUENCE



NEW SCALE !

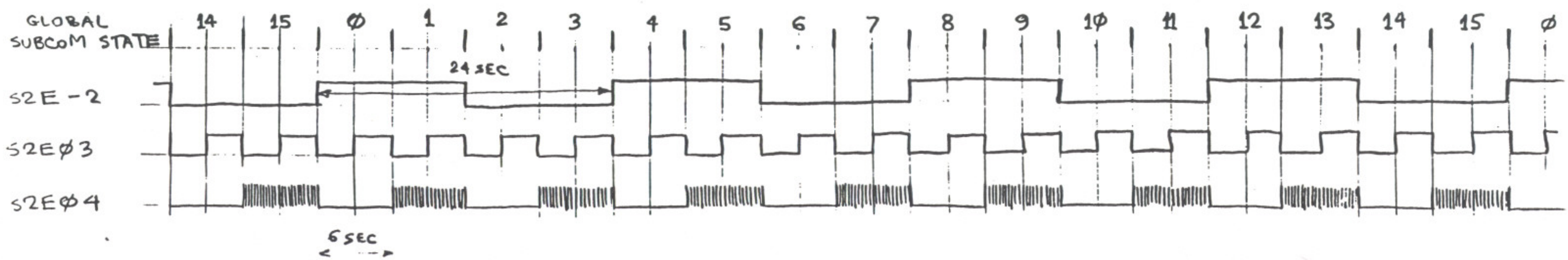


Figure 4: PET Rate Commutation and Readout

Time of each interval = 50 ms = (6/120) s.
One PET command must be sent every 50 ms.
Time of complete cycle = 96 s.

Interval #	Subcom State	Readout Addresses	
1	0	2,3,4	
2	0	4,7	
3	0	4	
4	0	4	
.	.	.	
.	.	.	
119	0	4	
120	0	2,3,4	
121	1	2,3,4	|
122	0	4,7	|
123	1	4	|
124	0	4	|
.	.	.	6 seconds
.	.	.	|
239	1	4	|
240	0	2,3,4	|
241	2	2,3,4	
242	0	4,7	
243	2	4	
244	0	4	
.	.	.	
.	.	.	
359	2	4	
360	0	2,3,4	
.			
.			
.			
1801	15	2,3,4	
1802	0	4,7	
1803	15	4	
1804	0	4	
.	.	.	
.	.	.	
1919	15	4	
1920	0	2,3,4	

3.7 Response Characteristics

PET Geometry Factors[a]

Name	Radius (cm)	Position (cm)	Number Traj.	Geom. Fac. (cm**2-sr)	+ or -	Secant ave.	Theta sig.	Max. Angle (deg)
P1 Mid	1.596	0.000	50000	25.14	0.00	1.970	2.229	88.72
P2 Mid	1.596	5.779	3259	1.64	0.03	1.034	0.030	28.14
P3A Top	1.702	6.122	3214	1.62	0.03	1.033	0.029	27.13
P3B Top	1.702	6.594	2902	1.46	0.03	1.029	0.026	25.73
P3C Top	1.702	7.028	2588	1.30	0.02	1.026	0.024	23.85
P3D Top	1.702	7.501	2281	1.15	0.02	1.023	0.022	23.30
P3E Top	1.702	7.935	2054	1.03	0.02	1.021	0.019	22.01
P3E Bot	1.702	8.255	1914	0.96	0.02	1.019	0.018	21.09
P4 Top	1.188	8.382	904	0.45	0.02	1.013	0.014	17.61
P4 Bot	1.188	8.702	854	0.43	0.01	1.012	0.013	17.41
P5 Top	1.188	9.042	777	0.39	0.01	1.011	0.012	16.38
P5 Bot	1.188	9.362	720	0.36	0.01	1.011	0.011	15.73
P6 Top	1.188	9.702	671	0.34	0.01	1.010	0.011	14.94
P6 Bot	1.188	10.022	638	0.32	0.01	1.009	0.011	14.94
P7 Top	1.188	10.409	584	0.29	0.01	1.009	0.010	14.00
P7 Bot	1.188	10.729	546	0.27	0.01	1.008	0.010	14.00
P8 Top	1.188	11.142	504	0.25	0.01	1.008	0.009	13.63
P8 Bot	1.188	11.462	482	0.24	0.01	1.007	0.009	12.86

a) Does not include EWG mode

PET Energy Intervals

I. LO-Z

Buffer No.	Particle Species	Energy (MeV/nuc - nuclei) (MeV - electrons)	Normal Coincidence Equation[a]
0	protons, alphas, low energy Li and Be	18 < E < 64	P1 P1A P2 P4* AL*
1	electrons	3 < E < 14	P1 P1A* P2 P4* AL*
2	electrons nuclei	14 < E < 120 64 < E < 130	P1 P2 P4 P8* ALR* " " " " "
3	electrons	14 < E < 120	P1* P2 P3B* P4 P8* ALE*
4	electrons and nuclei	E > 130	P1 P2 P8

II. HI-Z

Buffer No.	Normal Coincidence Eq.[a]	Energy Ranges (MeV/nuc) for various nuclei					
		p	He	Li	Be	C	O
0	P1 P1A P2 P4* AH*	none	none	21-24	25-41	34-103	39-141
1	P1 P1A* P2 P4* AH*	21.8-22.8	18-64	24-74	41-90	103-119	none
2	P1 P2 P4 AHR*	none	64-105	> 74	> 90	> 119	> 141
3	P1* P2 P3B* P4 P8* AHE*	data of doubtful use - buffer can be disabled with c412					
4	not triggered, since it requires LOZ mode						

NOTE : a) see logic section for definition of terms

PET MASS RESOLUTION

The curved detectors in PET allow for significant improvement in mass resolution when compared to flat-detector telescopes with the same opening angle. The theoretical pathlength distribution for both types of telescopes is shown in the attached figure. As shown $\frac{\sigma_l}{l}$ (curved) = .010 which is much less than the $\frac{\sigma_l}{l}$ (flat) = .028. Also note the long tail on the flat detector distribution which is significantly reduced with the use of curved detectors.

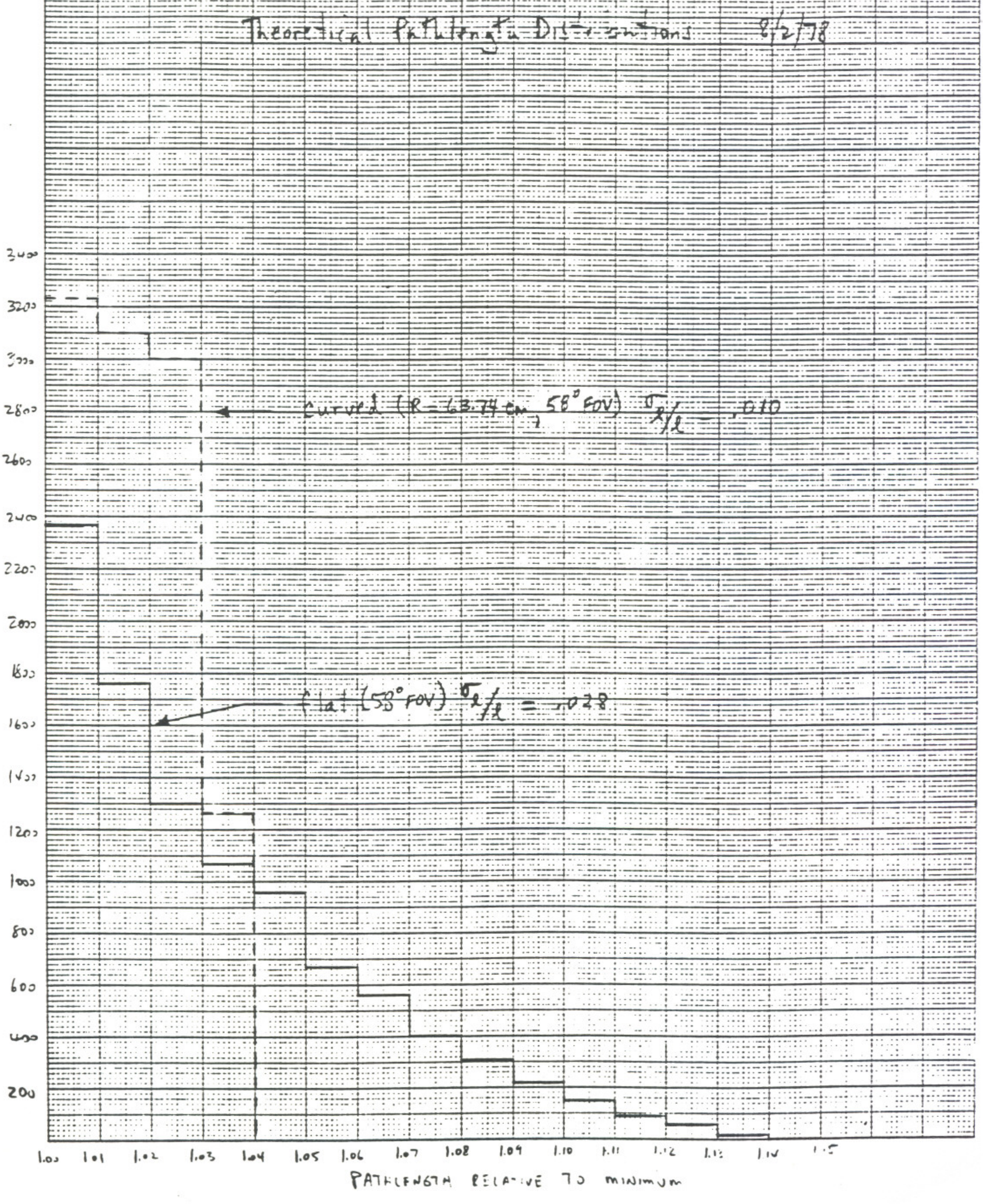
Data from a telescope with identical curved detectors as PET (HET 1 on Voyager 2) was analyzed to check the theoretical mass resolution. The σ_m for alpha particles from the November 1977 solar flare was measured for a restricted energy interval. $\frac{\sigma_l}{l}$ was then deduced from the measured $\frac{\sigma_m}{m}$ by assuming the only contribution to the mass resolution other than pathlength variations was due to ionization energy loss fluctuations (σ_m (fluc) $\approx$ .047).

$$\sigma_m \text{ (measured)} = .116 \rightarrow \sigma_m \text{ (pathlength)} \approx .106$$

Therefore,

$$\frac{\sigma_m}{m} \text{ (pathlength)} \approx .027 \rightarrow \frac{\sigma_l}{l} \approx \frac{.027}{1.3} \approx .021$$

This value falls between that expected for spherical and flat detectors.


Theoretical Pathlength Distributions 8/2/78
Curved (R = 63.74 cm, 58° FOV) σℓ/ℓ = .010
Flat (58° FOV) σℓ/ℓ = .028
NUMBER
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1.00
1.01
1.02
1.03
1.04
1.05
1.06
1.07
1.08
1.09
1.10
1.11
1.12
1.13
1.14
1.15
PATHLENGTH RELATIVE TO MINIMUM

PET Positron Detection

Although it was not specifically designed to do so, PET is capable of identifying cosmic ray positrons and thereby determining the e^+/e^- ratio. Although the efficiency for positron detection is low, the potential significance of positron measurements is such that this possibility bears further study. In particular, it is conceivable that the positron flux might increase as the Solar Polar Mission passes over the solar poles. This section will outline the principles for positron detection in PET, give estimates of the efficiency and background, and point out potential problem areas that could be looked at.

General Method

When a positron enters the telescope and annihilates, one of the 0.51 MeV γ-rays may Compton scatter in a detector deeper in the stack, producing an event signature that is difficult to obtain from normal electrons. Examples of positron signatures include:
$P1\cdot P2\cdot \overline{P3}\cdot (P4 + PX)\cdot \overline{P8}\cdot \overline{AL}$ and $P1\cdot P2\cdot P3\cdot \overline{P4}\cdot PX\cdot \overline{P8}\cdot \overline{AL}$ where PX is the logical "or" of P5, P6, and P7, and AL is the low level guard threshold. In the above cases it is the γ-ray that is presumed to trigger P4, P5, P6 or P7. The maximum energy Compton electron from a 0.51 MeV γ-ray is 0.34 MeV. Thus, we require that one and only one of the deep detectors trigger (threshold = 0.20 MeV), and that the P47 pulseheight be <u>below</u> the ADC threshold of 0.365 ± 0.15 MeV. Taking into account the expected noise value for P47, integration of the Compton electron spectrum gives 35% of the Compton electrons with $0.20 \le E_e \le 0.365$ MeV, and 3% with $E_e > 0.365$ MeV.

The table below lists possible positron signatures in PET along with other pertinent information. Preliminary calculations suggest that the P2 (~1.5-3 MeV) and P3 (~3-14 MeV) ranges will be the most useful, but flight data will in the end be the final arbitrator of this.

Positron Detection Efficiencies

The positron detection efficiencies in the Table were evaluated for the PET telescope configuration when P3 consisted of three 5mm-thick detectors rather than five 3mm detectors, as is presently the case. The revised numbers should be slightly lower, but very similar. The following factors were included: 1) Probability of hitting the later detector for isotropic emission of two back to back γ-rays of 0.51 MeV; 2) Attenuation of the γ-ray in intervening material, mainly the tungsten absorbers; 3) Compton cross section for scattering in later detector (probability = 0.058 for 3mm); 4) Probability of electron energy loss with $0.2 \le E \le 0.365$ MeV (=0.35). Thus, the efficiency for annihilation γ-rays originating in the middle of P3 to be detected in P5, P6 or P7 is ~0.004. A similar calculation for IMP-8 agreed with e^+ calibration data to within ~10%. Such calibrations can and should be done with PET (see Section 2.7.4).

Positron Background

The following potential sources of positron background have been identified. Initial estimates have been made of those deemed to be the most important on the basis of experience with the IMP instruments.

1) <u>Double Compton Scattering</u>: This mechanism involves γ-rays from the RTG or the spacecraft which undergo two Compton scatters. Although this

occurs quite frequently, the fraction of events that satisfy the pulse-height and range requirements is small. Note that most γ-rays come from the back of the instrument. Thus, in the typical case for, e.g., P1·P2·P3·P6 events, the first scatter must give $0.20 \leq E \leq 0.365$ MeV in P6, and the second scatter must produce an electron in P3 with the necessary angle and energy to pass out the front of the telescope through P2 and P1. Assuming the Apollo spacecraft γ-ray spectrum $j_\gamma \sim 0.9 E_\gamma^{-1.9}\ cm^{-2}sec^{-1}MeV^{-1}$, the background levels in the figure below were estimated. A typical accuracy might be a factor of ~3. The estimate was made for γ-rays hitting one of the back detectors first and then doubled to account for γ-rays striking, e.g., P3 first and then scattering back.

Note that RTG γ-rays have $E_\gamma \leq 2.6$ MeV and therefore should contribute only to the P1·P2 positron background. The estimated RTG background assumes $j_\gamma = 44\ cm^{-2}sec^{-1}MeV^{-1}$ for $1 \leq E \leq 3$ MeV, as calculated by JPL for the PET location.

Both the spacecraft and RTG γ-rays were assumed to be incident isotropically from the back hemisphere, with the once-scattered γ-rays isotropic in the front hemisphere. In the case of the RTG, where the source is localized, this might be a poor approximation. A monte-carlo calculation is necessary to do a reliable calculation of these backgrounds.

2) Positron Production in the Detector Stack: If a γ-ray of several MeV produces an e^+e^- pair in, e.g., P3, the electron may exit through P2 and P1, and the positron annihilate in P3, with the 0.51 MeV γ-rays triggering a later detector. This background was estimated for the spacecraft γ-ray spectrum. Complications involve the possibility that the positron also escapes, or that it triggers a guard.

3) Other Local Positron Production: Positrons can also be produced in inactive material surrounding the detector stack and then enter the detectors in a manner similar to real positrons. This contribution should be less important than production in the stack because of the unfavorable geometry (very little inactive material is viewed by the telescope), and because essentially none of the surrounding material has a higher Z than silicon (for example the window is Mylar, and the telescope housing is aluminum). This possibility should be looked at more closely.

4) Chance Coincidences: This possibility is reduced by the requirement that at least 3 detectors trigger for each of the positron modes proposed. An exact calculation is not possible without in-flight count rates, but the following estimate is possible. The quiet time rate of 3-14 MeV electrons should be $\sim 10^{-2} sec^{-1}$. Assuming a resolving time of 5×10^{-6} sec and singles rates for D5, D6 and D7 of $10^{-1} sec^{-1}$ (0.2-0.365 MeV), the fraction of electrons that will look like positrons is

$$f_{e^+}, \text{chance} \simeq \frac{(10^{-2} sec^{-1})(3 \times 10^{-1} sec^{-1})(5 \times 10^{-6} sec)}{10^{-2} sec^{-1}} = 1.5 \times 10^{-6}$$

This compares to the efficiency for positron identification of ~0.004. Thus the chance rate is ~3000 times lower than the counting rate would be if all electrons were positively charged.

5) Bremstrahlung: A stopping electron in P1P2P3 could emit a bremstrahlung γ-ray which could trigger the later detector. The probability of this has not yet been estimated but is believed to be small. The energy loss distribution in the later detector would differ from that for 0.51 MeV γ-rays.

6) Multiple γ-rays: A shower of coincident γ-rays from the spacecraft could trigger several detectors simultaneously. The possibility of this is hard to estimate, but both the energy loss and range distributions would differ from those expected from real positrons.

7) Electron Scattering: Electrons might scatter around the skipped detector and then trigger a deeper detector. The efficiency for this should be evaluated from electron calibration data.

Positron Data Analysis

There will inevitably be events with positron-like signatures. The question will be: are they positrons or background. This can best be answered by a thorough understanding of the response to real electrons, positrons, and γ-rays, requiring a combination of calibrations and calculations. Real positrons should have the proper energy loss distributions in D5, D6 and D7; have the proper distribution of events that include D5, D6 and D7 as the last detector; and depend in a reasonable way on time, count rates of other species, and other available parameters. Most imaginable backgrounds will not fit all of these criteria. In the end, time variations may provide one of the best discriminators. In particular, for the Solar Polar Mission, one would look for latitude and radial variations in the "positron" event rate. At the very least, it appears that useful upper limits could be obtained, since the estimated background levels are comparable to existing positron measurements.

The Table of positron detection modes also lists ways to monitor the background. In general, these involve very similar event signatures that will arise from background, but not from positrons. They provide for the possibility of background subtraction.

Note that the count rate of real positrons is expected to be small. The Simnett and McDonald electron spectrum, if all positrons, would give ~2 counts/day with 3-14 MeV. Thus the real positron rate in this energy interval is perhaps more like $\sim 10^{-1}$ per day. Thus long integration times will be necessary to study this component.

Positron Detection Modes

Positron Energy (MeV)	Signature (1)	AΩ	Efficiency (2)	Event Buffer #	Rate #	Pulse Height Restrictions D1,D2,D3	Pulse Height Restrictions D47	Background Monitors(3)
~1.5 to 3	$P1\cdot P2\cdot \overline{P3}\cdot P4\cdot \overline{P5}$	~1.6	0.002	2	5	~1.5-3	0.2-0.36	P47>0.36 MeV
	$\overline{P1}\cdot P2\cdot \overline{P3}\cdot \overline{P4}\cdot PX$ (4)	~1.6	0.002	1	3	"	"	"
?	$\overline{P1}\cdot P2\cdot \overline{P3}\cdot P4\cdot \overline{P5}$	~4.4	0.002	3	6	⩽2	"	"
~ 3 to 14	$P1\cdot P2\cdot P3\cdot \overline{P4}\cdot PX$ (4)	~1.3	.002-.006 (6)	1	4	~3-14	0.2-0.36	P47>0.36 MeV Neut Mode (5)
~14 to 25	$P1\cdot P2\cdot P3\cdot P4\cdot \overline{P5}\cdot (P6+P7)$	~0.44	~0.005	2	5	⩽14	⩽3	Neut Mode (5)
	$\overline{P1}\cdot P2\cdot P3\cdot P4\cdot \overline{P5}\cdot (P6+P7)$	~1	~0.005	3	6	"	"	"
~25 to 50	$P1\cdot P2\cdot P3\cdot P4\cdot P5\cdot \overline{P6}\cdot P7$	~0.38	~0.004	2	5	⩽10	⩽5	"
	$\overline{P1}\cdot P2\cdot P3\cdot P4\cdot P5\cdot \overline{P6}\cdot P7$	~1	~0.004	3	6	"	"	"
~50 to 75	$P1\cdot P2\cdot P3\cdot P4\cdot P5\cdot P6\cdot \overline{P7}\cdot P8$	~0.33	~0.004	4	7	⩽10	⩽7	"

(1) Also includes $\overline{AL}$ and ·no trigger from other detectors (e.g. P8).

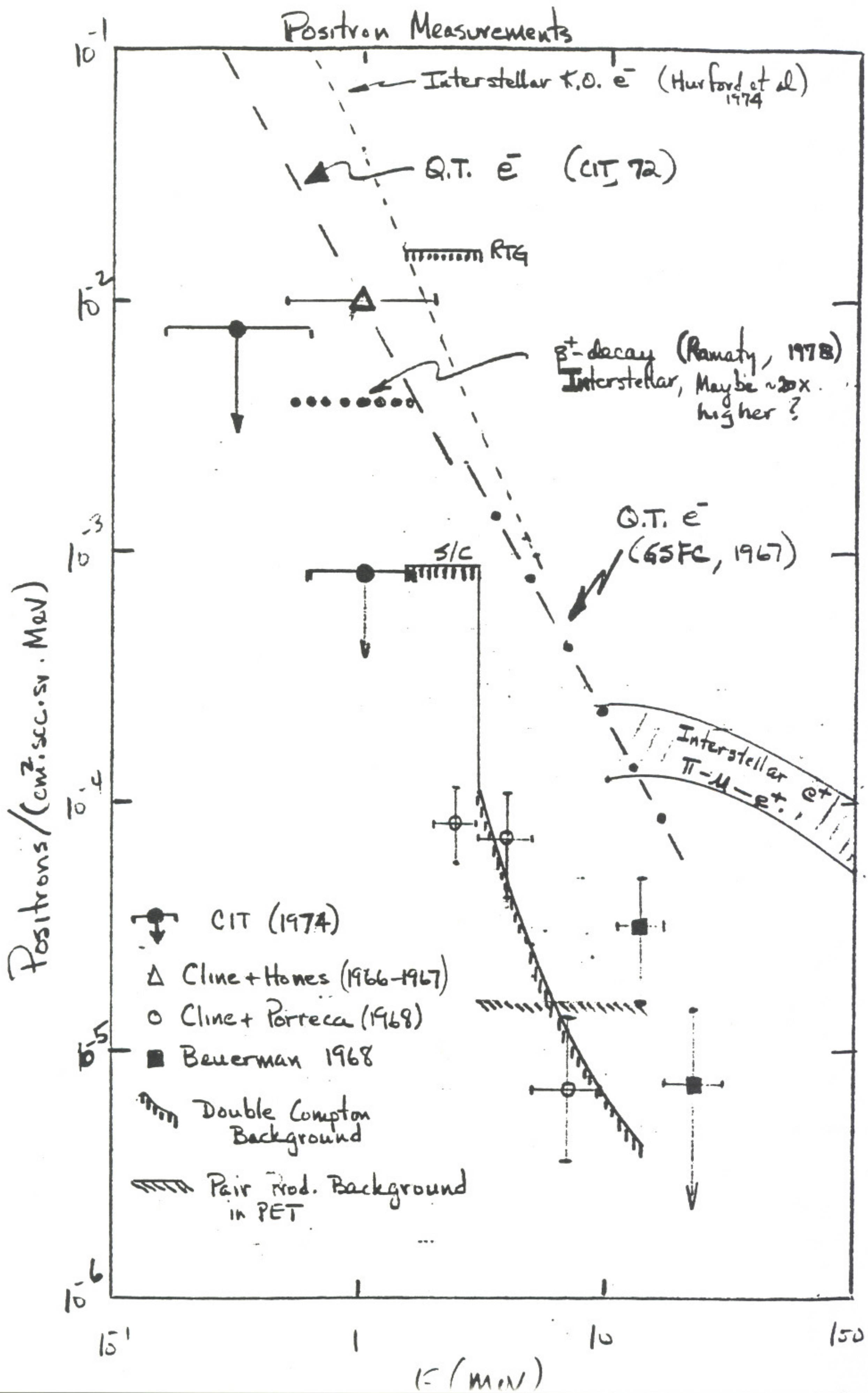
(2) Calculated for original PET where P3=3x5mm Should be redone

(3) Also events triggering ≥2 back detectors (e.g., P1·P2·P5·P6)

(4) PX is one and only one of P5, P6 or P7.

(5) The NEUT mode allows for various signatures that skip detectors (e.g. $P3\cdot P4\cdot \overline{P5}\cdot P6$). Useful to disable P4 requirement from this mode.

(6) Depending on depth in P3.



Positron Measurements
Interstellar K.O. e⁻ (Hurford et al 1974)
Q.T. e⁻ (CIT, 72)
RTG
β⁺-decay (Ramaty, 1978) Interstellar, Maybe ~20x higher?
Q.T. e⁻ (GSFC, 1967)
S/C
Interstellar π-μ-e⁺, e⁺
CIT (1974)
Cline + Hones (1966-1967)
Cline + Porreca (1968)
Beuerman 1968
Double Compton Background
Pair Prod. Background in PET
Positrons/(cm²·sec·sr·MeV)
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻¹
1
10
150
E (MeV)

The PET Neutral Mode

This mode can be entered by command, by modification of the EWG equation. Its purpose is to provide a better handle on estimating the contribution that neutral particles (γ-rays and neutrons) make to the various PET analysis modes. A similar analysis mode in the Caltech experiments on IMP-7 and 8 proved to be very useful.

Setting command bit c206=0 removes the P2E requirement from EWG and EWGE and inserts instead P2*. The object is to shield P3 against triggering by charged particle events. Although the shielding is not complete, making the above change does make a major change in the geometry factor for charged particles hitting P3, and therefore helps to isolate the neutral contribution.

Several further logic changes should also be included as part of a periodic monitoring of the neutral mode. Setting c215=1 removes P4 from the EWG and EWGE equation, so that they respond to P3 singles events with ≥0.8 MeV. (Note that P4 is also removed from the RNG and RNGE equations, which might not be desireable on a long-term basis). In the presence of an RTG, P3 singles ≥0.8 MeV would be dominated by RTG γ-rays. To eliminate these, set c210=0, which adds the P3A requirement (3.1±0.2 MeV), and therefore eliminates the vast majority of RTG γ-rays. Obtaining a periodic sample of data for these various possible command states would be the best way to monitor the neutral contribution as a function of time and spacecraft location.

Note that the events returned by this mode will include examples that trigger P3 (possibly P4) and also detectors deeper in the stack (e.g. P6, P7), after skipping a detector (e.g. P5). These event signatures are of interest for estimating the neutral contribution to the various positron modes (see Section 2.6.4).

Background Considerations

Nuclei

For nuclei with $3 \leq Z \leq 26$, including isotopes with $3 \leq Z \leq 10$, the most significant background is probably due to edge effects in P1 and P2. For P1·P2 events there is no handle on the this background. For events that penetrate to P3 and beyond, requiring agreement between P1 and P2 should eliminate the vast majority of edge events.

For H and He isotope studies, a second important background comes from nuclear reactions of high energy protons, etc., in both P1, and the window in front of P1. These telescope components are not protected by active shielding. The interaction products include ^2H, ^3H and ^3He nuclei with sufficient energy to reach P3, although the spectrum is peaked at low energies. Voyager HET data has shown that the quiet time flux of ^2H for B1·B2·C (equivalent to P1·P2·P3 in PET) is ~30 times the galactic ^2H flux if one ignores the B1 pulseheight. A sizeable ^3H flux is also evident ($^3H/^2H \simeq 0.2$). Presumably most of this comes from nuclear interactions in B1 which produce ^2H, ^3H, and/or ^3He, with no other fragments entering B2 or C. Placing restrictions on the B1 pulseheight eliminates most of these events, but probably not all. To study this in flight data, ^3H should be used as the tracer. For interactions that occur in the window, pulseheight restrictions do not help, and one is left with using ^3H as a tracer of this background.

Electrons

There are several sources of background for electron measurements with PET. They will be summarized qualitatively here; in all cases more quantitative estimates are possible with additional work.

At the lowest energies (several MeV), Compton electrons dominate the background. The γ-rays that produce this background come from nuclear interactions of high energy cosmic rays with spacecraft material, and in the case of the Solar Polar Mission, from the RTG. The figures below show the Voyager RTG γ-ray spectrum, the resulting Compton electron spectrum, and a comparison of this background to interplanetary electron measurements. Note that the spectrum drops by ~10^3 beyond ~2.5 MeV. The latest RTG estimates for the Solar Polar RTG at PET's location on the American spacecraft give an RTG γ-ray flux that is about a factor of 5 lower than on Voyager (122 γ's $cm^{-2} sec^{-1}$) with a similar spectrum. Thus these background estimates can be scaled accordingly. Laboratory calibrations with γ-ray sources (especially ^{228}Th, see Section 2.7.4) would be of great help in relating the calculated RTG spectrum (accuracy better than a factor of 2) to the absolute event rate in PET for various event signatures.

For spacecraft produced γ-rays, the large amount of work on this background in the Caltech IMP-7 and 8 instruments, coupled with PET γ-ray calibrations, would give reasonably good estimates of this background for $1 \leq E \leq 5$ MeV. At higher energies calculations would have to suffice. Note that the spacecraft γ-ray spectrum was measured on Apollo. This spectrum should be similar on other spacecraft.

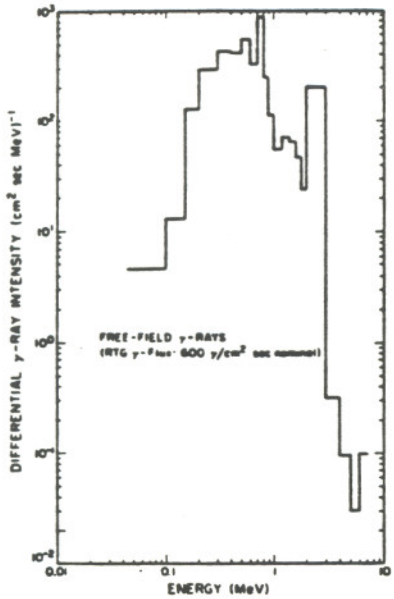
An additional source of background for low energy electron measurements in PET is knock-on electrons produced by high energy nuclei passing through the window and through P1. These telescope components are not actively shielded. A back of the envelope estimate suggests that this background might be 10-20% of quiet time electron fluxes measured at 1 AU. The knock-on spectrum is known to be similar to the quiet-time electron spectrum (mostly Jovian electrons). Better estimates of this background are possible and should be done. Possibly some data is available from the Voyager TET proton calibration at LBL.

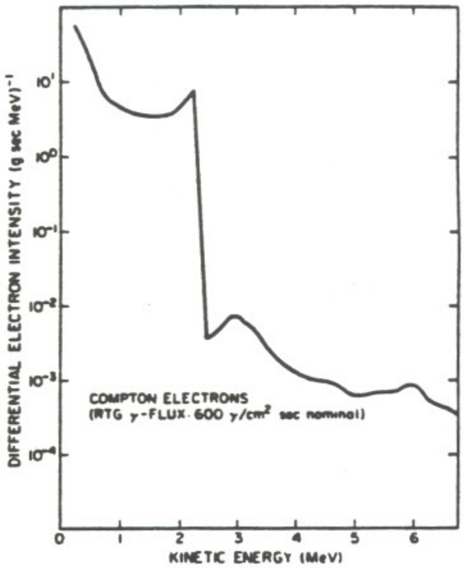
At higher energies (~10 to ~100 MeV) the major source of background is expected to be from high energy protons that somehow simulate an electron event. This includes minimum ionizing protons from the front that somehow manage to give electron-like range and pulse-height signatures without triggering the guard detectors or P8. Also important are protons incident from the side that pass between the guards, and by means of an interaction in the tungsten, produce a minimum ionizing particle that passes out through the front of the telescope. The figure below shows a calculation of this background that is ~5 to 10 times lower than the expected interplanetary electron flux (20-120 MeV). A better estimate should now be possible using the results of the Voyager TET proton calibration.

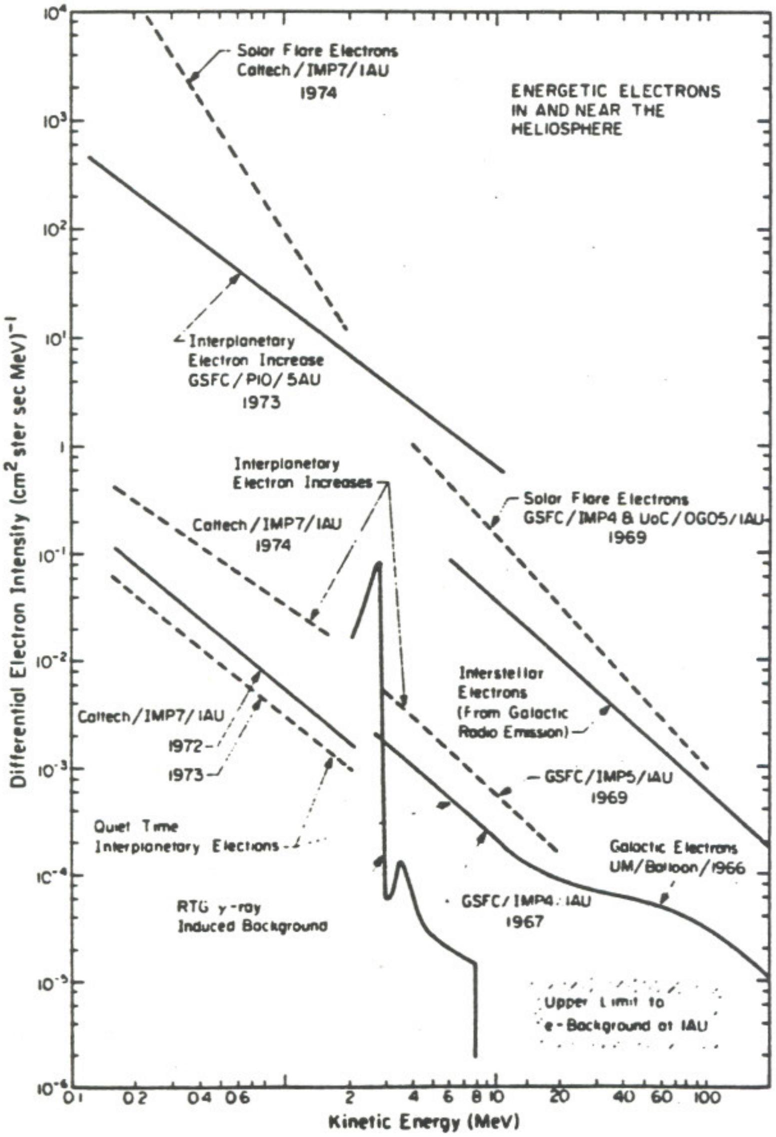
The history of cosmic ray electron measurements show that they are among the most difficult. At energies from ~100 Kev to 100 GeV, measurements have been reported that differ in absolute flux by factors of ~10. These experimental differences, some of which remain unresolved, are a testament to nature's cleverness in producing electron background. Clearly a major effort is necessary to have confidence in quiet time electron measurements in PET, or any other instrument.

<u>Positrons</u>

Potential sources of background for positron measurements in PET are discussed in Section 2.6.4.


FREE-FIELD γ-RAYS
(RTG γ-Flux 600 γ/cm² sec nominal)
DIFFERENTIAL γ-RAY INTENSITY (cm² sec MeV)⁻¹
ENERGY (MeV)


COMPTON ELECTRONS
(RTG γ-FLUX 600 γ/cm² sec nominal)
DIFFERENTIAL ELECTRON INTENSITY (g sec MeV)⁻¹
KINETIC ENERGY (MeV)


ENERGETIC ELECTRONS IN AND NEAR THE HELIOSPHERE
Solar Flare Electrons Caltech/IMP7/1AU 1974
Interplanetary Electron Increase GSFC/P10/5AU 1973
Interplanetary Electron Increases
Caltech/IMP7/1AU 1974
Solar Flare Electrons GSFC/IMP4 & UoC/OGO5/1AU 1969
Interstellar Electrons (From Galactic Radio Emission)
Caltech/IMP7/1AU
1972
1973
GSFC/IMP5/1AU 1969
Quiet Time Interplanetary Elections
Galactic Electrons UM/Balloon/1966
RTG γ-ray Induced Background
GSFC/IMP4/1AU 1967
Upper Limit to e-Background at 1AU
Differential Electron Intensity (cm² ster sec MeV)⁻¹
Kinetic Energy (MeV)

3.8 Testing and Calibration

1 Draft 3.8.1

SPACE RADIATION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

TO Sampex distribution DATE 10/31/91

FROM Richard Selesnick EXTENSION 6637 MAIL CODE 220-47

SUBJECT PET β spectrometer, γ-ray and positron calibrations

Electrons

Calibrations of the PET telescope for low energy electrons were made in the SRL β spectrometer between June 5 and June 17, 1991. Details of the calibration were recorded in a laboratory notebook labeled β-spectrometer log. Vol VI, that is kept in the clean room. The data were recorded on 8 mm magnetic tapes by the Macsys data collection system from the P1, P2, P3, and A3 detectors, using 20 different electron energies from 0.3 MeV to 3.0 MeV, and 10 different incidence angles relative to the telescope axis from 9° to 90°. A summary of the energy and angle values at which calibration runs were made, and the time per run, is given in the attached table. The angles in the table are relative to the vertical direction. The beam was tilted by an additional ~9° perpendicular to the plane of rotation, so to convert from the angle in the table (and the run logs), θ, to the the angle of the beam relative to the telescope axis, θ_B, use the formula $\cos\theta_B = \cos\theta\cos 9°$.

Several calibrations of the electron beam were also required to determine the beam flux as a function of energy and position in the beam, and to convert β spectrometer magnet current, which is the independent variable, to beam energy. These were made with a single solid-state Si detector of 4.5 cm^2 active area and the data were recorded in a similar way to the PET data. Preliminary analysis of the beam calibrations were made with data taken independently by a pulse height analyzer and are described in the notebook. They were used to choose the beam parameters for the PET measurements. For the final PET calibration analysis these preliminary estimates of the beam parameters should be replaced with accurate results based on the beam calibration data that was recorded by Macsys simultaneously to the pulse height analyzer data.

At the location of the PET calibration, the beam had an area of ~6 cm by ~10 cm. However, the flux was not perfectly uniform within this area. Since event position information was not recorded, the non-uniformity of the electron beam, which can be reconstructed from the beam calibration data, should be taken into account during the analysis of the PET calibration data.

The calibrations were made with the telescope front window at a distance of 45 cm from the beam exit hole. The electron flux at 1 MeV was ~6 $cm^{-2}s^{-1}$. The electrons were from a Ru^{106} source, so that the flux at other energies approximately follows a β spectrum with an end-point energy of 3.54 MeV. However, the measured flux values should be used in the final analysis, because of systematic deviations from the β spectrum. The run times at each energy were chosen to give approximately equal beam fluence densities of ~3000 counts cm^{-2}. The total number of recorded events of each type of event from each run was therefore ~10,000 times the efficiency for each type of event. The statistical errors therefore increase with decreasing efficiency, which is reasonable because the low efficiency configurations are also less important to the flight data analysis.

Source tests

Various radioactive sources were used to test the PET response to γ-rays and positrons. The tests were carried out in the SRL clean room between 5/21/91 and 5/24/91. Details were recorded in the notebook that was also used for the EG&G calibrations. The results were recorded on 8 mm magnetic tapes for later analysis. The telescope was mounted in a fixed position and the sources were placed at various distances and angles relative to it. Pulse heights from all of the detectors were recorded by Macsys. The angles used typically varied from 0° to 180° relative to the telescope axis in steps of 30°. The distances varied from 15 cm to 45 cm in steps of 5 or 10 cm. Not all distances and angles were used for each source, the total number of data runs being ~70. The run times varied from ~5 to ~30 minutes. The sources used were: Cs^{137} (~6 μCi, 0.662 MeV γ), Ge^{68} (~10 μCi, < 1.9 MeV e^+, γ), Th^{228} (~21 μCi, various energy γ to 2.6 MeV), Co^{60} (10 μCi, 1.173 and 1.332 MeV γ). Room background runs were also made.

β spec. calibrations

Angle θ	E (MeV) .30	.35	.4	.45	.5	.55	.62	.7	.8	.9	1.0	1.1	1.3	1.5	1.75	2.0	2.25	2.5	2.75	3.0	Backg
0		x		x		x		x		x		x		x		x		x		x	x
10		x		x		x		x		x		x		x		x		x		x	x
20	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
30		x		x		x		x		x		x		x		x		x		x	x
40	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
50		x				x				x				x				x			x
60	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
70		x				x				x				x				x			x
80		x		x		x		x		x		x		x		x		x		x	x
90		x				x				x				x				x			x
Minutes per run	30	30	20	20	20	15	15	15	10	10	10	10	10	10	10	15	15	20	30	40	30
Σ minutes	90	300	60	140	60	150	45	105	30	100	30	70	30	100	30	105	45	200	90	280	300

Total with 30 min angle changeovers = 44 hours

3.8.1-3

California Institute of Technology

Pasadena CA, 91125

11/17/91

To: MAST/PET Investigators
From: Dick Mewaldt
Subject: Summary of High Energy Electron Calibrations of PET
(MAST/PET Memo RAM-91-11)

Introduction: This memo summarizes the data that is available as a result of high energy electron calibrations that were conducted of the PET telescope during May, 1991. The calibrations were carried out at the DOE linear electron accelerator operated by EG&G at their Santa Barbara facility, and cover the energy range from ~1 to 27 MeV.. The response of PET was measured at a total of 15 different beam energies within this range, at angles of incidence with respect to the telescope axis that ranged from −30 to +80 deg. This memo provides an overview of the data that are available, including an introduction to some of the experimental details that will have to be considered in analyzing these data.

The Accelerator: Table 1 summarizes nominal information about the EG&G electron accelerator, which normally produces beam intensities many orders of magnitude greater than we could handle. At our suggestion, Dr. Rosemary Baltrusaitus, our technical contact at EG&G, agreed to attempt to achieve beam intensities of ~1 electron per pulse. by operating the machine on "dark current" alone. This operating mode had not been attempted before, but fortunately EG&G personnel were successful in meeting our beam intensity and stability requirements on very short notice. As Table 1 indicates, the nominal operating range of the accelerator is 2 to 25 MeV; for our run they agreed to attempt to exceed these limits, and as a result, beams from 1.5 to 27 MeV were obtained. EG&G personnel deserve a great deal of credit for the success of this calibration, and their facility should be considered for future electron calibrations.

Experimental Setup: Figure 1 shows a schematic view of the experimental setup. The electron beam exited the beam line through a 0.001 inch thick stainless steel window with a nominal spot size of 1 cm fwhm. In order to provide uniform illumination of PET it was positioned a distance of about 1 m downstream from the beam pipe., and a xx cm long bag of He was introduced in an effort to reduce the energy loss and multiple scattering of the beam in the intervening air. A multi-wire proportional counter (MWPC-A) was positioned just in front of PET to measure the X-Y positions of individual incident electrons. PET itself was mounted on a remotely-controlled rotating stage that permitted the orientation of the telescope to be efficiently varied over a wide range of angles. A second MWPC, positioned to the side of the primary setup, was used to tune the beam intensity and allignment in order to avoid risking unnecessary radiation exposure of the PET detectors. The entire setup was mounted on a table that could be translated laterally to alternate between MWPC-A (PET setup) and MWPC-B (Tuning setup). Scintillators S1 and S2 could also be moved into the beam to monitor the beam intensity prior to exposing PET. In addition, the entire table could be lowered out of the beam, as it was during the initial tuning of the accelerator.

The PET Setup: Although the fabrication of the MAST and PET instruments was far from complete at the time of this calibration, the PET telescope had been assembled in order to permit calibrations such as this to proceed using laboratory electronics in place of flight electronics. The PET telescope was mounted in an auxilliary housing that included connectors for interfacing with laboratory electronics. The outputs of the individual PET detectors were pulse-height analyzed by the SRL MACSYS system, which can process up to 24 parallel channels at event rates of several thousand per second. All PET detectors, including P1 to P8 and the guards, were pulseheight analyzed in a manner that should permit reconstruction of the signals to be expected from the flight instrument. The four MWPC-A signals are available to locate the X-Y position of all PET events; the signals from MWPC-B, S1, and S2 are available only for beam tuneup runs when PET was moved out of the beam. The standard trigger condition to initiate analysis was that all four signals from the MWPC be above threshold. Note that this will include many events that miss PET completely.

Each of the MACSYS channels is analyzed with a 12-bit ADC. The threshold of each MACSYS "channel" was adjusted to be as low as possible, typically well below the flight thresholds for PET. In addition, it is also possible to analyze energy losses "below threshold" in a given detector as long as some other channel triggered the analysis. The individual ADCs were continuously calibrated throughout the runs. The MACSYS channel widths are in all cases several times narrower than in the flight ADCs, so that it should be possible to transfer measured energy losses measured by MACSYS to those appropriate to the flight electronics.

Pileup: In order to minimize the possibility of pileup the beam intensity was limited to ~50 to 100 particles per second, so that there is a low probability of there being more than 1 electron during a 4 microsecond beam pulse. In spite of this precaution, there is evidence for some pileup events in the data, as evidenced by occasional pulseheights that are approximately twice the beam energy. There are several possibilities for eliminating these events, including consistency checks with the beam energy (the measured energy should not exceed that of the beam) and detailed examination of the pulse shape information available from MACSYS. Note that the MWPCs do not identify multiple events explicitly (only an average of the positions of coincident particles is measured), but it is possible that pulse height data from the MWPCS will be of some use in this regard, since multiple particles will on the average lose more energy in both the X and Y chambers.

Electron Scattering Effects: The intervening material between the end of the beam pipe and the PET window will, of course, scatter the electrons at small angles about the beam direction. Estimates of the mean scattering angle in beam pipe cap vary from ~20 deg at 1.5 MeV to ~1 deg at the highest energies. Some of this scattering is desirable to ensure uniform illumination of the front of the PET collimator. The additional scattering that occurs in the material between the beam cap and the PET window is estimated to be somewhat less than that in the beam cap. The energy loss in the beam cap and intervening material is estimated to be ~0.2 MeV, which will be significant at the lower beam energies. These scattering and energy loss effects need to be taken into account in interpreting the measured angular and energy response of PET.

Energy and Angle Coverage: Table 2 summarizes the energy and angular coverage obtained in more than 130 individual runs. A typical run lasted ~5 minutes and contains 10,000 to 20,000 events. Runs at both negative and positive angles should be compared to check for any offset in the zero deg orientation. Note that there is considerable overlap in the coverage with the Beta Spectrometer calibrations at Caltech that spanned 0.2 to 3 MeV and covered a similar angular range (see memo by R. Selesnick).

Related Documentation: The data from this calibration are stored on 8 mm tapes labeled xxxxxx to xxxxx; for details of the format see the 11/15/91 memo by T. L. Garrard entitled "......." Details of the setup and runs are contained in the bound logbook labeled "PET ....". Additional information can be found in R. A. Mewaldt's 3-ring note-book labeled "PET Electron Calibrations - 1991." For more information on the nominal design, operation, and electronic specifications of PET see the MAST/PET Definition Document. Actual measurements of the gain, offset, and thresholds of the PET ADCs were performed prior to integration (contact R. Mewaldt). Finally, for additional information on the MWPC design and response see the "RPC Handbook" by W. R. Cook.

PET HIGH ENERGY ELECTRON CALIBRATIONS

ANGLE (Deg)

ENERGY (MeV)	-30	-25	-15	0	10	15	20	25	30	35	40	50	60	70	80
1.5				X	X		X		X		X	X	X		
2				X	X		X		X		X	X	X		
2.5				X	X		X		X		X	X	X		
3				X	X		X		X		X		X		
3.5		X	X	X	X	X	X	X	X	X	X	X	X	X	
4.2				X	X		X		X		X		X		
5				X	X	X	X	X	X	X	X	X	X	X	
6				X	X		X		X		X		X		
8	X		X	X	X	X	X	X	X	X	X	X	X	X	X
10				X	X	X	X		X		X	X	X		
13				X	X		X		X		X		X		
16		X	X	X	X	X	X	X	X	X	X	X	X	X	X
20				X	X		X		X		X		X		
24				X	X		X		X		X		X		
27				X	X	X	X	X	X	X	X	X	X	X	X

3,8,1-8

PET Calibration Setup for High Energy Electrons

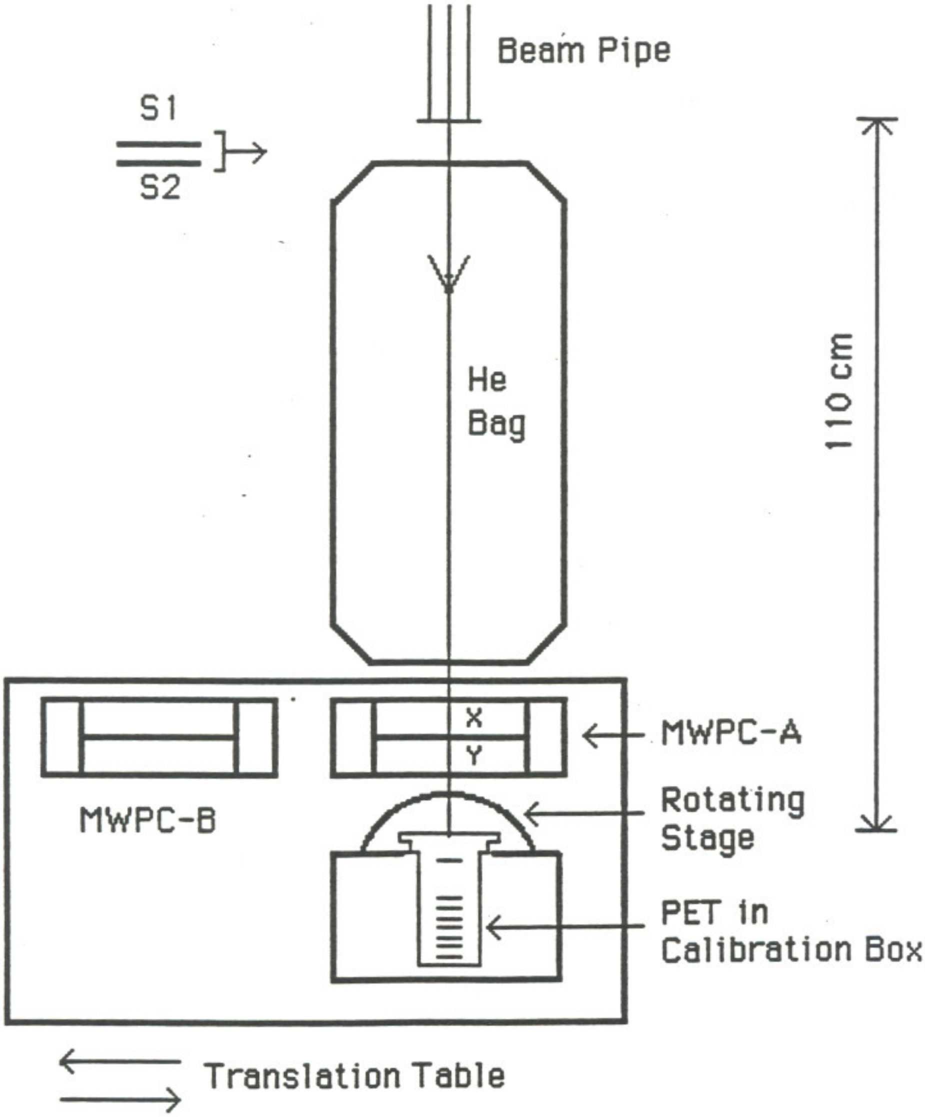


Figure 1: Top view of setup for high energy electron calibrations of PET conducted at EG&G.

2.7.2 PET Internal Calibration

Overview
The PET internal calibration scheme is very similar in design and intent to that in MAST (Section 2.8.2), although there are some differencies in detail. Because of this similarity, this discussion will focus on the MAST/PET differencies. As in MAST, there are three separate tests: Logic (takes 32 subcom states, one subcom state is 6 seconds long), Ramp (takes 16 subcom states), and ADC (takes 32 subcom states), which can be initiated either as part of the automatic calibration sequence (every 6.8266 hours) or by command. The internal calibration sequence takes 80 subcom states or 8.0 minutes.

Design
In PET the calibrator circuitry generates -Vref and test drive pulses for each 15 test pulsers:

1 each for P4, P5, P6, P7 and P8.
1 each for A3, A4, A57 and A68.
2 each for P1, P2 and P3.

There are two test pulsers for P1, P2 and P3 corresponding to the two dynamic ranges for these detectors (LoZ and HiZ). The Vref levels are derived from circuitry identical to that in MAST. This circuitry also provides for logic control of two level testing of the guard discriminators, two level testing of P1 (ADC threshold and P1A discriminator) and three level testing of P3 (ADC threshold, P3A and P3B discriminators). The test drive source is 4 us wide and has a period of 640 us.

Command Control
Overall control of the internal calibration is provided by the CAL DIS bit (c431) which disables the calibration (c431=1) by shutting off power to the test pulsers. When the instrument is powered up, the following sequence is required to reset the calibrator circuitry:

1) Set the CAL DIS (c431), LOG CAL DIS (c420), RMP CAL DIS (c421), and ADC CAL DIS (c422) command bits all equal to 1.

2) Clear all of the above four bits (set them = 0).

Once the above procedure has taken place, the calibration sequence starts automatically every 6.8266 hours at REV count 8000 HEX, or as a result of a CMND CAL TRIG command (c423=1), which can be issued at any time. The resulting commanded sequence will begin when the REV count modulo 0800 HEX is 0 (this occurs every 12.8 minutes). Once the commanded calibrate sequence begins, the CMND CAL TRIG bit should be cleared before an additional 0800 HEX REVs have occurred, or a new calibrate sequence will begin. (REV counts are counted in the 16-bit Subcom State Counter which is part of the Control Word. MSB of the counter is S2E15; LSB is S2E00, it has a period of 750 ms, and is the only bit that does not have a square wave shape.)

Each of the three PET calibration tests can be individually enabled/disabled by command bits c420 (LOG CAL DIS), c421 (RMP CAL DIS), and c422 (ADC CAL DIS). If any of these three bits or c431 (CAL DIS) are set = 1 during a calibrate sequence, they should not be cleared until that sequence would have normally ended. If CAL DIS is set during a calibrate sequence, to avoid having to reinitialize, LOG CAL DIS, RMP CAL DIS, and ADC CAL DIS should also be set.

External calibration through the GSE connector is enabled by the GSE EN command (c424). GSE calibration should not be allowed to coincide with the internally generated calibration sequence.

Calibrate Data
As in MAST, the rate data resulting from the internal calibration is indistinguishable from cosmic ray induced counts. Calibration periods can, however, be identified by the Status Byte data (see Section 3.6.3).
Event data is generated only by the PET ADC Test, and read out through the CAL event buffer (see 3.4.2, 3.4.4, and 3.6.1). See also further discussion in MAST Section 2.8.2.

Logic Test
The PET Logic Test uses a pulse-routing counter (PRC, as in MAST) to select a total of 2power16 - 1 different pulse patterns during one logic exercise to be directed to the test pulsers (pulse period = 640 us). The bit assignments of this counter are given in the table on the next page.

Note that bit 11 selects whether the LoZ or HiZ test pulsers are used for P1, P2 or P3, independent of the LoZ/HiZ instrument mode. This can result in ADC overflows or pulses of insufficient magnitude to trigger thresholds. This should be taken into account in calculating the distribution of various logic equations that are satisfied.

The counter generates a pause of 256x640 us = 163.84 ms whenever a carry from bits 0-11 to bit 12 occurs in order to allow the test pulser -Vrefs to settle to new selected values. No test pulses are generated during this pause. Pulses are generated during a 2power12 x 640 us = 2.62 s interval between two pauses. Given a 6 s subcom state duration, there are only two 2.62 s intervals that can fit in, and they are bounded by three pauses which occur at 0 s, at 2.78 s and at 5.4 s of the subcom state time, respectively. The third pause (PAUSE B) is prolonged by an additional 265.6 ms so to last to the end of the subcom state. However, next subcom state begins also with a pause, so PAUSE B lasts 593.28 ms. There are 2x(2power12 - 1) = 8,190 pulses generated in every subcom state.

One full logic exercise takes 8 subcom states, and is repeated 4 times during the PET Logic Test, which thus takes (2power18 + 3x32x256)x640 us + 32x265.6 ms or 192 s. The test starts in subcom state 0 when the calibrate sequence begins (REV count 8000 HEX during automatic calibration), and makes two cycles through subcom states 0-15 (it ends at REV count 8200 HEX during automatic calibration). There is a 429.44 ms prolonged pause between the last pulse in Logic and the first pulse in the following Ramp Test, to allow the test pulser -Vrefs to settle back to 0 volts.

Unfortunately, not all of the subcommutated rates will be tested during the PET Logic Test (that was also a case in the original COMPAS scheme). From the PET PRC's bits 13, 14 and 15 it is possible to find out amplitude levels for triggering of ADCs and discriminators during 8 subcom states of one full logic exercise.

The following table shows which subcommutated rates are tested during the PET Logic Test (x denotes missed rates):

Subcom state	Trigger level P1	P3	Guards	Rate 9	Rate 10
0	H	H,L	H	P1 ADC	P4

1	H	M	H	ADC OR	P5
2	L	H,L	H	P2 ADC	P6
3	L	M	H	x	P7
4	H	H,L	L	P3 ADC	P8
5	H	M	L	x	A3L
6	L	H,L	L	P47 ADC	x
7	L	M	L	HAZ	A4L
8	H	H,L	H	P1 ADC	A4H
9	H	M	H	ADC OR	x
10	L	H,L	H	P2 ADC	A57H
11	L	M	H	x	x
12	H	H,L	L	P3 ADC	x
13	H	M	L	x	P1A
14	L	H,L	L	P47 ADC	x
15	L	M	L	HAZ	x
Tested rates [%]:				75	62

Note: Subcommutated rates 9 and 10 can be tested in their entirety by switching accumulation times of the missing rates so to coincide with the trigger levels. It would require installing of 8 interrupt pads and 8 haywires.

Pulse Routing Counter for the PET Logic Test

	Bit#	Function		Comments
LSB	0	P1	LoZ/HiZ selected by bit 11.	
	1	P2		
	2	P3		
	3	P4		Routes pulses to test pulsers.
	4	P5		
	5	P6		
	6	P7		
	7	P8		
	8	AX		

	9	AY	See Note #1.
	10	AZ	
	11	Z	
	PAUSE A		
Lsb	12	P3X	HiZ test pulsers when
of 8	PAUSE B		on P3 amplitude.
subcoms in 1	13	P3Y	See Note #2.
logic exercise	14	P1A	P1A on when this off.
Msb	15	AH	Hi-level guard when this off.
	16	Not	
	17	used.	
MSB	18	Stop Logic Test	

Note #1: Bits 10, 9, 8 decoded as follows:

	000	001	010	011	100	101	110	111
A3					x			
A4						x		
A57							x	
A68								x

Note #2: Bits 13, 12 decoded as follows:

00 = P3B,   01 = P3A* x P3B*,   10 and 11 = P3A.

Ramp Test
As in MAST, this test uses a series of pulses (4 us wide, 640 us period), sent simultaneously to all test pulsers, that test the stability and proper functioning of the ADC threshold and various discriminator levels. This test tracks the LoZ/HiZ mode of the instrument, so that the proper test pulsers for P1, P2 and P3 are selected. The pulse amplitude is stepped through a two-level sawtooth (as in MAST) with V1 voltage peaks of 0, -1, 0, -6, 0, -1, 0, -6, 0 volts. There are total of 8 ramps (4 up and 4 down) in each subcom state. Each of the sawtooth ramps is made up of 255 discrete steps, each held for 4 pulses.

The PET Ramp Test starts 32 subcom states (192 s) after the calibrate sequence begins (REV 8200 HEX during automatic calibration). Noting that the first 0 volt step gets pulsed only 2 times, each subcom state takes (2x1)+(4x254)+7(4x255) = 8,158 pulses or 5.22 s. Test pulses are blanked for the remaining 778.88 ms of the subcom state. This sequence is repeated for 16 consecutive subcom states. Thus the PET Ramp Test takes 16x6 = 96 s (ends at REV 8300 HEX during automatic calibration).

For further discussion see Section 2.8.2 on the MAST Internal Calibrator.

ADC Test
The PET ADC Test starts 48 subcom states (288 s) after the calibration sequence begins (REV 8300 HEX during automatic calibration). It is not identical to the MAST ADC Test. For P1, P2 and P3 the test drive pulses are routed either to the LoZ or HiZ test pulsers, depending on the state of the instrument. In order to test P4, P5, P6 and P7, these chains are pulsed individually in a circular sequence that is stepped every 750 ms.

The pulses occur every 750 ms, for a total of 8 pulses per subcom state. In PET there are four subcom states devoted to one of eight Vref levels (unlike MAST), so that the PET ADC Test takes 32 subcom states or 192 s (ends at REV 8500 HEX during automatic calibration). The whole internal calibration sequence ends with this test.

The results of this test are readout as event data through the calibration event buffer (see Sections 3.4.2 and 3.4.4). Thus calibration events are tagged by buffer #7 in the event data format (see 3.6.1). See the MAST Internal Calibration write-up (Section 2.8.2) for further discussion.

Calibrations with Radioactive Sources

γ-ray Response and Background

The major background for PET electron measurements is expected to be due to Compton scattered electrons. It is only at ~15 MeV that the pair production cross section in silicon becomes equal to that for Compton scattering. The γ-ray threshold for P1·P2 events (ELO) is ~1 MeV, while that for P1·P2·P3 events (EHI) is ~2 MeV (determined from the thresholds for these detectors and the optimum secondary electron energies and trajectories). Thus the γ-ray background can be calibrated by sources available in the laboratory, including ^{60}Co ($E_{max}(\gamma)$=1.33 MeV), ^{88}Y ($E_{max}(\gamma)$= 1.84 MeV), ^{228}Th ($E_{max}(\gamma)$= 2.61 MeV), and a Pu-Be neutron source ($E_{max}(\gamma)$=4.4 MeV).

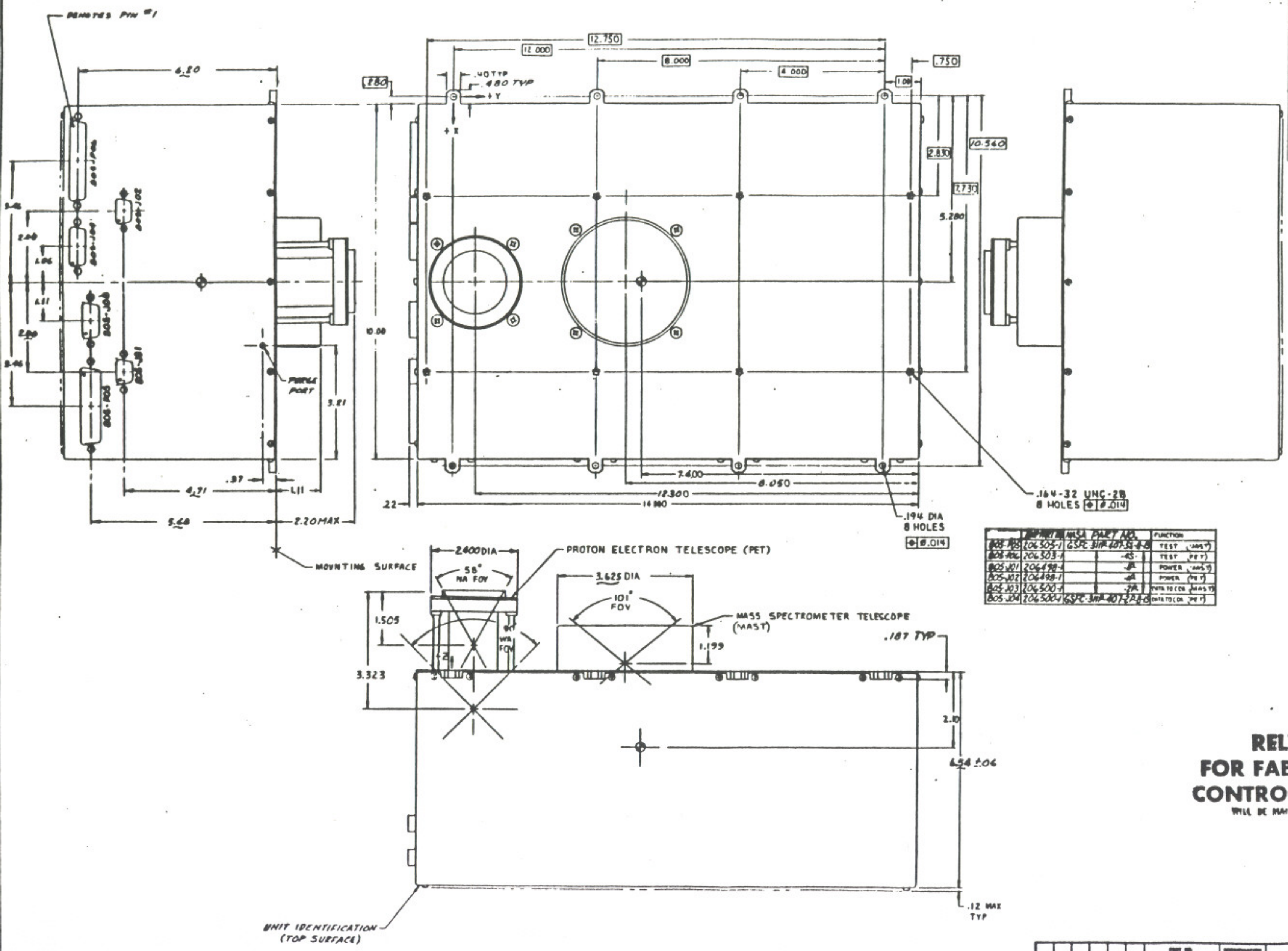
Such calibrations should explore the angular dependence of the response, and monitor all available counting rates, including singles rates. Command states that alter the electron triggering requirements (e.g., the P3AE term) should also be tried. In using the Pu-Be source, there will also be a neutron response in PET detectors with energy losses $\leq$8 MeV due to np and nα reactions on Si nuclei.

Were PET to be carried on the Solar Polar Mission, the dominant source of γ-rays would be the RTG, where $E_{max}(\gamma) \simeq 2.6$ MeV. In this case calibrations with the SRTG in the lab or with the RTG, once mounted on the spacecraft, would certainly be useful, but were not definitely scheduled. Some Voyager RTG data does exist for a similar telescope and could be looked at. Laboratory calibrations with ^{228}Th, coupled with the calculated RTG spectrum at PET, could probably do almost as well as an SRTG calibration.

Position Detection Efficiency

Laboratory positron sources include ^{22}Na ($E_{max}(e^+)$= 0.54 MeV), ^{56}Co ($E_{max}(e^+)$=1.49 MeV), and ^{67}Ge ($E_{max}(e^+)$=3.1 MeV). Others with higher energies may also be available. These should be used in combination with calculations to determine PET's positron detection efficiency (Section 2.6.4) as a function of positron range in the telescope and detection mode. Since these sources also give off γ-rays, care must be taken to separate the γ-ray and positron response.

3.9 Assembly Drawings



		NASA PART NO.	FUNCTION
805-P05	206505-1	GSFC-311P-407-51-4-B	TEST (MAST)
805-P06	206503-1	-45	TEST (PET)
805-J01	206498-1	-4	POWER (MAST)
805-J02	206498-1	-4	POWER (PET)
805-J03	206500-1	-7A	DATA TO CDH (MAST)
805-J04	206500-1	GSFC-311P-407-7A-B	DATA TO CDH (PET)

C — CHANGED CONNECTOR TO & PART NO. ADDED PURGE PART LOCATION CHANGED PET TELESCOPE OUTLINE 3.625 WAS 3.812 & 6.06 WAS 6.00

MAST/PET Interface Control Drawing

RELEASED FOR FABRICATION CONTROLLED COPY

WILL BE MAINTAINED CURRENT

OCT 12 1981

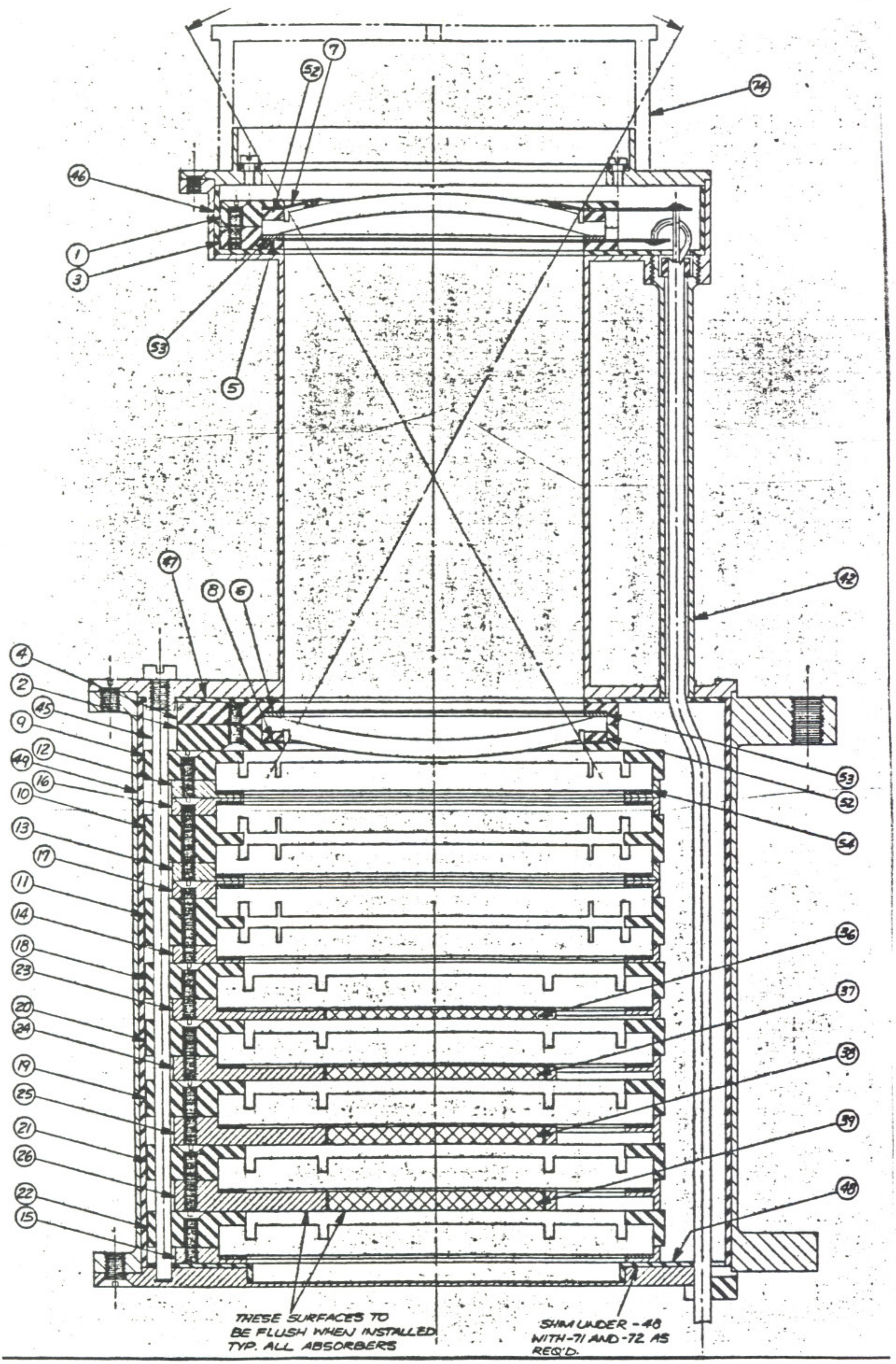
3.9.1

3. SYMBOL ⊕ DENOTES CG
2. FINISH: MOUNTING SURFACE & TABS, AL ALLOY/MIL-C-5541 (IRIDITE), COVER, AL ALLOY/MIL-A-8625 (BLACK ANODIZE)
1. WEIGHT: TBD

LIST OF MATERIALS

INTERFACE CONTROL DWG. ISEE MAST/PET

PET Telescope Assembly



PET Telescope Assembly