#313

71-063A-08A

APOLLO 15

GAMMA RAY SPECT. MERGED DATA

Table of Contents

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1. INTRODUCTION:

The documentation for this data set was originally on paper, kept in NSSDC's Data Set Catalogs (DSCs). The paper documentation in the Data Set Catalogs have been made into digital images, and then collected into a single PDF file for each Data Set Catalog. The inventory information in these DSCs is current as of July 1, 2004. This inventory information is now no longer maintained in the DSCs, but is now managed in the inventory part of the NSSDC information system. The information existing in the DSCs is now not needed for locating the data files, but we did not remove that inventory information.

The offline tape datasets have now been migrated from the original magnetic tape to Archival Information Packages (AIP’s).

A prior restoration may have been done on data sets, if a requestor of this data set has questions; they should send an inquiry to the request office to see if additional information exists.

2. ERRATA/CHANGE LOG:

NOTE: Changes are made in a text box, and will show up that way when displayed on screen with a PDF reader.

When printing, special settings may be required to make the text box appear on the printed output.

Version	Date	Person	Page	Description of Change
01				
02				

3 LINKS TO RELEVANT INFORMATION IN THE ONLINE NSSDC INFORMATION SYSTEM:

http://nssdc.gsfc.nasa.gov/nmc/

[NOTE: This link will take you to the main page of the NSSDC Master Catalog. There you will be able to perform searches to find additional information]

4. CATALOG MATERIALS:

a. Associated Documents — To find associated documents you will need to know the document ID number and then click here. http://nssdcftp.gsfc.nasa.gov/miscellaneous/documents/

b. Core Catalog Materials

APOLLO 15

MERGED DATA TAPES, GAMMA-RAY SPEC.

71-063A-08A PSPG-00585

THIS DATA SET HAS BEEN RESTORED. ORIGINALLY IT CONTAINED 47 7-TRACK, 800 BPI TAPES WRITTEN IN BINARY. THERE ARE 15 RESTORED TAPES. THE DR TAPES ARE 3480 CARTRIDGES AND THE DS TAPES ARE 9-TRACK, 6250 BPI. THE ORIGINAL TAPES WERE CREATED ON A 7044 COMPUTER SYSTEM AND THEY WERE RESTORED ON AN IBM 9021 COMPUTER. THE DR AND DS NUMBERS ALONG WITH THE CORRESPONDING D NUMBERS AND TIME SPANS ARE AS FOLLOWS:

DR#	DS#	D#	FILES	TIME SPAN	
DR005029	DS005029	D019684	1	07/28/71 - 07/28/71	
		D019685	2	07/28/71 - 07/28/71	
		D019686	3	07/28/71 - 07/29/71	
		D019687	4	07/29/71 - 07/29/71	(a)
DR005030	DS005030	D019688	1	07/29/71 - 07/30/71	
		D019689	2	07/30/71 - 07/30/71	(b)
		D019690	3	07/30/71 - 07/30/71	
DR005031	DS005031	D019692	1	07/30/71 - 07/30/71	
		D019693	2	07/30/71 - 07/30/71	
		D019691	3	07/30/71 - 07/30/71	(c)
DR005032	DS005032	D019694	1	07/30/71 - 07/30/71	
		D019695	2	07/31/71 - 07/31/71	
		D019698	3	07/31/71 - 07/31/71	(d)
DR005033	DS005033	D019696	1	07/31/71 - 07/31/71	
		D019697	2	07/31/71 - 07/31/71	
		D019699	3	07/31/71 - 08/01/71	
DR005034	DS005034	D019700	1	08/01/71 - 08/01/71	
		D019702	2	08/01/71 - 08/01/71	(e)
		D019707	3	08/01/71 - 08/02/71	
DR005035	DS005035	D019703	1	08/01/71 - 08/01/71	
		D019701	2	08/01/71 - 08/01/71	(f)
		D019704	3	08/02/71 - 08/02/71	
DR005036	DS005036	D019710	1	08/02/71 - 08/02/71	
		D019709	2	08/02/71 - 08/02/71	
		D019711	3	08/02/71 - 08/03/71	

DR#	DS#	D#	FILES	TIME SPAN
DR005037	DS005037	D019705	1	08/02/71 - 08/02/71
		D019708	2	08/02/71 - 08/02/71
		D019706	3	08/02/71 - 08/02/71
DR005038	DS005038	D019712	1	08/03/71 - 08/03/71
		D019716	2	08/03/71 - 08/03/71
		D019718	3	08/03/71 - 08/04/71
DR005039	DS005039	D019717	1	08/03/71 - 08/03/71 (g)
		D019715	2	08/03/71 - 08/03/71
		D019713	3	08/03/71 - 08/03/71
DR005040	DS005040	D019714	1	08/03/71 - 08/03/71 (h)
		D019719	2	08/04/71 - 08/04/71
		D019722	3	08/04/71 - 08/05/71 (i)
DR005041	DS005041	D019720	1	08/04/71 - 08/04/71 (j)
		D019721	2	08/04/71 - 08/04/71 (k)
		D019723	3	08/05/71 - 08/05/71
DR005042	DS005042	D019725	1	08/05/71 - 08/05/71
		D019726	2	08/05/71 - 08/05/71
		D019724	3	08/05/71 - 08/05/71
DR005043	DS005043	D019729	1	08/06/71 - 08/06/71
		D019730	2	08/06/71 - 08/06/71
		D019728	3	08/06/71 - 08/06/71
		D019727	4	08/06/71 - 08/06/71 (l)

(a) D019687 - 12 ERRORS OCCURRED ON RECORDS 304, 308, 312, 316, 320, 336, 348, 360, 364, 368, 376, 380, FILE 1
(b) D019689 - 1 ERROR OCCURRED ON RECORD 3, FILE 1
(c) D019691 - 2 ERRORS OCCURRED ON RECORDS 1439 AND 12792, FILE 1
(d) D019698 - 4 ERRORS OCCURRED ON RECORDS 28, 508, 716, 724, FILE 1
(e) D019702 - 1 ERROR OCCURRED ON RECORD 1091, FILE 1
(f) D019701 - 1 ERROR OCCURRED ON RECORD 250, FILE 1
(g) D019717 - 1 ERROR OCCURRED ON RECORD 2060, FILE 1
(h) D019714 - 2 ERRORS OCCURRED ON RECORDS 143 AND 772, FILE 1
(i) D019722 - 1 ERROR OCCURRED ON RECORD 2721, FILE 1
(j) D019720 - 1 ERROR OCCURRED ON RECORD 32, FILE 1
(k) D019721 - 1 ERROR OCCURRED ON RECORD 2604, FILE 1
(l) D019727 - 4 ERRORS OCCURRED ON RECORDS 658, 660, 1316, 1320, FILE 1

REQ. AGENT	RAND NO.	ACQ. AGENT
CMT	RC3990	TNK

APOLLO 15

GAMMA RAY SPECTROMETER MERGED DATA

71-063A-08A

This data set consists of 44 tapes written in Binary in odd parity. The tapes are 7-track with a density of 800 bits per inch (BPI) and were created on a 7094 computer.

Each tape contains only 1 file. The following pages contain the data format for each record of the file, the 'D' and 'C' numbers and the time span.

D#	C#	ORBITS	TIME SPAN
D-19684	C-16119	0	07/28/71 - 07/28/71
D-19865	C-16120	1	07/28/71 - 07/28/71
D-19686	C-16121	2	07/28/71 - 07/29/71
D-19687	C-16122	5	07/29/71 - 07/29/71
D-19688	C-16123	7	07/29/71 - 07/30/71
D-19690	C-16124	19	07/30/71 - 07/30/71
D-19691	C-16125	20	07/30/71 - 07/30/71
D-19692	C-16126	22	07/30/71 - 07/30/71
D-19693	C-16127	24	07/30/71 - 07/30/71
D-19694	C-16128	26	07/30/71 - 07/31/71
D-19695	C-16129	29	07/31/71 - 07/31/71
D-19696	C-16130	31	07/31/71 - 07/31/71
D-19697	C-16131	33	07/31/71 - 07/31/71
D-19698	C-16132	34	07/31/71 - 07/31/71
D-19699	C-16133	36	07/31/71 - 08/01/71
D-19700	C-16134	40	08/01/71 - 08/01/71

D#	C#	ORBITS	TIME SPAN
19701	16135	42	08/01/71 - 08/01/71
19702	16136	42	08/01/71 - 08/01/71
19703	16137	46	08/01/71 - 08/01/71
19704	16138	56	08/02/71 - 08/02/71
19705	16139	55	08/02/71 - 08/02/71
19706	16140	53	08/02/71 - 08/02/71
19707	16141	51	08/01/71 - 08/02/71
19708	16142	58	08/02/71 - 08/02/71
19709	16143	60	08/02/71 - 08/02/71
19710	16144	61	08/02/71 - 08/02/71
19711	16145	63	08/02/71 - 08/03/71
19712	16146	64	08/03/71 - 08/03/71
19713	16147	66	08/03/71 - 08/03/71
19714	16148	68	08/03/71 - 08/03/71
19715	16149	69	08/03/71 - 08/03/71
19716	16150	71	08/03/71 - 08/03/71
19717	16151	72	08/03/71 - 08/03/71
19718	16152	58	08/03/71 - 08/04/71
19719	16153	60	08/04/71 - 08/04/71
19720	16154	60	08/04/71 - 08/04/71
19721	16155	60	08/04/71 - 08/04/71
19722	16156	60	08/04/71 - 08/05/71
19723	16157	60	08/05/71 - 08/05/71
19724	16187	60	08/05/71 - 08/05/71
19725	16188	60	08/05/71 - 08/05/71
19726	16189	60	08/05/71 - 08/05/71
19729	16190	60	08/06/71 - 08/06/71
19730	16191	60	08/06/71 - 08/06/71

APOLLO GAMMA-RAY SPEC.

1. Merged TAPE FORMAT

The AGRS merged tapes contain four (4) record types. Each record type is separated from its neighbors by an inter-record gap.

The tapes have these characteristics:

6250 ~~800~~ Bpi
36 bit words
Unblocked Records
Mixed type data within a record

Record	Words	Time Word	Data Type
1	32	1	Floating Point
2	13	1	Mixed
3	13	1	Mixed
4	513	1	Integer
5	32	1	Floating Point
6	13	1	Mixed
7	13	1	Mixed
8	.	.	
.	.	.	
.	.	.	Integer (Ø11111111111)
N	32	None	Integer (Ø222222222222) Last Reel

→ Records 1-4, 5-8 form groups of related data. The records within a selected group (4 records each) are as follows:

Record

1. NASA Apollo Trajectory Data
2. Apollo Gamma-Ray Spectrometer and Apollo X-Ray Spectrometer Common Parameter
3. Service Module Housekeeping Data
4. Apollo Gamma-Ray Spectrometer Data

Mixed Type Data

The entire contents of Record 2 are single precision 36 bit integers except for Word 2 (Sim Bay Temp), Words ~~8~~ 3 and 13 (28 VDC Pwr) which are floating point, single precision words.

Six of the 13 words in Record 3 are floating point words. These are Words 3, 4, and 5 (temperature data) and words 8, 9, 10 (shield, coincidence events data, and live-time). The remaining 7 words are 36 bit integers.

The last record on each reel contains 32 words of Ø11111111111 followed by two End-of-file marks.

Record

1. NAT DATA are located in this record. Table 1 shows the parameters contained in each word at the two mission phases. The column labeled DATA TYPE defines the type of the data item as it is written on tape (eg., floating point (F) or integer (I)). A LINEAR INTERPOLATION is performed on the NAT DATA to find values (Record 1) at each AGRS tape time.

   Time words (Word 1 of each record) in each record type (1-4) are identical in magnitude (not in type). Appendix A describes the symbols used in Table 1.

2. AGRS/AXRS COMMON DATA appear in this record. Table 2 describes the parameters stored in Record 2. The DATA TYPE column of Table 2 shows that the data are MIXED TYPE DATA.

   A linear interpolation is performed on the SIM BAY TEMP, and the 28 VDC power to find values at each AGRS tape time. These two parameters appear as degrees Fahrenheit and volts direct current respectively.

   The remainder of the words in Record 2 are integer flags denoting mission events.

Record

3. SERVICE MODULE HOUSEKEEPING DATA are found in Record 3 (see Table 3). These data, like Record 2 data, are mixed type. Six of the 13 words are floating point values. The temperatures: words 3, 4, and 5, are derived by the same method employed with the SIM BAY TEMP in Record 2. The remaining three floating point words are the SHIELD, LIVE TIME, and COINCIDENCE EVENTS register averaged over 10 PCM frames. Shield and Coincidence Events values are expressed in counts/second. The Live Time word is an average (%) over 10 PCM frames. The remaining seven integer words are TIME, EVENT FLAGS, and HV GAIN.

4. AGRS DATA are contained in Record 4. Table 4 describes the content of this record. Word 1 is the time word which has a 1:1 correspondence with the AGRS binary tape time (AGRS binary tape time is milliseconds while AGRS merged binary tape time is truncated to seconds). The remaining 512 integer words are the total accumulated counts (over 10 PCM frames, 3.2768 sec) in each of the 512 (0-511) channels.

RCB:sd

TABLE 1. MERGED TAPE FORMAT
NASA Apollo Trajectory Parameters

Word	Lunar Orbit	Changes in Trans-Lunar/Trans Earth	Changes in Requested Attitude Data	Data Mode
1	GMTs, Sec			F
2	Ho, n. mi			F
3	Φs, deg.	Blank	(See note a)	F
4	λs, deg.	Blank	"	F
5	Rs, ft.	Blank	"	F
6	Vis, fps.	Blank	"	F
7	$\emptyset$, deg.	Blank		F
8	O, deg.	Blank		F
9	Rev. No., n.d.	Blank	(See note a)	F
10	γas, ft.	γa, ft.	"	F
11	γps, ft.	γp, ft	"	F
12	has, n. mi	ha, n. mi.	"	F
13	hps, n. mi.	hp, n. mi.	"	F
14	Xis, ft.	Blank	"	F
15	Yis, ft.	Blank	"	F
16	Zis, ft.	Blank	"	F
17	$\dot{X}$is, fps.	Blank	"	F
18	$\dot{Y}$is, fps.	Blank	"	F
19	$\dot{Z}$is, fps.	Blank	"	F
20	$\ddot{X}$is, ft/sec.^{2}	Blank	"	F
21	$\ddot{Y}$is, ft/sec.^{2}	Blank	"	F
22	$\ddot{Z}$is, ft/sec.^{2}	Blank	"	F
23	$\ddot{X}$p, ft/sec.^{2}			F
24	$\ddot{Y}$p, ft/sec.^{2}			F
25	$\ddot{Z}$p, ft/sec.^{2}			F
26	$\dot{X}$p, fps.			F
27	$\dot{Y}$P, fps.			F
28	$\dot{Z}$p, fps.			F
29	HLLs, ft.	Blank	(See note a)	F
30	$\dot{H}$LLs, fps.	Blank	"	F

Word	Lunar Orbit	Changes in Trans-Lunar/Trans Earth	Changes in Requested Attitude Data	Data Mode
31	Blank		α_s, deg.	F
32	Blank		β_s, deg.	F

a. Parameter to be obtained from either the lunar orbit or the trans lunar/trans earth column as is applicable.

b. See document "Manned Spacecraft Center Internal Note No. 71-FM-222, dated June 17, 1971" for a presentation of the Project Apollo Standard Coordinate Systems.

TABLE 2. MERGED OUTPUT TAPE FORMAT
AGRS/AXRS Common Data

Word Output	Data Type	Description
1	I	GMT OF Ground Receipt (Sec., year to date)
2	F	SIM. BAY Temp. (°F)
3	F	28 volt Power A (VDC)
4	I	Pwr. on - off Flag (1 = on, 0 = off)
5	I	Playback vs. Realtime Flag (1 = Realtime, 0 = Playback)
6	I	LEM Docking and Separation (1 = Docked, 0 = Separation)
7	I	Waste Dump (1 = yes, 0 = no)
8	I	RCS Firing (1 = yes, 0 = no)
9	I	SPS Firing (1 = yes, 0 = no)
10	I	Loss of Telemetry (1 = yes, 0 = no)
11	I	Loss of Frame Sync (1 = yes, 0 = no)
12	I	Word Parity Error Count (Apollo 16 RT; 0 = valid, 1 = invalid)
13	F	28 volt Power B (VDC)

TABLE 3. MERGED OUTPUT TAPE FORMAT
Housekeeping Data

Word Output	Data Type	Content of Word
1	I	GMT of Ground Receipt (Sec., year to date)
2	F	Electronics Temperature (°F)
3	F	Detector Temperature (°F)
4	F	Boom Temperature (°F)
5	I	Boom Position Flag (3 bit flag)
		Retracted = 0
		Partially Extended 1 = 1 (4 feet)
		Paritally Extended 2 = 2 (8 feet)
		Partially Extended 3 = 3 (15 feet)
		Fully Extended = 4 (25 feet)
6	I	Veto (0 = disabled, 1 = normal)
7	I	Mapping Camera Lens Covered (1 = yes, 0 = no)
8	F	Shield Events Counter, averaged over 10 PCM frames (count/sec.)
9	F	Coincident Events Counter, averaged over 10 PCM frames (count/sec.)
10	F	Live Time Counter, averaged over 10 PCM frames (% of 3 sec,)
11	I	Gain, High Voltage (VDC)
12	I	Shield Events Overflow (number of overflows/Rec.)
13	I	Coincident Events Overflow (number of overflows/Rec.)

TABLE 4. OUTPUT TAPE FORMAT
Gamma-Ray Spectrum (3.2768 sec interval)

Word Output	Data Type	Content of Word
1	I	GMT of Ground Receipt (Sec., year to date)
2	I	Channel 0, Events in 10 PCM Frames
3	I	Channel 1, Events in 10 PCM Frames
4	I	Channel 2, Events in 10 PCM Frames
.	.	
.	.	
.	.	
.	.	
.	.	
.	.	
513	I	Channel 511, Events in 10 PCM Frames

APOLLO-15 GAMMA-RAY SPECTROMETER

Time Range on Reels MAS 1501-1503; MAS 1508-1548

Reel	GET Start (sec)	GET Stop (sec)
MAS 1501	270484	287486
1502	287489	314960
1503	314964	341278
1508	380886	406066
1509	406069	419928
1510	419964	432368
1511	432372	447534
1512	447565	453595
1513	453632	464359
1514	464379	488494
1515	488497	499954
1516	499957	511763
1517	511766	522305
1518	522308	534940
1519	534969	537287
1522	549429	562796
1523	562799	575573
1524	575603	589796
1525	589799	604995
1528	628470	644805
1529	644809	657047
1530	657050	669319
1531	669322	681371
1532	681374	692541
1533	692544	704141
1534	704144	714678
1535	714681	725453
1536	725456	725997
1537	726000	737629
1538	737633	750335
1539	750338	759395

Reel		GET Start (sec)	GET Stop (sec)
MAS	1540	759398	770682
	1541	770702	781196
	1541A	781200	792182
	1541B	792185	814921
	1541C	814924	828494
	1541D	828497	846778
	1541E	846781	885485
	1541F	885488	900133
	1541G	900137	914709
	1541H	914712	933353
	1541I	933357	953549
	1542	943552	957468
	1543	957471	979264
	1544	979267	989794
	1545	989797	1007429
	1546	1007432	1023649
	1547	1023653	1030593
	1548	1030597	1036822

2. Summary of AGRS Operational Characteristics

Instrument Description

The Apollo 15 gamma ray spectrometer is shown in Fig. 1. Within the cylindrical thermal shield are the detection, amplification, encoding and data processing systems which result in the identification and characterization in time and energy of incident gamma rays. Figure 2 is a generalized block diagram of the instrument. The sensing element of the detector shown in schematic in Fig. 3 is a 2-3/4" x 2-3/4" cylindrical scintillation crystal of NaI(Tℓ). The energy lost by gamma rays in traversing the crystal is converted, via ionization processes, into light which is sensed and transformed into a proportionate charge output by a 3" diameter photomultiplier tube (PMT) optically coupled to the NaI(Tℓ) crystal. After amplification and shaping, the output signal passes to an analog-to-digital converter (ADC), controlled by a crystal clock pulse generator, which transforms the detector signal into an accurately measured pulse train. This pulse train is counted in an accumulator resulting in a number proportional to the charge output of the detector for that particular event. The data is sent on an event-by-event basis either to the spacecraft telemetry system for direct transmission or to a tape recorder for intermediate storage when the spacecraft is behind the moon.

The NaI(Tℓ) scintillator responds to charged particles as well as gamma rays. To eliminate charged particle events, a shield of Pilot B plastic scintillator surrounds the NaI(Tℓ). The plastic scintillator detects all charged particles above a minimum energy, but has a low probability of interacting with gamma rays. Events in the plastic scintillator produce a signal in the 1.5 inch PMT which is transmitted to a gate ahead of the ADC to inhibit (veto) the acceptance of a coincident pulse from the NaI(Tℓ) PMT. This is the veto enable (VE) mode in which the bulk of the data is obtained. Periodically the veto function is disabled (VD) which adds the detected flux of charged particles to the gamma ray flux.

In addition to the accumulators which handle the primary data pulse train, separate accumulators are provided for counting the number of events in the plastic scintillator shield, the number of events coincident in both the NaI(Tℓ) and plastic scintillators and a live time pulse train. The latter provides the factor to obtain the rate at which gamma rays are entering the NaI(Tℓ) crystal from the number which are analyzed. The command capability of the instrument consists of the ability to enable and disable the veto function as described in the previous paragraph, to vary the high voltage bias on the 3" PMT in eight steps (HV-0 through HV-7) amounting to a total range in gain of about a factor of 3, and to turn power on and off.

Besides the passive thermal control provided by the striped paint pattern on the thermal shield, a thermal control circuit supplies power to a heating blanket around the central detector whenever a control sensor indicates that the temperature in the immediate vicinity of the central detector has dropped below 15°C. The purpose of this is to minimize thermally-induced variations in gain which, if rapid and continuous, will degrade the energy resolution of the instrument.

In normal operation the instrument is deployed on a 25-foot boom extending normal to the SIM bay surface. The purpose of this boom is to decrease the response of the instrument to cosmic-ray interactions and radioactive sources in the spacecraft. The importance of this effect can be seen from the observation, that the count rates observed when the boom was retracted during the transearth coast (TEC) period were close to those in lunar orbit with the boom extended. That is, the instrument response to the spacecraft was about the same as that to the moon, in similar geometry. In the extended position the response to the spacecraft is reduced to the order of a few percent of the total count rate. To assist in separating the spacecraft contribution from the observed flux, data was obtained with the boom extended to intermediate distances during the TEC period.

Instrument Operation

When the instrument was first turned on shortly before injection into lunar orbit, its gain was within 2% of the final pre-launch checkout value. The gain immediately began to decline at a rate of 1% per hour. This rate decreased with time until the instrument was essentially stable by the end of the lunar orbiting phase of the mission. The overall drop in gain amounted to 39%. The gain step command capability was used successfully to offset this trend. In the task of data reduction the recognizable features in the spectrum, including the prominent 0.51 MeV peak, along with a calibration source of Hg^{203} at 0.279 can be used to normalize any part of the data. The hypothesis that the effect was the result of aging on the part of the 3" PMT in the high energy cosmic ray flux environment of space has been confirmed by ground testing, although the tube in the Apollo 15 instrument was apparently unusually sensitive to the comparatively high current levels produced by this flux in the PMT.

The presence of a radioisotopic thermoelectric generator on the LEM, while interfering almost totally with lunar observations prior to undocking, provided several prominent high energy features which showed that both the energy resolution and zero offset (the intercept of channel number and energy) were nominal. However, immediately after the first extension of the gamma ray boom in transearth coast the zero offset shifted by 7.9 channels. The shift disappeared when the instrument was repowered after astronaut EVA. Subsequent operation was normal for about 30 hours, when the offset shift reappeared and remained until mission completion. The shift was due to the loss of a timing signal in the ADC which will result in an 8-channel offset in the spectrum, as well as the recording of the first 8 channels of information in channel 1. The latter effect was also noted in the data when the zero offset shift was present. The flight data can be corrected for this shift without difficulty.

All scaler functions operated properly. The shield count rate in the instrument deployed position is the value expected for the cosmic ray flux. The effectiveness of the charged particle veto system is shown by a comparison of the veto enabled and veto disabled spectra. It becomes more important with increasing energy. The threshold of the veto system is close to 0.6 MeV.

Temperature measurements agreed well with predictions, both in lunar orbit and in transearth coast. The thermal control system maintained the detector temperature within $\pm 2^{\circ}C$ of the nominal value as intended except for periods immediately following boom extension when slightly lower temperatures occurred at times. The boom was operated through its many cycles of extension and retraction without mechanical difficulty although the variations in measured times put the estimated locations of the intermediate portions at 6 $\pm$.6 feet, 8 $\pm$.3 feet and 15 $\pm$.3 feet.

To summarize, operation of the instrument was normal in all respects except for the gain change and zero offset occurrences described above for which appropriate corrections can be made.

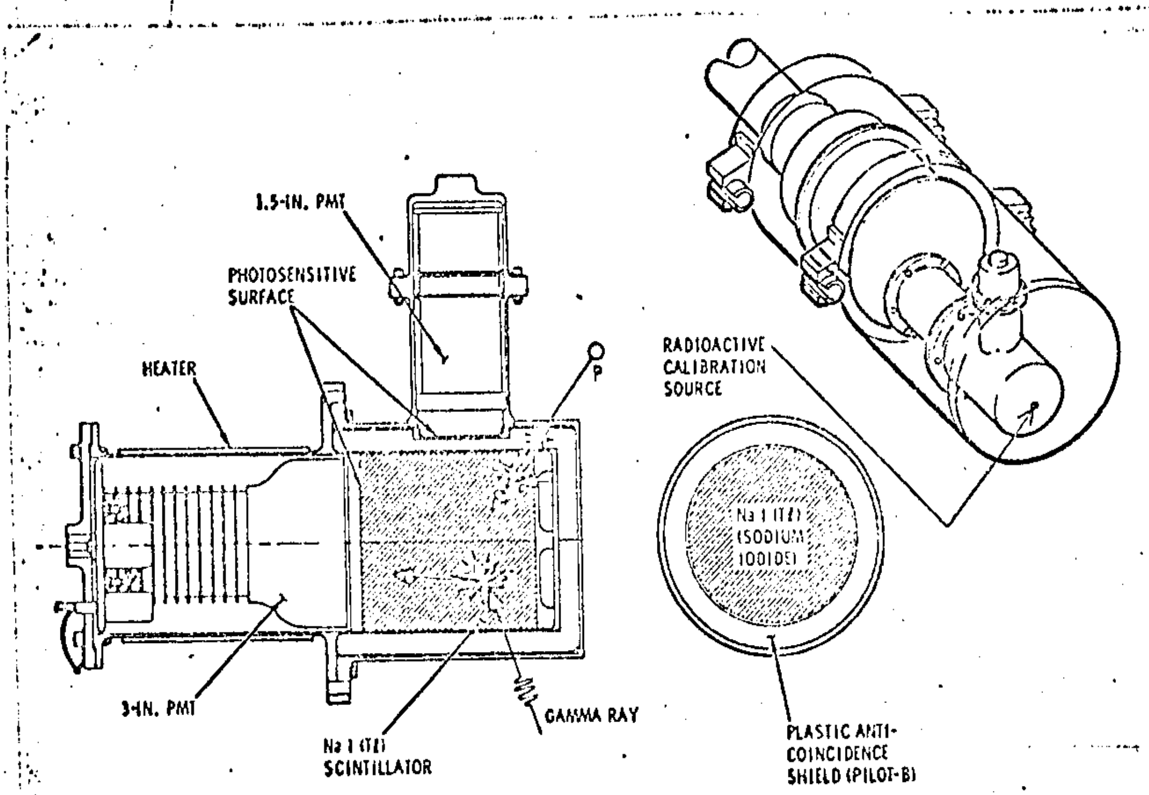
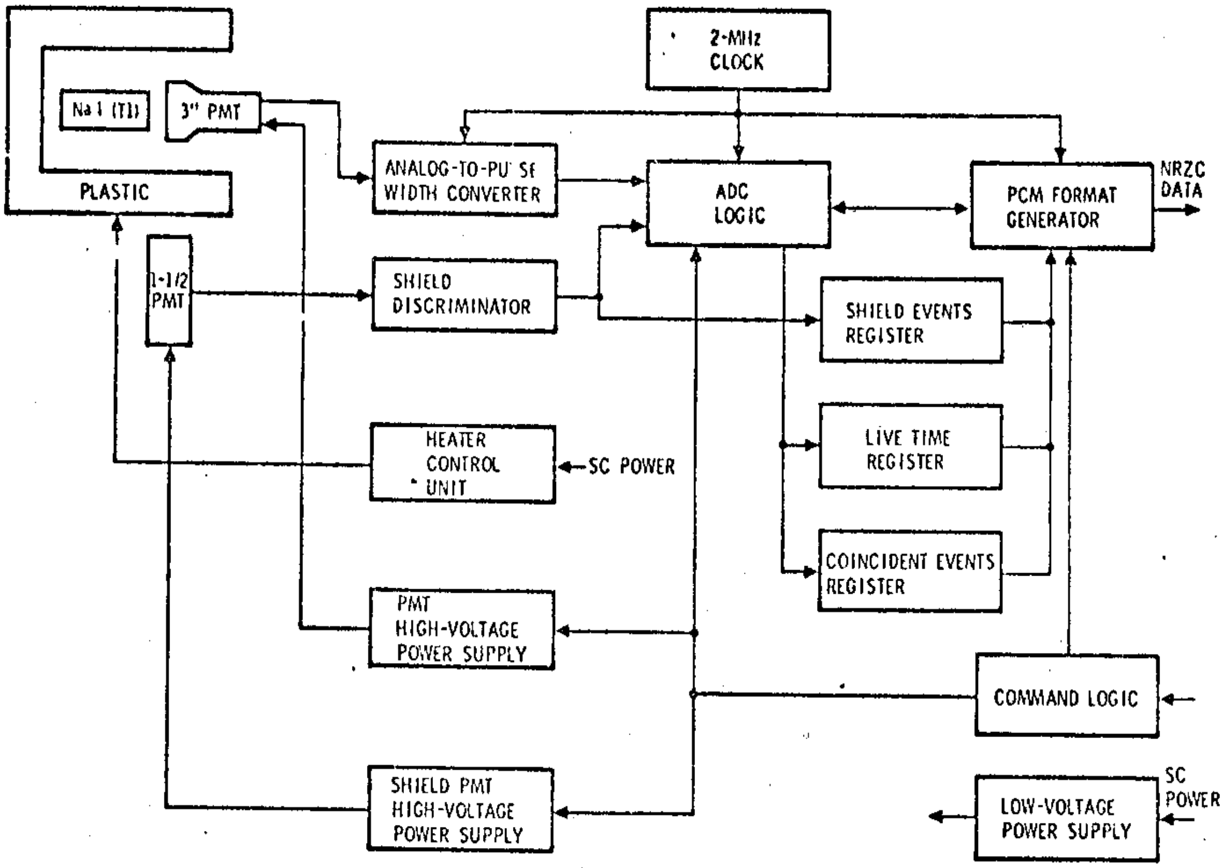

1.5-IN. PMT
PHOTOSENSITIVE
SURFACE
HEATER
P
RADIOACTIVE
CALIBRATION
SOURCE
3-IN. PMT
GAMMA RAY
Na I (Tl)
SCINTILLATOR
Na I (Tl)
(SODIUM
IODIDE)
PLASTIC ANTI-
COINCIDENCE
SHIELD (PILOT-B)

Figure 1



PLASTIC
Na I (Tl)
3" PMT
1-1/2 PMT
2-MHz CLOCK
ANALOG-TO-PULSE WIDTH CONVERTER
ADC LOGIC
PCM FORMAT GENERATOR
NRZC DATA
SHIELD DISCRIMINATOR
SHIELD EVENTS REGISTER
LIVE TIME REGISTER
COINCIDENT EVENTS REGISTER
HEATER CONTROL UNIT
SC POWER
PMT HIGH-VOLTAGE POWER SUPPLY
COMMAND LOGIC
SHIELD PMT HIGH-VOLTAGE POWER SUPPLY
LOW-VOLTAGE POWER SUPPLY
SC POWER

Figure 2

3. AGRS-15 OPERATING TIME PERIODS*

8/17/72

Overall Total	187:30
In Lunar Orbit	
Total	130:49
Prime-A (no LEM, deployed, pointed, MC door closed, VE)	58:04
Prime-B (no LEM, deployed, pointed, VE)	64:53
Prime-C (no LEM, deployed, MC door closed, VE)	65:35
Retracted no LEM	36:37
Retracted with LEM	9:01
Extended with LEM	10:22
Prime-D (no LM, deployed, VE)	73:32
In TEC	
Total	56:41
Deployed at 25'	41:34
Deployed at 25' with PTC	32:39
Deployed at 25' S/C attitude fixed	7:12
Retracted	8:55
Deployed at 6' (4')	2:02
Deployed at 8'	2:23[1]
Deployed at 15'	1:47[1]
Deployed at 25' in HV-1 with VE	4:15
Deployed at 25' in HV-1 with PTC	2:15
Retracted in HV-1	1:12
Deployed at 25' in HV-7 with VE	11:07

[1] all in HV-7

*Recovered data periods run 10-20% less than operating periods but final totals are not yet available.

PTC ≡ passive thermal control

MC ≡ mapping camera

PRELIMINARY

rev: 1-6-72

4. APOLLO 15 EVENT CHRONOLOGY

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
								D H M S
00:00								Liftoff CDT(00:08:34:00.6)
02:56								Translunar injection
74:07								SIM Door Jettison
75:08		On	HV-3	On				
77:28		Off						
78:31								LOI
78:32								Revolution 1
79:01	1	On						
79:04	1					NP		
79:49	1			Off				
79:59	1			On				
80:40								Revolution 2
82:18	2	Off						
82:40	2							DOI
82:49								Revolution 3
84:05	3	On						
84:06	3						Open	
84:08	[illegible]				Deploy (BP + [illegible] sec only)			

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
84:09	3				Retract			
84:16	3					P		
84:42								Revolution 4
84:57	4				Deploy, Deploy Time 2:28			
85:15	4			Off				
85:25	4			On				
85:42	4					NP		
86:00	4					P		
86:36								Revolution 5
88:30								Revolution 6
90:23								Revolution 7
92:17								Revolution 8
94:04	8		HV-4					
94:11								Revolution 9
94:38	9		HV-3			NP		
94:43	9		HV-4					
95:09	9			Off				
95:13	9						Closed	
95:18	9			On				
95:19	9				Retract, Retract Time 3:09			
95:55		Off						

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
96:04								Revolution 10
96:17	10							DOI Trim
96:22	10	On		On				
97:58								Revolution 11
99:51								Revolution 12
100:39	12							LM undock/separation
100:51	12			Off				
100:59	12			On				
101:11	12	Off						
101:39	12							CSM Circularization
101:45								Revolution 13
101:50	13	On	HV-3					
103:19	13					P		
103:43								Revolution 14
105:41	14						Open	
105:42								Revolution 15
106:19	15					NP		
106:27	15						Closed	
106:44	15		HV-4					
106:46	15						Open	
106:48	[illegible]				Deploy, Deplo time 2:30			

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
106:49	15					P		
107:38	15				Retract, Retract time 3:07			
107:39								Revolution 16
108:45	16		HV-5		Deploy tb-BP (~2:45)			
109:14	16						Closed	
109:15	16					NP		
109:37								Revolution 17
110:00	17							Start Bistatic Radar Test
111:16	17							End Bistatic Radar Test
111:36								Revolution 18
111:42	18					P		
113:34								Revolution 19
115:32								Revolution 20
117:30								Revolution 21
119:08	21					NP		
119:16	21						Open	
119:17	21				Retract, Retract time 2:30			
119:28						P		Revolution 22
120:41	22			Off				
120:48	22			On				
121:26								Revolution

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
121:35	23					NP		
122:58	23						Closed	
123:25								Revolution 24
125:23								Revolution 25
125:43	25				Deploy, Deploy time 2:30			
125:47	25					P		
126:22	25			Off				
126:32	25			On				
127:21								Revolution 26
128:20	26						Open	
129:19								Revolution 27
129:20	27				Retract, Retract time 3:07			
129:56	27			Off				
130:02	27			On				
130:28	27				Deploy, Deploy time 2:41			
130:50	27						Closed	
130:53	27					NP		
131:17								Revolution 28
131:39	28							Start Bistatic Radar Test
132:55	28							End Bistatic Radar Test
133:15						P		Revolution 29

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
135:13								Revolution 30
137:12								Revolution 31
139:10								Revolution 32
140:50	32					NP		
141:01	32						Open	
141:07	32				Retract tb-BP (~3:15)			
141:08								Revolution 33
141:11	33					P		
141:40	33			Off				
141:50	33			On				
142:17	33				Deploy tb-BP (~2:45)			
143:06								Revolution 34
143:07	34				Retract, Retract time 3:08			
143:09	34					NP		
144:29	34				Deploy tb-BP (~2:45)	P		
145:04	34				Retract tb-BP (~3:15)			
145:05								Revolution 35
145:06	35					NP		
146:22	35			Off				
146:33	35			On				
146:34	[illegible]		HV-6					
146:55	35						Closed	

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
147:02								Revolution 36
147:22	36				Deploy, Deploy time 2:31			
147:27	36					P		
149:01								Revolution 37
150:03	37						Open	
150:58								Revolution 38
151:05	38				Retract, Retract time 3:08			
151:39	38			Off				
151:48	38			On				
152:10	38				Deploy, Deploy time 2:37			
152:14	38						Closed	
152:15	38					NP		
152:17								Revolution 39
152:36	39					P		
154:55								Revolution 40
156:53								Revolution 41
158:51								Revolution 42
160:49								Revolution 43
162:18	43						Open	
162:19	43				Retract tb-BP (~3:15)			
162:27	43					NP		

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
162:47						P		Revolution 44
163:40	44			Off				
163:50	44			On				
164:00	44	Off						
164:07	44						Closed	
164:46								Revolution 45
165:12	45							CSM Plane Change (LOPC)
165:20	45	On	HV-3	On				
165:23	45					NP		
165:29	45		HV-6					
166:24	45				Deploy tb-BP (~3:15)			
166:28	45					P		
166:44								Revolution 46
167:35	46			Off				
167:45	46			On				
168:02	46					NP		
168:08	46				Retract, Retract time 3:06			
168:42								Revolution 47
170:40								Revolution 48
171:25	48	Off						
172:38								Revolution 49

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
173:36	49							Docking
174:17	49					P		
174:25	49	On		On				
174:37								Revolution 50
174:40	50						Open	
175:50	50			Off				
175:55	50					NP		
176:01	50			On				
176:05	50						Closed	
176:35								Revolution 51
178:02	51					P		
178:33								Revolution 52
179:30	52							LM Jettison
179:50	52							CSM Separation
180:31								Revolution 53
182:29								Revolution 54
182:58	54				Deploy tb-BP (~2:45)			
184:27								Revolution 55
186:25								Revolution 56
188:23								Revolution 57
189:04	57					NP		

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
189:24	57					P		
190:21								Revolution 58
192:19								Revolution 59
194:17								Revolution 60
194:19	60	Off/On	HV-3					
194:35	60				Retract tb-BP (~3:15)		Open	
194:58	60		HV-6					
195:35	60						Closed	
195:36	60				Deploy tb-BP (~2:40)			
195:39	60					NP		
196:15								Revolution 61
196:37	61					P		
198:13								Revolution 62
198:25	62						Open	
199:05	62			Off				
199:29	62			On				
199:32	62						Closed	
200:11								Revolution 63
200:23	63				Retract tb-BP (~3:15)			
200:25	63						Open	
201:32						NP	Closed	

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
201:50	63					P		
202:02	63				Deploy tb-BP (~2:40)			
202:10								Revolution 64
204:08								Revolution 65
206:06								Revolution 66
208:04								Revolution 67
210:02								Revolution 68
211:54	68					NP		
212:00								Revolution 69
212:14	69					P		
213:20	69			Off				
213:30	69			On				
213:58								Revolution 70
214:12	70				Retract tb-BP (~3:15)		Open	
215:19	70				Deploy tb-BP (~2:45)			
215:25	70					NP		
215:56								Revolution 71
216:00	71				Retract tb-BP (~3:15)			
217:20	71				Deploy tb-BP (~2:45)	P	Closed	
217:54								Revolution 72
218:08	[illegible]						Open	

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
218:11	72				Retract tb-BP (~3:15)			
219:16	72						Closed	
219:19	72				Deploy tb-BP 2:33			
219:52								Revolution 73
220:20	73			Off				
220:34	73			On				
220:50	73	Off						
220:55	73				Retract tb-BP (~3:15)			
221:21	73							CSM Shaping
221:44	73					NP		
221:46	73	On	HV-3					
221:50								Revolution 74
222:39	74							Subsat Launch
223:06	74	Off						
223:49	74							TEI
224:06							Open	
224:08		On		On				
224:13			HV-3					
224:45				Off				
224:55				On				
224:56			HV-6					

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
226:14							(Open)	X-RA Pt. Att. (Centauras) P 13, Y 212
226:30					Deploy tb-BP (~2:45)			
227:44								Passive Thermal Control P -40, Y 90
236:05				Off				
236:21								Optics Calib. Att. P -70, Y 295
236:26					Retract tb-BP			
236:28								Sighting Att. P -57, Y 360
236:45			HV-7	On				
236:59			HV-0					
237:15			HV-6	On				X-RA Pt. Att. (Mid-Galactic Lat.)
238:30		Off						
241:13								EVA Att. P 4, Y 225
244:04								Thermal Att.
245:41					Deploy tb-BP (~2:45)			
245:44		On						
245:45								X-RA Pt. Att. (SCO X-1) P -76, Y 117
246:05			HV-7					
246:35								X-RA Pt. At (CYG X-1) P 00, Y 240

TIME	REV. NO.	AGRS POWER	CAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
247:48					Retract tb-BP 72 sec for 15' ext.		(Open)	
247:50								Passive Thermal Control P -40, Y 90
249:35					Retract tb-BP			
249:37					Deploy tb-BP 63 sec for 8' ext.			
251:10								Optics Calib. Att. P -69, Y 301
251:15								Sighting Att. P -59, Y 001
251:54								Passive Thermal Control P-40, Y 90
252:00					Deploy tb-BP (~2:45)			
252:03				Off				
252:27				On				
261:48				Off				
261:50								X-RA Pt. Att. P 24, Y 264
262:05			HV-1	On				
264:05								Passive Thermal Control P -40, Y 90
266:20				Off				
267:18					Retract 2:30			
267:20				On				
268:00								Thermal Att

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
268:30			HV-6				(Open)	
271:31				Off				
271:45				On	Deploy tb-BP 41 sec for 4' ext.			
273:05								Optics Calib. Att. P -67, Y 314
273:14								Sighting Att. P -59, Y 359
273:47					Deploy to 25' (~4:00)			
274:15								X-RA Pt. Att. (North Galactic Pole)
275:00								X-RA Pt. Att. (Galactic Plane Anticntr)
276:01								Optics Calib. Att. P -66, Y 317
276:09								Sighting Att. P -59, Y 359
276:55				Off				
277:04								Passive Thermal Control P -40, Y 90
277:07				On				
286:50				Off				
287:33				On				
287:43				Off				
288:00				On				
288:03		Off						

TIME	REV. NO.	AGRS POWER	GAINSTEP	SHIELD	BOOM	SIM ATTITUDE	MC COVER	MISSION EVENTS
288:05					Retract tb-BP (~3:15) then off		(Open)	
290:45								P 52 Att. P -23, Y 217
291:57								MCC-7
294:44								CM/SM Sep.
294:58:54								EI
295:12								Landing

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THE COSMIC γ-RAY SPECTRUM BETWEEN 0.3 AND 27 MeV MEASURED ON THE APOLLO 15

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NOVEMBER 1972

GSFC

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ABSTRACT

The spectrum of the total (diffuse and discrete sources) cosmic γ-ray background over the 0.3 - 27 MeV range has been measured with a 7.0 cm dia. x 7.0 cm long uncollimated NaI(Tℓ) scintillation counter located on a boom 7.6 m from the Apollo 15 Service Module. Data on cosmic γ-rays were taken during Transearth Coast at various boom extensions, detector gains, and with the plastic anticoincidence scintillator enabled and disabled. The energy loss spectrum at full extension with the anticoincidence enabled, corrected for monochromatic spacecraft γ-rays, is 0.18 counts $(cm^2\text{-sec-MeV})^{-1}$ at 1 MeV, in agreement with previous measurements on the Ranger III and the ERS-18. At 5 MeV, the Apollo measurement of 7×10^{-3} counts $(cm^2\text{-sec MeV})^{-1}$ is about a factor of 5 below that determined from the ERS-18. Corrections for line contributions and spacecraft continuum at higher energies give a steep equivalent

photon spectrum with a broad feature in the 1-3 MeV region. This flattening can be reduced but not eliminated with an estimated correction for spallation effects in the detector, leaving a spectrum which we interpret as an upper limit to the true cosmic photon spectrum in the 0.3 - 27 MeV range. At 3 MeV, this limit is a factor of three and at 27 MeV a factor of ten above a power law which extrapolates from measurements below 1 MeV. We have also measured a flux of 0.03 ±0.015 photons $(cm^2\text{-}sec)^{-1}$ at 0.51 MeV which may be mostly of local origin.

CONTENTS

ILLUSTRATIONS

I. INTRODUCTION

We report a new measurement of the total cosmic gamma-ray spectrum in the range from 0.3 to 27 MeV obtained on Apollo 15. Previous measurements in this range have extended only to 6 MeV. These data were obtained with an isotropic scintillation counter similar to that used on the Ranger III (Metzger et al., 1964) and ERS-18 (Vette et al., 1970). The new high precision data permit extension and clarification of the spectrum above 1 MeV, where recent balloon (Damle et al, 1971; Vedrenne et al., 1971) and earth satellite observations (Golenetski, 1971) have caused doubts as to the validity of the ERS-18 data. Furthermore, Fishman (1972) has suggested that most of the counts near 2 MeV are not of cosmic origin but are associated with cosmic ray produced spallation products decaying in the scintillation counter crystals. The observational situation has been recently reviewed by Pal (1972). These results are of interest because of the considerable discussion regarding the astrophysical and cosmological importanct of γ-rays in this region.

II. INSTRUMENTATION

The Apollo 15/16 gamma-ray spectrometer (Adler and Trombka, 1970) consists of a 7.0 cm dia x 7.0 cm long NaI(Tℓ) central detector viewed by a 3" photomultiplier. Except at the photomultiplier end, the crystal is surrounded by a 1 cm thick plastic scintillator shield which detects charged particles. The plastic scintillator is viewed by a 1-1/2" photomultiplier and has a threshold of about 1.0 MeV for generating an anticoincidence event when interactions occur in the most optically unfavorable location. Central detector events with no shield anti-coincidence are pulse-height analyzed into 511 channels and are transmitted at a maximum event rate of 369 counts/sec. The shield rate, the coincidence rate, and the livetime are transmitted every 0.328 seconds. The spectrometer and associated electronics are enclosed in a thermal shield and mounted on a boom which could be extended from one side of the Service Module by an astronaut. The components carried on the boom present $\sim 5\,gm/cm^2$ averaged over all directions. The astronaut could fully deploy the detector to 7.6 m from the spacecraft edge or position it at intermediate distances using stop-watch timing. Furthermore, he could step the high voltage supply or disable the anti-coincidence.

III. RESULTS

(a) Energy Loss Spectra

The data reported here were obtained during portions of the Transearth Coast of Apollo 15 from about 2200 4 August to 1500 7 August 1971, and represent ~4 hours of operation in the extended position. During this period the earth and moon solid angles were always less than 10^{-2} sr and in the fully extended boom position, the spacecraft subtended ~0.28 sr. Spectra were obtained with the detector at various boom positions, with the anti-coincidence both on and off, and with the high voltage set to give several energy ranges up to 27 MeV. Although data were obtained over a 0.16 to 27 MeV range, the analysis reported here is based on energy losses >0.3 MeV. Calibration was obtained with a Hg^{203}

source and by means of known, easily identifiable spacecraft background γ-rays. Counting rate anisotropies, if they exist, were averaged out over long runs from which these results were derived, since the Command/Service Module rotated ~3 RPH in the ecliptic plane.

Figure 1 shows energy-loss spectra, corrected for livetime, channel width, and the isotropic detector geometry factor of $57.5\,cm^2$, for several important data modes. Here counts have been summed over channels consistent with the detector energy resolution which was 8.6% at 662 keV. With the exception of the strong line at 0.51 MeV, most of the γ-ray lines measured inboard largely disappear with boom extension, leaving a continuum extending to 27 MeV, on which is superposed a number of weak lines. Since the intensity changed only about a factor of five, while the spacecraft solid angle changed a factor of 20, most of the rate in the extended position is not of spacecraft origin. From a detailed analysis of the rates vs solid angle, we estimate $\sim 6.6 \times 10^{-3}$ c(cm^2-sec-MeV)$^{-1}$ at 2.4 MeV and $\sim 1.9 \times 10^{-3}$ c(cm^2-sec-MeV)$^{-1}$ at 5 Mev are due to the spacecraft. These are 0.1 and 0.2, respectively, of the spectrum with the boom extended.

The flat energy loss spectrum of 0.052 c(cm^2-sec-MeV)$^{-1}$ above 5 MeV with the anti-coincidence disabled in the extended position agrees with that expected from the shield rate of 450 c/sec, from which a cosmic-ray flux of 3.50 (cm^2-sec)$^{-1}$ may be derived. The large ratio of cosmic-ray to photon energy losses near 27 MeV requires effective charged particle rejection, which could not be measured before launch to the required accuracy. However, preliminary results from an identical experiment on the Apollo 16 in April 1972 confirm the Apollo 15 differential energy loss spectrum below 10 MeV to within ~12 percent. We interpret this as indicating that there were not systematic differences in the behavior of the instruments.

The energy loss spectrum with the anti-coincidence enabled in the extended position is shown with other measurements obtained in cislunar space in Figure 2. The NaI(Tℓ) Apollo 15/16 detector is identical in size to the CsI(Tℓ) detector in Ranger III, both of which differ only slightly from the NaI(Tℓ) crystal on the ERS-18. The 8 kg mass on the end of the Apollo 15 boom is nearly the same as that of the total ERS-18, while the Ranger III detector carried only ~3 kg. Clearly, the present data are in good agreement with previous measurements below ~2 MeV, but are well below the 3.7 - 6.0 MeV point measured by the ERS-18, which is apparently erroneous.

(b) Equivalent Photon Spectra

The equivalent photon spectra have been obtained from the precision energy loss spectra in Figure 1 and 2 by using a measured response "library" and a matrix inversion technique as described by Adler and Trombka (1970). The γ-ray lines are separated from the continuum by using an iterative procedure developed by Trombka (Trombka, et al., 1970; Reedy, Arnold, and Trombka, 1972). Here the pulse-height spectrum is transformed to photon space where lines appear as discontinuities, which may be subtracted by requiring the remaining continuum to be slowly varying with energy. This procedure results in the removal of 2.5 c/sec over the 0.6 to 3.5 MeV range due to lines or about 17% of the energy loss spectrum, and leaves a smooth equivalent photon continuum shown in Figure 3.

(c) Spallation Correction

Fishman (1972) has suggested that radioactive spallation nuclei produced by cosmic-ray interactions in the scintillation crystals may account for a large fraction of the counting rate measured in the 1-3 MeV region. Although a direct measurement of this effect in the cosmic-ray beam is difficult and has not been accomplished, calculations and laboratory measurements by Fishman (1972) and Dyer and Morfill (1971 and private communication), have indicated the spectra shape and approximate magnitude of the energy loss spectrum. We have attempted to correct the spectra of Figure 3 for this effect by subtracting from the equivalent energy loss spectrum a spallation model spectrum whose normalization was a free parameter. Since spallation contributes mostly to the energy losses in the 0.6 to 3 MeV range, the normalization was determined, rather arbitrarily, by the criterium that the resultant photon spectrum be relatively smooth. This was found to occur when a spallation spectrum, based on the work of Fishman (1972) and Dyer and Morfill (private communication) but of approximately half their intensity was subtracted out. As shown in Table 1, this results in removal of about 16% of the energy loss spectrum in the 0.6 to 3.5 MeV range and a negligible amount at higher energies. Subtracting a much larger spallation component, such as the full Dyer and Morfill value, would give no energy losses in the 1-2 MeV range, while still requiring an external photon component above 3 MeV, which is not physically possible. Although there seems no doubt that a spallation energy loss contribution exists, its spectral shape and intensity is only approximately known.

(d) Cosmic Photon Spectrum

The photon spectrum incident on the central detector, shown in Figure 3 as a dashed line, has also been corrected for continuum production in the spacecraft using data obtained in various boom positions and an estimate of the effective solid angle. The contribution of the various components over the 0.6 - 3.5 MeV and the 3.5 - 9.0 MeV ranges are summarized in Table 1. Despite the many corrections, about 50-75% of the energy losses cannot be accounted for by presently understood local processes and therefore must originate externally. Obtaining the photon spectrum incident isotropically on the spectrometer requires a correction for local matter. Taking this to be equivalent to a uniform shell 5.0 gm/cm^2 thick of Al surrounding the NaI crystal, and correcting for absorption, but not scattering results in the final photon spectrum shown in Figure 3. We have assumed the photon continuum extends as $E^{-2.0}$ above 27 MeV; however, the result is rather independent of this shape.

Systematic errors, which are difficult to estimate, completely dominate the statistical uncertainties in this analysis. Correcting for the spacecraft lines can be done to high precision. The effective solid angle for continuum production in the spacecraft may be less certain. No correction has been made for production in local material, which is believed to be small (Vette et al., 1970). We estimate the equivalent photon spectrum, before correction for spallation, to be accurate to about ±20%. The spallation correction cannot be much larger than that indicated in Figure 3. Correcting for absorption, but not scattering, results in an upper limit to the external flux.

These results may be compared to those of others who have presented spectra at various stages of correction. The Apollo 15 photon equivalent continuum is considerably below that determined from ERS-18, which had no corrections for γ-ray lines, effects of local material, or spallation, and which apparently had an instrumental malfunction at higher energies. The final photon Apollo 15 spectrum is compared direction with balloon and low altitude satellite work (Vedrenne et al., 1971; Golenetskii et al., 1971) in Figure 4. The result of Damle et al. (1971) is considerably above the other work and is therefore not shown. Although the low latitude observations should not require a significant correction for spallation, they do require an altitude and latitude dependent model to correct for cosmic-ray produced γ-rays, and in some cases, an additional large correction for counter efficiency.

The new results, in addition to being in reasonable agreement with the more recent work above 1 MeV, also agree with data near 100 keV (Pal, 1972) when extrapolated as an E^{-2} power law. Furthermore, the Apollo spectrum is consistent with new data on the diffuse component near 30 MeV by Pinkau (Mayer-Hasselwander et al., 1972), and by Share, Kinzer and Seeman (1972) at NRL.

Figure 4 shows some of these results, as well as that of Kraushaar et al. (1972) at 100 MeV obtained from the OSO-3.

Also shown in Figure 4 is a single power law which has been suggested (Pal, 1972) as capable of representing the total cosmic γ-ray spectrum between ~ 0.02 and 1.0 MeV. It is clear that the derived Apollo 15 spectrum is well above this extrapolation and even though we interpret our result as an upper limit, we do not believe that the remaining small corrections and uncertainties can reduce the final cosmic spectrum to the extrapolated value.

IV. DISCUSSION

Assuming that the γ-ray fluxes are of extragalactic origin (Stecker, Vette, and Trombka, 1971) a number of workers have attempted to account for the spectra shown in Figure 4. Compton scattering of electrons leaking from radio galaxies (Brecher and Morrison, 1969), redshifted γ-rays from π° decays produced by cosmic-ray collisions at an early epoch of the expanding Universe (Stecker, 1971), nuclear γ-rays from supernovae in distant galaxies (Clayton and Silk, 1969), intergalactic electron bremsstrahlung (Arons, McClay and Silk, 1971; Stecker and Morgan, 1972) and matter-antimatter annihilation (Stecker, Morgan and Bredekamp, 1971) have all been suggested. Vette et al. (1970), in attempting to account for the ERS-18 data, fitted a model in which a π° decay component produced at an epoch with a redshift ≈ 70 was superposed on a Compton scattering X-ray background. Based on the present data, large fluxes at very early epochs are no longer required, and a π° decay component, if it exists at all, must have originated in a lower density universe at more recent times. Although the final spectrum of Apollo 15 does require an additional component above a simple power law, it appears that several combinations of the various models can provide a fit to the data.

The analysis process used here subtracts out all discrete γ-ray lines and produces a smooth continuum, as presented in Figure 3. Discrete γ-rays of cosmic origin, if they exist, would therefore be removed along with known spacecraft and spallation contributions. Only considerable further analysis can separate these components, and place valid limits on possible cosmic components.

The γ-ray line near 0.51 MeV has an intensity after correction for spacecraft production and local absorption estimated to be $3.0 \pm 1.5 \times 10^{-2}$ photons $(cm^2\text{-}sec)^{-1}$. The uncertainty is an estimate of the effect of systematic errors in the correction for weak γ-ray features near this energy and for detector efficiency and absorption. The 0.51 MeV γ-ray measured on Apollo 15 cannot originate in the spacecraft since this component decreases less rapidly with spacecraft solid angle than the continuum. The intensity of the line seems inconsistent with upper limits on the cosmic flux at 0.51 MeV of $<10^{-2}$ photons $(cm^2\text{-}sec)^{-1}$ obtained from balloon measurements (Chupp et al., 1970) and on the Ranger III (Metzger et al., 1964). Since the Ranger III, which also measured in interplanetary space, had considerably less matter locally to the detector, it may be possible to attribute the flux to annihilation of positrons produced by cosmic-rays or spallation β^+ decays in the local mass. It is also possible that low energy positrons of either solar or cosmic origin with a flux of $\sim 10^{-2}$ $(cm^2\text{-sec})^{-1}$ could stop and annihilate in the inert matter surrounding the detector. Such a mechanism has been suggested by Stephens (private communication) and is in fact consistent with the interplanetary medium flux of 2×10^{-2} positrons $(cm^2\text{-sec})^{-1}$ at $\sim$2 MeV reported by Cline and Hones (1969). Haymes (Johnson, Harnden and Haymes, 1972) has reported a γ-ray line at $\sim$470 keV whose intensity is 2×10^{-3} photons $(cm^2\text{-sec})^{-1}$ originating from the galactic center. The γ-ray line measured on Apollo 15 is definitely at 0.511 $\pm$0.012 MeV, and the 2σ upper limit to a γ-ray at 0.47 MeV is $\sim 2 \times 10^{-3}$ photons $(cm^2\text{-sec})^{-1}$, based on the analysis of four hours of data.

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Table 1

Composition of Apollo 15 Energy Loss Spectrum

Transearth Coast, Deployed Position

Composition	Energy Range	
	0.6 - 3.5 MeV	3.5 - 9.0 MeV
γ-Ray Lines	15.9%	3.7%
Spallation in NaI crystal	15.8%	0.5%
Spacecraft Continuum	10.2%	21.7%
Cosmic Upper Limit	58.1%	74.1%
Total	100.0%	100.0%

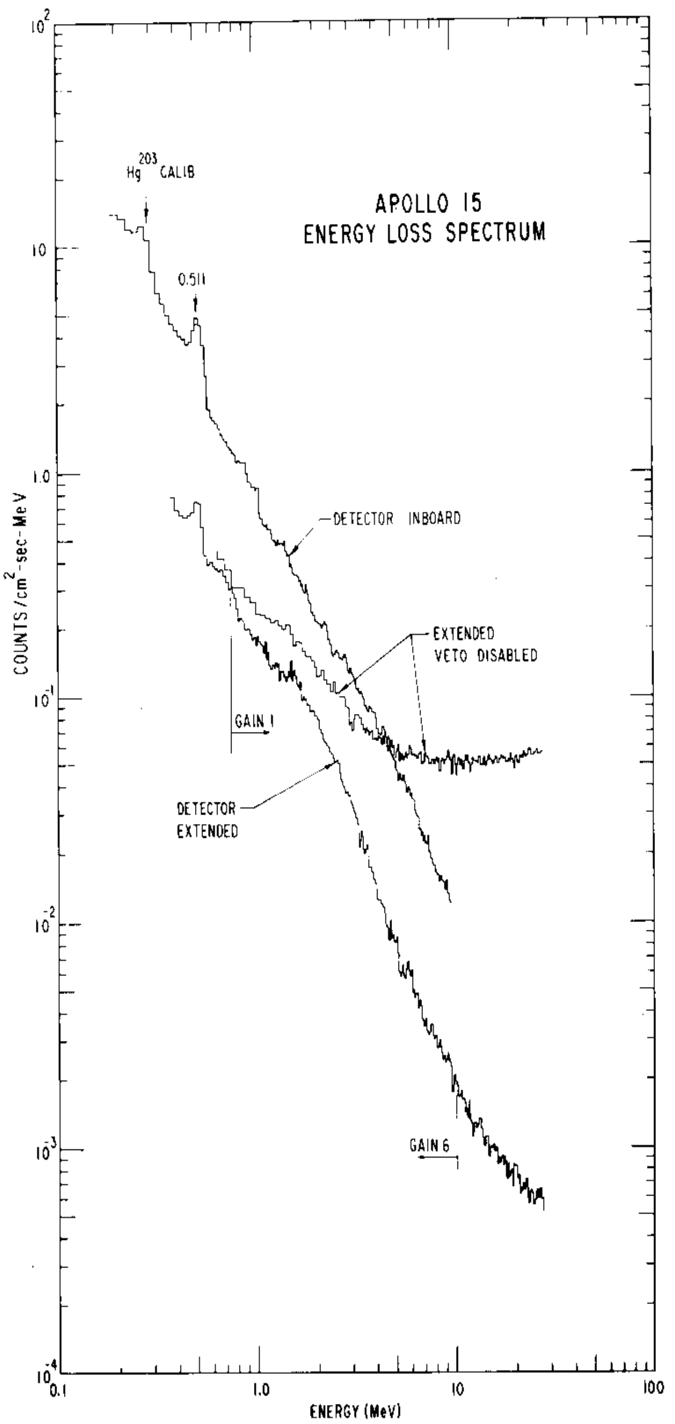

Figure 1. Energy loss spectra in the 7.0 cm dia x 7.0 cm long NaI(Tℓ) scintillation counter measured on Apollo 15 during Transearth Coast. Since the rates decreased only a factor of about 5 when the detector was extended to 7.6 m, while the solid angle subtended by the spacecraft decreased a factor of 20, we interpret most of the rate in the extended position to be associated with cosmic γ-rays. The spectrum with the anticoincidence disabled agrees with that expected from cosmic-rays passing through the crystal edges.

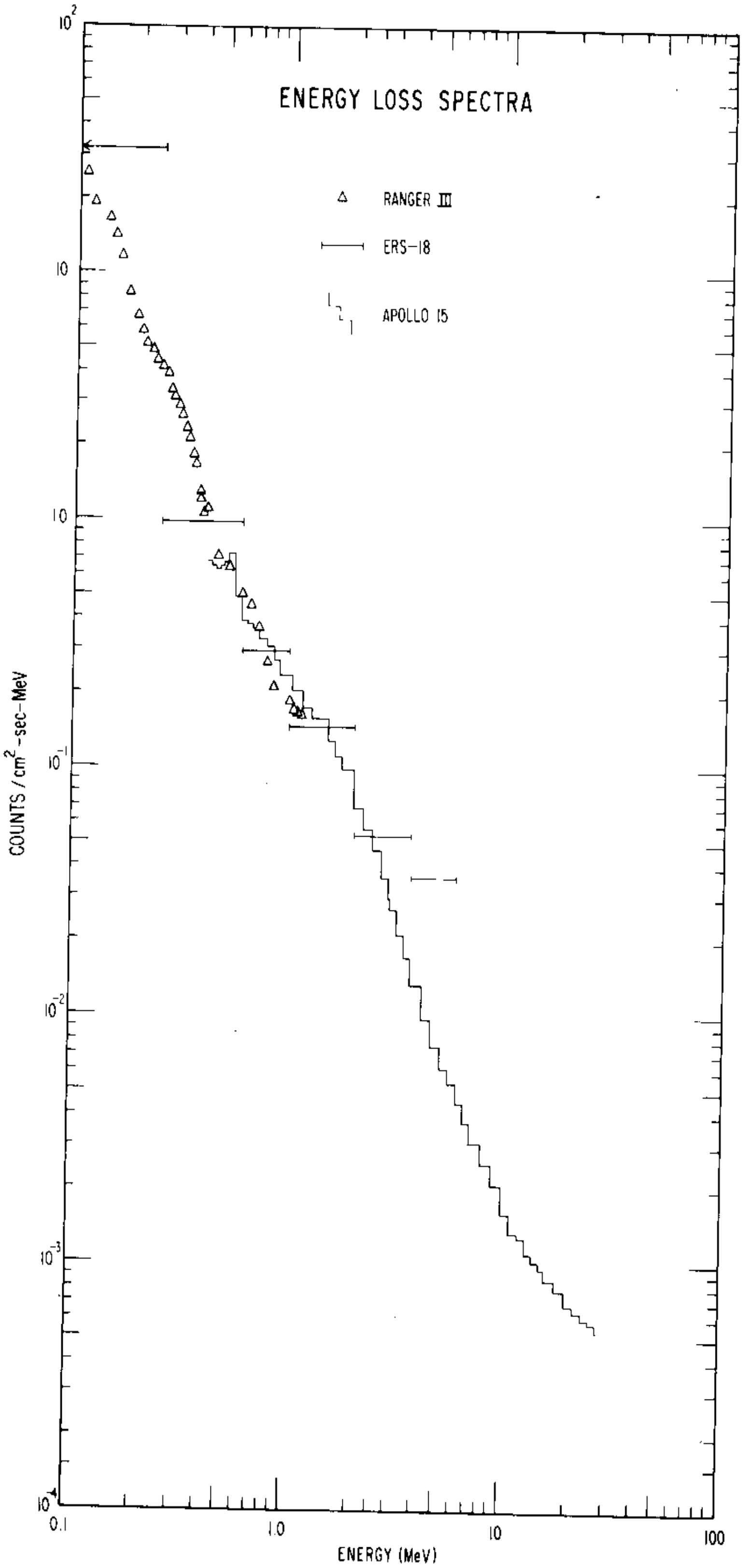

Figure 2. Energy loss spectra are compared directly with other measurements obtained outside the magnetosphere. These data were obtained with counters that differ only slightly in geometry and materials.

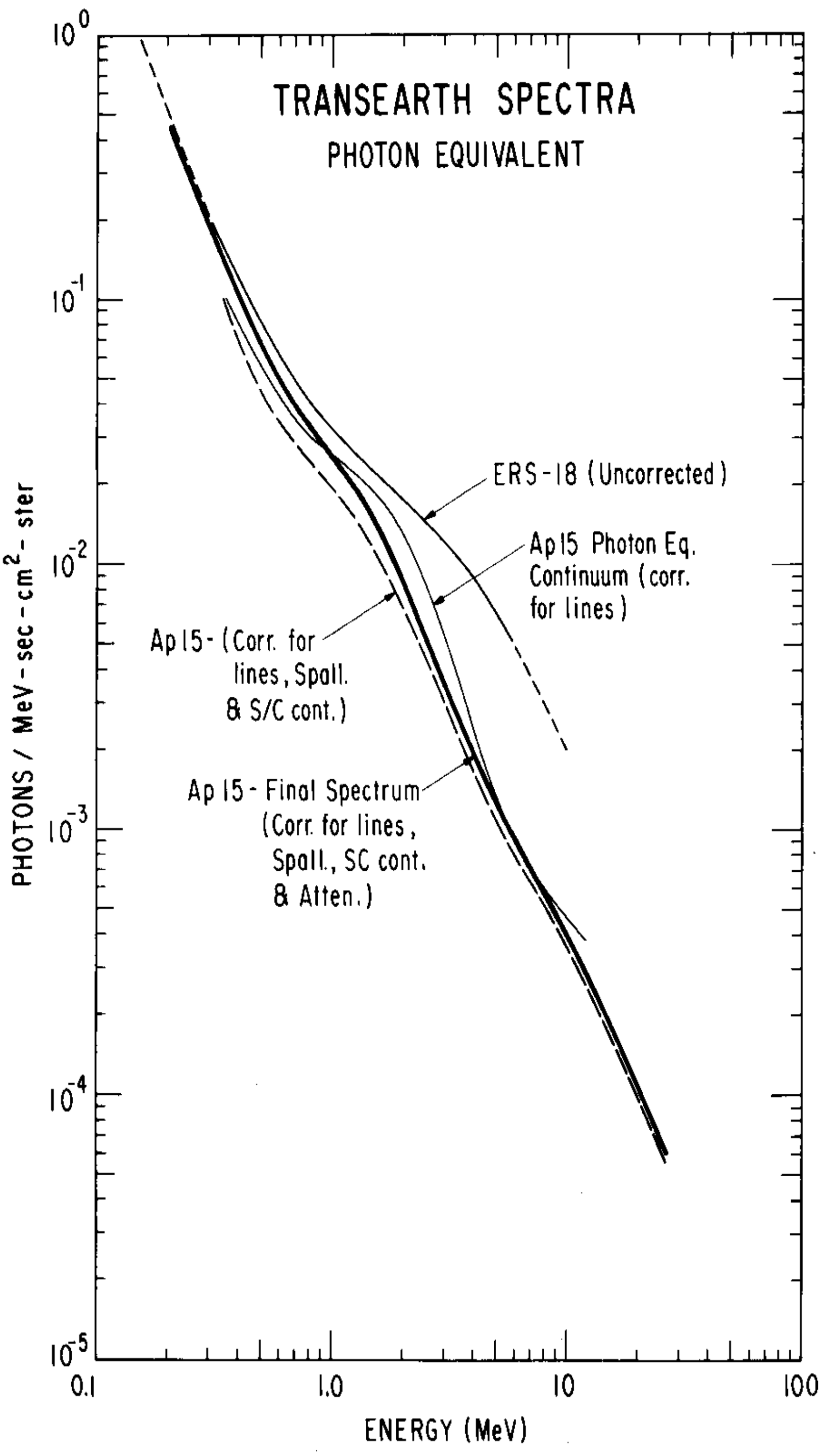

Figure 3. Equivalent photon spectra derived from the Apollo 15 are shown at various stages of data correction. First all components due to discrete γ-ray lines are removed, then the spacecraft continuum contribution, and an estimate of energy losses due to spallation nuclei are subtracted. The final result contains a correction for absorption of local material, assuming all energy losses at this stage are due to an external isotropic γ-ray flux.

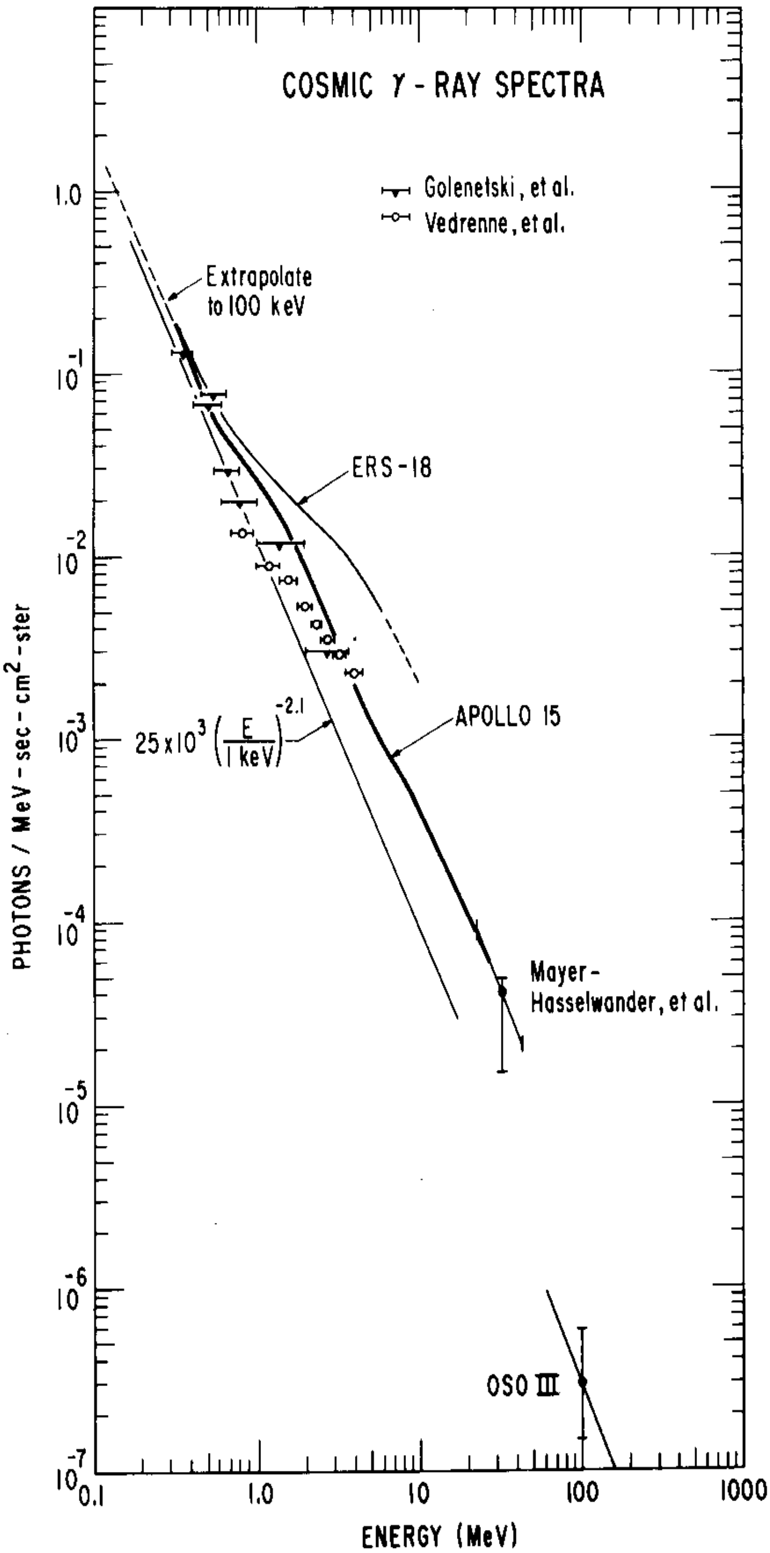

Figure 4. The cosmic photon spectrum derived from the Apollo 15 data agrees with previous results below 1 MeV, but is well below that determined from the ERS-18 at higher energies. Limits derived from balloon and low altitude satellite work, despite large corrections for efficiency and cosmic-ray produced γ-rays, are in agreement with the Apollo results.

FIGURE CAPTIONS

1. Energy loss spectra in the 7.0 cm dia x 7.0 cm long NaI(Tℓ) scintillation counter measured on Apollo 15 during Transearth Coast. Since the rates decreased only a factor of about 5 when the detector was extended to 7.6 m, while the solid angle subtended by the spacecraft decreased a factor of 20, we interpret most of the rate in the extended position to be associated with cosmic γ-rays. The spectrum with the anticoincidence disabled agrees with that expected from cosmic-rays passing through the crystal edges.
2. Energy loss spectra are compared directly with other measurements obtained outside the magnetosphere. These data were obtained with counters that differ only slightly in geometry and materials.
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          0625 000000000000  000000000000  000000000000  000000000000  000000000001  000000000000  000000000000  000000000000
          0673 000000000000  000000000000  000000000000  000000000000  000000000001  000000000001  000000000000  000000000000
          0721 000000000000  000000000001  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          0769 000000000000  000000000000  000000000001  000000000000  000000000000  000000000000  000000000000  000000000000
          0817 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          0865 000000000000  000000000000  000000000000  000000000000  000000000000  000000000001  000000000000  000000000000
          0913 000000000000  000000000001  000000000000  000000000000  000000000000  000000000001  000000000000  000000000000
          0961 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1009 000000000001  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1057 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1105 000000000000  000000000000  000000000001  000000000000  000000000000  000000000000  000000000000  000000000000
          1153 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1201 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000001  000000000000
          1249 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1297 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1345 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1393 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1441 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1489 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1537 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1585 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1633 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1681 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1729 000000000000  000000000000  000000000001  000000000000  000000000000  000000000000  000000000000  000000000000
          1777 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1825 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1873 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000001
          1921 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          1969 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2017 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2065 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2113 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2161 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2209 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2257 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2305 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2353 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2401 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2449 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
          2497 000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000  000000000000
```

FILE 0001 REC 0010 CH 3078

1585	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
1633	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
1681	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
1729	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
1777	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
1825	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
1873	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
1921	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000001
1969	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2017	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000	000000000000	000000000000
2065	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2113	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2161	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2209	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2257	000000000000	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000	000000000000
2305	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000	000000000000	000000000000
2353	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2401	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2449	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2497	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2545	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2593	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2641	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000001	000000000000
2689	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2737	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2785	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2833	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2881	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2929	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
2977	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
3025	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
3073	000000000006							

FILE 0001 REC 0011 CH 0192

0001	231440113571	220613616263	234445021101	634576044530	634517732340	211523344251	207545534240	202626104377
0049	206740000000	606427166327	207564364130	606550047172	207467136007	606722037435	207504163435	210461076356
0097	173721600214	577704263106	200713065434	572534427100	600713252245	577704165341	200777607156	170613274724
0145	573756644267	210647167576	604640542244	211421535227	206775636274	205623765667	205647401020	206740000000

FILE 0001 REC 0012 CH 0078

0001	000110022736	000000000000	000000000000	000000000001	000000000001	000000000000	000000000000	000000000000
0049	000000000000	000000000000	000000000000	000000000000	000000000000			

FILE 0001 REC 0013 CH 0078

0001	000110022736	000000000000	000000000000	000000000000	000000000004	000000000001	000000000000	211707731511
0049	210637173123	207560337410	000000000006	000000000000	000000000000			

FILE 0001 REC 0014 CH 3078

0001	000110022736	000000002026	000000000073	000000000004	000000000002	000000000004	000000000005	000000000002
0049	000000000001	000000000004	000000000000	000000000004	000000000002	000000000002	000000000004	000000000004
0097	000000000002	000000000001	000000000001	000000000001	000000000000	000000000004	000000000002	000000000001
0145	000000000002	000000000001	000000000000	000000000000	000000000001	000000000001	000000000002	000000000000
0193	000000000001	000000000001	000000000001	000000000000	000000000003	000000000001	000000000001	000000000000
0241	000000000000	000000000001	000000000001	000000000001	000000000000	000000000000	000000000001	000000000000
0289	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000001
0337	000000000001	000000000000	000000000001	000000000000	000000000000	000000000000	000000000000	000000000000
0385	000000000000	000000000000	000000000000	000000000000	000000000000	000000000001	000000000001	000000000000
0433	000000000002	000000000000	000000000001	000000000001	000000000000	000000000001	000000000000	000000000000
0481	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000	000000000000	000000000000
0529	000000000000	000000000000	000000000000	000000000000	000000000000	000000000002	000000000000	000000000000
0577	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000	000000000000	000000000000
0625	000000000001	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
0673	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000	000000000000	000000000000
0721	000000000000	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000	000000000000
0769	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
0817	000000000000	000000000000	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000
0865	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000	000000000000
0913	000000000000	000000000000	000000000000	000000000000	000000000000	000000000001	000000000000	000000000000