Instrument Description Document (IDD) for the
Lunar Prospector Spectrometers
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1.0 Scientific Objectives

Gamma Ray Spectrometer (GRS):

To provide global maps of the lunar elemental composition to depths of 20 cm. Scientifically discriminating results are expected for Fe, Ti, U, Th, K, Si, and perhaps Al and Ca.

Neutron Spectrometer (NS):

To search for, and determine the abundance of water ice to depths of 50 cm within permanently shaded craters at the lunar poles.
To search for, and determine the abundance of, hydrogen implanted by the solar wind into lunar regolith to depths of 50 cm thereby providing maps of regolith maturity.

Alpha-Particle Spectrometer (APS):

To search for, map, and provide a measure of, the time history of gas release events at the lunar surface.

2.0 Measurement Requirements

Gamma-Ray Spectrometer:

Energy spectrum of gamma rays with and without anticoincidence shield; $0.3 \text{ MeV} < E\gamma < 9.0 \text{ MeV}$.
Energy resolution better than 9% at 662 keV.
Continuous in-flight gain calibration is essential.
Determination of backgrounds during Earth-Moon transit is essential.
Data corrections needed for spin phase variations.

Neutron Spectrometer:

Flux intensity of thermal and epithermal neutrons.
Coarse energy spectrum of fast neutrons, $0.5 \text{ MeV} < E_n < 5.0 \text{ MeV}$.
Continuous in-flight gain calibration is essential.
Determination of backgrounds during Earth-Moon transit is essential.
Data corrections needed for spin phase variations.

Alpha-Particle Spectrometer:

Energy spectrum of lunar alpha particles between 4.5 and 6.6 MeV.

Energy resolution needs to be less than 60 keV at $E_\alpha = 5.5 \text{ MeV}$.
Occasional in-flight gain calibration is essential.
Determination of backgrounds during Earth-Moon transit is important.
Data corrections needed for spin phase variations.

3.0 Instrument Description

Gamma Ray Spectrometer (GRS)

The sensor for the Gamma Ray Spectrometer (GRS) is composed of a 7.62-cm diameter by 7.62-cm long BGO scintillator placed within a well-shaped-configured plastic scintillator anticoincidence shield loaded with 5% by mass of natural boron (marketed by Bicron Corp as BC454). This scintillator is 12-cm in diameter and 20-cm in length. The cylindrical well-shaped cavity in one end of the BC454 will be about 8.2-cm inner diameter and 10-cm deep. Each scintillator is viewed by separate 7.62-cm diameter Burle 4900A photomultiplier tubes (PMTs). Both scintillators will be contained within a common cylindrically-shaped housing composed of a carbon-epoxy material using a manufacturing technique developed by Lockheed-Martin Corp. It will be covered by a thermal blanket designed to maintain operation at -40° C while in orbit about the Moon. The axis of the GRS sensor will be oriented perpendicular to the boom and aligned with the spacecraft (S/C) spin axis.

Each PMT will have two, 7.4-cm diameter polyamide circuit boards soldered to the flying leads at their back ends. These will hold voltage-distribution bleeder strings and preamplifier / line drivers. Each bleeder string will be fed by one of two redundant 2 kV high voltage power supplies (HVPS), each having its own 8-bit controller. These power supplies will be placed within the spectrometer electronics subsystem (SES) box on the equipment shelf in the spacecraft.

The harness connecting the GRS to the spacecraft bus needs to contain two shielded twisted pair cables containing low voltage power, one HV coaxial cable, and two shielded twisted-pair signal cables identified as follows:

1) three low voltage lines for the analog electronics (+ 5 V, - 5 V and ±5 V return),
2) one coaxial high voltage cable carrying 2 kV maximum, and
3) two shielded twisted-pair cables that carry the BGO and BC454 analog signals back to the main electronics box in the S/C bus.

Two twisted, shielded-pair cables will be needed for a thermostat to keep the sensor temperature between -45$^{\rm o}$ C and -35$^{\rm o}$ C with a stability of ±1$^{\rm o}$ C, and to measure the temperature of the BGO scintillator for incorporation into the engineering data string.   The total harness complement will be split into three bundles, one for each longeron of the Astromast.   Both signal cables will be routed along one of the longerons, both low-voltage power cables will be routed along a second longeron, and the high-voltage and heater/thermostat cables will be routed along the third longeron (see Table I for the cabling specification).

The front-end electronics of the GRS will be designed to recognize compound events consisting of two interactions within 26 µs, and to measure the elapsed time (time-to second-pulse, TTSP) between them.   Pulse heights for each interaction will be digitized using analog-to-digital converters (ADCs) fed by the BGO and BC454 analog electronics.   Whereas the BGO ADC will have 12-bit resolution for energies ranging up to 9 MeV (17.6 keV per high-order 9-bit channel), the BC454 ADC will have 8-bit resolution for energies up to 2.55 MeV equivalent electron energy (10 keV per channel).

TABLE I
Boom Cable List

Boom	Longeron #	Cable Types	Cable Functions
GRS	1	2 Twisted, Shielded Pairs #22	+5 and -5 Volt Power and Return
GRS	2	2 Twisted, Shielded Pairs #24	BGO and BC454 PMT Signals
GRS	3	1 High-Voltage Coaxial Cable	2000 V Power to GRS PMTs
	3	2 Twisted, Shielded Pairs #22	PRI & RED Heater Power & Return
NS/APS	1	3 Twisted, Shielded Pairs #22	+25, +5, -5 V APS Power & Return
	1	2 Twisted, Shielded Pairs #22	+5 and -5 V NS Power & Return
	2	1 High-Voltage Coaxial Cable	2000 V Power to NS Cd He3 Tube
NS/APS	2	1 High-Voltage Coaxial Cable	2000 V Power to NS Tin He3 Tube
	2	2 Twisted, Shielded Pairs #22	PRI & RED NS Htr Pwr & Return
	2	2 Twisted, Shielded Pairs #22	PRI & RED APS Htr Pwr & Return
NS/APS	3	5 Twisted, Shielded Pairs #24	APS Analog Sensor Signals
	3	2 Twisted, Shielded Pairs #24	NS He3 Tube Analog Signals

Only four of the possible combinations of prompt and delayed BGO and BC454 interactions will be recognized by the front-end electronics (FEE) for transfer to the experiment microprocessor (located in the SES box in the S/C bus) for formatting into an output data packet. Packet accumulation times will be 32 s. The four categories of pulse combinations for which data will be transmitted to ground, correspond to:

Category 1) a single BGO interaction unaccompanied by a coincident (within 100 ns) BC454 interaction,

Category 2) a single coincident (within 100 ns) BGO and BC454 interaction,

Category 3) a prompt BC454 interaction having energy less than about 2.55 MeV followed by a single, delayed BC454 interaction having energy less than about 640 keV (equivalent to pulse-height channel 64) and occurring within a 25.6 μs gate window beginning about 350 ns after the firing of the constant-fraction discriminator (CFD) fed by the BC454 analog electronics,

Category 4) a prompt BC454 interaction having energy less than about 2.55 MeV followed by a coincident (within 100 ns) BC454 and BGO delayed interaction, having energies less than about 640 keV and 1125 keV, respectively (equivalent to pulse-height channels 64 in both the BC454 and BGO ADCs), and occurring within a 25.6 μs gate window beginning about 350 ns after the firing of the CFD fed by the BC454 analog electronics.

A logically possible fifth category, corresponding to a prompt BC454 interaction followed either by a single BGO delayed interaction or by no delayed interaction within 26 μs, will: 1) be recognized by the FEE logics, 2) have its contribution to detector dead time (DT) recorded, but 3) not have its digitized data (consisting of three pulse heights and the time-to second-pulse, TTSP) transferred to the microprocessor.

Logics in the front-end electronics (FEE) and spectrometer electronics subsystem (SES) will be programmed using field-programmable gate arrays (FPGAs) to categorize and histogram each event immediately after its front-end analog processing is completed. Definition of a first interaction will be decided by the first BGO Constant Fraction Level Discriminator (CFLD) and/or the BC454 CFD trigger that is detected after the generation of an end-of-process (EOP) trigger (which denotes the finish of analysis of the last detected event). The EOP, in turn, resets a busy gate to its low state thus arming the FEE for detection of the next event. In the case of detection of a Category-1 or Category-2 event (signaled by detection of either a single BGO prompt CFLD trigger or a coincident BGO CFLD and BC454 prompt CFD trigger, respectively), the time required for a complete analysis (consisting of amplitude digitization, event categorization, and incrementation of event counters) will be fixed at about 10 μs. Detection of

a Category-3 or Category-4 event (signaled by the detection of a single prompt BC454 CFD trigger (corresponding to a non-overload BC454 interaction) followed by either a single BC454 delayed CFD trigger or a delayed coincident BC454 CFD - BGO CFLD trigger (corresponding to pulse-height channels (channel 64), respectively) will require a variable processing time that depends on the time-to-second-pulse (TTSP). For these category types, event processing times can range up to about 36 µs. The total processing time in each 32-s accumulation interval (Dead Time) will be recorded by summing every second positive edge from a 20 MHz clock (gated by the busy logics gate), in a 16-bit scaler. This scaler will be fitted with an 8-bit prescaler to yield a digitization uncertainty of 25.6 µs.

A 'truth table' that allows visualization of the total number of different possibilities of GRS event category types is given in Table II.

Information that will be digitized by the front-end electronics for transfer as data words to the experiment microprocessor for packetization into an output telemetry format will consist of subsets of:

1) a 12-bit BGO ADC address,
2) an 8-bit prompt BC454 ADC address,
3) an 8-bit delayed BC454 ADC address, and
4) an 8-bit digitized time-to-second-pulse (TTSP)

TABLE II
GRS Event Category Types

Prompt Pulse

BC454	BGO	Category	DT Counter	Transfer Data	Scaler #	Dead Time
0	1	I	No	Yes	1	10 µs
1	1	II	No	Yes	4	10 µs
1	0	III, IV, V	Yes	See Dlyd Pulse	2	Variable

Delayed Pulse

BC454	BGO	Category	DT Counter	Transfer Data	Scaler #	Dead Time
1	0	III	Yes	Yes	2	< 36 µs
1	1	IV	Yes	Yes	2	< 36 µs
0	1	V	Yes	No	2	< 36 µs
0	0	V	Yes	No	2	< 36 µs

One-bit flags required to identify detected event types by the Digital Acquisition (DACQ) subsystem of the SES correspond to:

1) a Category 1 or 2 event (CATFLAG = 0,1, respectively)
2) a Category 3 or 4 event (CATFLAG = 0,1, respectively)
3) a BGO interaction within the BGO pulse-height window (BGOW = 0,1)
4) a BC454 interaction within the BC454 pulse-height window (BC454W = 0,1)
5) an early-time delayed BC454 interaction (ET = 0,1)
6) a late-time delayed BC454 interaction (LT = 0,1).

Three strobes will be required to route data from the FEE to the proper DACQ boards in the histogramming subsection of the SES.   These strobes correspond to:

1) a Category 1 or 2 event,
2) a Category 3 or 4 event, and
3) a Category 2 event for which BGOW=1 and the BC454 pulse-height channel   64.

The portion of this information that will be used by the microprocessor to construct an output data packet from each of the four categories of interactions will consist of:

Category 1)   the highest order 9 bits of the 12-bit address returned by the BGO ADC,

Category 2)   a set of pulse-height addresses consisting of;

a) the top 9 bits of the 12-bit BGO ADC,
b) the bottom 6 bits of the 8-bit address returned by the BC454 ADC,
c) a one-bit indicator (BGOW) reflecting whether (1) or not (0) the BGO address is contained within an energy window, nominally extending from 380 keV (channel 21) to 600 keV (channel 34), and
d) a one-bit indicator (BC454W) reflecting whether (1) or not (0) the BC454 address is contained within an energy window, nominally extending from 20 keV (channel 2) to 135 keV (channel 14),

Category 3)   a set of addresses consisting of;

a) the top 4 bits of the prompt BC454 8-bit pulse height (corresponding to fast neutrons having energy less than about 6.45 MeV),
b) the bottom 6 bits of the delayed BC454 8-bit pulse height (corresponding to electrons having energy less than about 640 keV),
c) the 8-bit address corresponding to a digitization of the time difference between prompt and delayed BC454 interactions in increments of 100 ns,
d) a one-bit indicator (ET) reflecting whether (1) or not (0) the time-difference address is contained within a 5 μs-wide window occurring at early times (nominally between 0.35 μs and 5.35 μs), and
e) a one-bit indicator (LT) reflecting whether (1) or not (0) the time-difference address is contained within a 5 μs-wide window occurring at late times (nominally between 20 μs and 25 μs),

Category 4) a set of addresses consisting of;

    a) the top 4 bits of the prompt BC454 8-bit pulse height (corresponding to fast
        neutrons having energy less than about 6.45 MeV),
    b) the bottom 6 bits of the delayed BC454 8-bit pulse height (corresponding to
        electrons having energy less than about 640 keV),
    c) the bottom 6 bits of the (high-order 9-bit) BGO 12-bit pulse height
        (corresponding to gamma rays having energy less than about 1.126 MeV),
    d) the 8-bit address corresponding to a digitization of the time difference between
        prompt and delayed BC454 interactions in increments of 100 ns,
    e) a one-bit indicator (ET) reflecting whether (1) or not (0) the time-difference
        address is contained within a 5 µs-wide window occurring at early times
        (nominally between 0.35 µs and 5.35 µs), and
    f) a one-bit indicator (LT) reflecting whether (1) or not (0) the time-difference
        address is contained within a 5 µs-wide window occurring at late times
        (nominally between 20 µs and 25 µs).

Additional information accumulated for all events regardless of category will be contained in four 16-bit scalers that correspond to:

    1) the number of Category 1 and 2 events,
    2) the accumulated dead time in units of 25.6 µs resulting from BC454 first interactions,
    3) the number of overload BC454 pulses defined by a minimum energy of 2.55 MeV,
    4) the number of Category 3 and 4 events.

A fifth 16-bit scaler will record:

    5) those Category 2 events for which BGOW = BC454W = 1.

Any event containing either a prompt or a delayed BC454 overload pulse will be discarded before transmitting digitized data to the microprocessor, although it will be counted in the third scaler as well as in one of the other three scalers depending on the category of event. Otherwise, all digital information developed by the front-end electronics to characterize events corresponding to one of the four acceptable categories just defined, will be transferred to the microprocessor immediately after it is generated.

The contents of the first three 16-bit counters will be incorporated into the output data packet by the microprocessor after successive 32-s data-cycle accumulation intervals. The contents of the fourth counter will be truncated at its lowest 10 bits and then packetized after successive 4 s intervals, and that of the fifth counter will be packetized as an 8-bit word after successive 0.5 s intervals. After readout, all counters will be reset to zero and restarted.

The repetitive cycle time of the GRS will be 32 s. Its share of the Lunar Prospector telemetry downlink will be 690 bps. This allocation will be apportioned to events and their pulse-height spectra (PHS) in the four different categories of detected events. All pulse-height

spectra will be accumulated using 16-bit counting registers but will be compressed to 8 bits/register after successive 32-s accumulation periods using the algorithm in Appendix I.

The composition of each 32-s data packet, formatted appropriately for transfer to the spacecraft data bus, is:

Category 1;

PHS of BGO, giving [8 (bits/channel) x 512 (channels)] / 32 (s) = 128 bps.

Category 2;

a) PHS of BGO, giving [8 (bits/channel) x 512 (channels)] / 32 (s) = 128 bps
b) PHS of BGO for BC454W=1, giving [8 (bits/channel) x 64 (channels)] / 32 (s) = 16 bps
c) PHS of BC454 for BGOW=1, giving [8 (bits/channel) x 64 (channels)] / 32 (s) = 16 bps
d) Number of events having BGOW=BC454W=1 accumulated during successive 0.5 s intervals, giving [8 (bits/scaler) x 1 (scaler)] / 0.5 (s) = 16 bps.

Categories 3&4;

a) two sets of PHS (corresponding to early and late times) of;

i) prompt BC454 PHS (16 channels),
ii) delayed BC454 PHS (64 channels),
iii) delayed BGO PHS (64 channels),

for ET=1 and LT=1 separately, yielding a contribution to the GRS bit rate amounting to 2 x [(16 + 64 + 64) channels] x 8 (bits/channel) / 32 = 72 bps.

b) 24-bits from the first 412 individual event addresses consisting of:
i) a 4-bit prompt BC454 address,
ii) a 6-bit delayed BC454 address,
iii) a 6-bit delayed BGO address, and
iv) an 8-bit time-difference address,

yielding [412 x 24] / 32 = 309 bps. The GRS event data are packed into three 8-bit words labeled low, middle, and high. If the bits of these words are labeled in the following manner

$$\text{low} = \begin{bmatrix} L7, & L6, & L5, & L4, & L3, & L2, & L1, & L0 \end{bmatrix}$$
$$\text{middle} = \begin{bmatrix} M7, & M6, & M5, & M4, & M3, & M2, & M1, & M0 \end{bmatrix}$$
$$\text{high} = \begin{bmatrix} H7, & H6, & H5, & H4, & H3, & H2, & H1, & H0 \end{bmatrix}$$

then the event data is packed with the following configuration:

$$\text{Prompt BC454} = [\text{H7, H6, H5, H4}]$$
$$\text{Delayed BC454} = [\text{L5, L4, L3, L2, L1, L0}]$$
$$\text{Delayed BGO} = [\text{H3, H2, H1, H0, M7, M6}]$$
$$\text{Time difference} = [\text{M5, M4, M3, M2, M1, M0, L7, L6}]$$

These pulse-height spectra will be supplemented by three 16-bit scalers (a category1/2 scalar, a dead time scalar, and an overload scalar) (1.5 bps), the eight 4-s subtalleys of the category 3/4 scaler (10 bits / 4 s = 2.5 bps), and a 32-bit ID header (1 bps) yielding [128 + 128 + 16 + 16 + 16 + 72 + 309 + 1.5 + 2.5 + 1] = 690 bps.

Neutron Spectrometer (NS)

The Lunar Prospector Thermal / Epithermal Neutron Spectrometer (NS) will consist of two identical Reuter Stokes model RS-P4-1808-225 ^{3}He gas proportional counters mounted at the tip of S/C Boom 2 on a bracket that also supports the Alpha-Particle Spectrometer (APS). Each sensor will be 5.8-cm diameter, have a 20-cm long active length (29.0 cm total length), and be filled with 10 atmospheres of ^{3}He. One of the sensors will be wrapped with a 0.75-mm thick sheet of Cd and the other with a 0.75-mm thick sheet of Sn. Whereas the first responds only to epithermal neutrons (energies greater than about 0.25 eV, yielding an expected counting rate of about 5 s^{-1}), the second responds to both thermal and epithermal neutrons (yielding an expected counting rate of about 23 s^{-1}). The cylindrical axes of both detectors will be aligned perpendicular to both the boom and the spacecraft spin axis.

The two ^{3}He counters will have separate 2 kV high voltage power supplies (HVPS), each having separate 8-bit controllers. The supplies will be contained within the SES box mounted on the equipment shelf of the spacecraft bus. Cylindrical Al shells that house the two ^{3}He gas proportional counters will be mounted to an aluminum chasis attached to the boom. Separate charge-sensitive preamplifiers (CSPs) and line drivers for the two counters (now baselined as AMPTEK A203 CSPs) will be placed on circuit boards mounted just behind the central-wire feedthrough of the gas proportional counters.

The harness connecting the NS to the spacecraft bus needs to contain two shielded twisted-pair cables containing low voltage power, two HV coaxial cables, and two shielded twisted-pair signal cables identified as follows (see list in Table I):

1) three low voltage lines for the analog electronics (+ 5 V, - 5 V and ±5 V return),
2) two coaxial high voltage cables carrying 2 kV maximum, and
3) two shielded twisted-pair cables that carry the ^{3}He counter analog signals to the FEE in the SES box in the S/C bus.

Two shielded twisted-pair cables will be needed for a thermostat to maintain a temperature above -25° C during lunar eclipse and to monitor the temperature at the neutron sensor throughout the mission (TBR).

Front-end electronics will consist of a pair of charge-sensitive preamplifiers (such as the AMPTEK A203) mounted just behind the sensors, and a pair of 8-bit ADCs mounted in the spectrometer electronics subsystem (SES) box, which cover the energy range up to 1 MeV. Digitized pulse heights for each detected event will be used to set a one-bit indicator depending on whether (1) or not (0) the pulse height is within an energy interval that brackets the 765 keV peak in the ^{3}He pulse height spectrum stemming from the ^{3}He(n,p)T reaction. Channels needed to define the pulse-height window (HECDW, HESNW) are set by ground command. This indicator will, in turn, be used to increment a 16-bit counter for each sensor, whose counts are related (through on-board calibration), to the number of detected epithermal (EPI) and combined thermal plus epithermal (TPE) neutrons. These counters will be read out and compressed to 8 bits using Appendix I every 0.5 s, and then reset and restarted. The resultant contribution to the NS bit rate is [2 (sensors) x 8 (bits per counter)] / 0.5 (s) = 32 bps.

The 8-bit addresses of each detected event will be transferred to the microprocessor where they will be accumulated into two 32-channel pulse-height spectra (using FPGAs programmed to use only the 5 highest-order bits). The resultant contribution to the bit rate is then 2 x [8 (bits/channel) x 32 (channels)] / 32 (s) = 16 bps. A 32-bit identification header will be added to the NS data record every 32 s (amounting to 1 bps) yielding a total bit rate of [32 + 16 + 1] = 49 bps.

Alpha-Particle Spectrometer (APS)

The Alpha-Particle Spectrometer (APS) consists of five sets of two silicon ion-implant detectors, each collimated to a 45° half-angle cone, and mounted with cone axes perpendicular to each of the five outward-pointing faces of a rectangular parallelopiped chasis mounted at the tip of S/C boom 2. This chasis also supports the NS sensor. Figure 1 shows a diagram of how each APS face is orientated relative to the spacecraft.
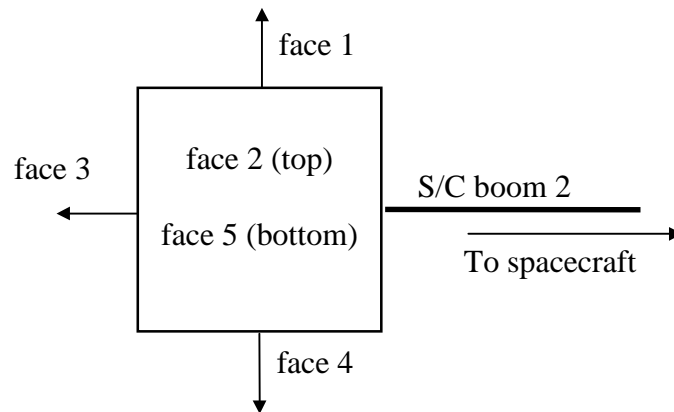

Figure 1: APS Detector view from top spin axis of the Lunar Prospector spacecraft.

Each of the Si ion-implant sensors will have a depletion thickness of 50 microns, will be covered with an aluminized (2000 Ä thick) polypropylene (48 mg/cm2 thick) foil to eliminate direct illumination by sunlight, and will feed individual AMPTEK A250 charge sensitive preamplifiers that are mounted just behind the sensors on each of five removable faces of the sensor cube.   The outputs of the two preamplifiers on each of the faces will be summed and buffered sufficiently to drive a shielded twisted pair cable to the APS front-end electronics board in the SES box.   Here, the analog signals will be processed by a single amplifier having 50 µs shaping time.   Preliminary computer simulations indicate the feasibility of achieving better than 25 keV FWHM noise resolution from the summed output of each pair of the 50 micron thick, 3-cm x 3-cm rectangular ion-implant sensors.   When added in quadrature to the broadening in alpha-particle energy due to penetration of the light-tight foils at angles ranging between 0° and 45° (amounting to 75[Cos-1(45o) - 1] = 31 keV) and the straggling in the front-end sensor dead layer (39 keV) yields an expected FWHM energy resolution of 55 keV.   A capability will be incorporated into the FEE (through use of an FPGA) to disconnect (using an 8-bit Enable-Disable word, APSED, which can be reset by ground command) one or more of the sensor analog chains before they activate the 50 µs shaping amplifier to prevent paralysis of the system due to a noisy sensor.   This command will also contain a one-bit identifier to set the threshold for acceptance by the shaping amplifier to either 1.5 MeV or 4.5 MeV.   This capability will be needed to prevent paralysis by enhanced fluxes of energetic protons known to be accelerated occasionally in interplanetary space.   Occasional operation at the 1.5 MeV threshold will allow a gain calibration of the APS sensors using the ubiquitous fluxes of energetic protons..

A single bias power supply (having a single voltage level of -25 V) will provide bias for all 10 sensors.   It will be transferred to the APS sensor from the SES LVPS through the harness.

The harness connecting the APS to the spacecraft bus needs to contain three shielded twisted pair cables containing low voltage power, and five shielded twisted-pair signal cables identified as follows (see list in Table I):

      1) two low voltage lines for the analog electronics (+ 5 V, - 5 V and ±5 V return),
      2) one low voltage line for the bias voltage supply (-25 V and 25 V return), and
      3) five shielded twisted-pair cables that carry the sensor analog signals to the APS FEE in
            the SES box.

Two shielded twisted-pair cables will be needed for a thermostat to maintain a temperature above -25° C during lunar eclipse and to monitor the temperature at the APS sensor throughout the mission (TBR).

Each of the five analog signals sent to the electronics box will be digitized using a common 8-bit ADC, spanning the nominal energy range between 1.5 MeV and 6.6 MeV (corresponding to 20 keV per channel).   Count rates in the upper half of this energy range, which covers the ^{222}Rn information-containing alpha-particle energy lines (5.3 MeV for ^{210}Po, 5.48 MeV for ^{222}Rn, 6.0 MeV for ^{218}Po), are expected to total no more than 4 s^{-1} for the sum of all 10

sensors.   We therefore choose an event-mode (EM) format to transmit prime APS data to the ground.   One digital window discriminator (APSEWL) will be used on the output of the ADC to define a one-bit identifier (APS Event Strobe) to choose events having energies in the range between APSEWL (nominally equal to 4.5 MeV) to 6.62 MeV.   Information that will be transferred to the microprocessor for further processing will consist of:

> 1) the 8-bit address of the ADC,
> 2) the energy-window flag in the form of an event strobe, and
> 3) a 3-bit face identifier specifying which of the five faces contained the
>   sensor that detected the event.

After receipt of this information, the microprocessor will initiate three operations:

> 1) increment one of 128 pulse-height registers given by the upper seven bits of the
>   ADC address (regardless of which Si sensor detected the event),
> 2) increment a 16-bit counter (to account for the total number of events in each 32-s
>   cycle period that had a detected energy above APSEWL), and
> 3) create a 16-bit word for storage in an appropriate portion of the output data packet for
>   every detected event that satisfies the energy-window requirements.

The words in the third operation will be composed of three parts:

> 1) 6 bits of time relative to the present 32-s cycle period (yielding a time resolution of 0.5
>   s, which corresponds to 36° of spin phase),
> 2) 3 bits to identify the face of the cube from which the event was detected, and
> 3) the least-significant 7-bits of the 8-bit pulse-height address giving the particle energy
>   relative to 4.06 MeV digitized to 20 keV resolution.

The total number of events that will be accepted for storage in the EM data block will be 294. No more events will be accepted in a filled block until after its contents are transferred to the output APS data packet, the current contents are zeroed, and the current location pointer is reset to one.

At the end of each 32-s cycle period a data packet will be constructed from the foregoing stored data that is composed of three parts:

> 1) a 32-bit ID header followed by the 128-channel pulse height spectrum for the summed
>   output of all 10 sensors (contributing 33 bps to the APS data rate).
> 2) a data train consisting of:
>   a) a 16-bit ID header,
>   b) the 16-bit EM counter, and
>   c) a sequence of 294, 16-bit words. If the number of detected events given by the
>   EM counter value, N, is less than 294 then only 16 x N bits of the EM data block
>   will contain non-zero values. If N is greater than 294, then information for only
>   the first 294 detected events will be stored in the EM data block.

The data for each of the 294 events are packed into two 8-bit words labeled high and low. If the bits of these words are labeled in the following manner

$$low = [L7,\ L6,\ L5,\ L4,\ L3,\ L2,\ L1,\ L0]$$
$$high = [H7,\ H6,\ H5,\ H4,\ H3,\ H2,\ H1,\ H0]$$

then the APS EM data is packed with the following configuration:

$$Time = [L4,\ L3,\ L2,\ L1,\ L0,\ H7]$$
$$Face = [L7,\ L6,\ L5]$$
$$Pulse\ height = [H6,\ H5,\ H4,\ H3,\ H2,\ H1,\ H0]$$

The APS data rate totals:

[32 (bits/header) + 8 (bits/channel) x 128 (channels) + 16 (bits/header) + 16 (EM counter bits) + 16 (bits/event) x 294 (events)] / 32 s = [1 + 32 + 0.5 + 0.5 + 147] = 181 bps.

TABLE IV

COMMAND DEFINITIONS

Spectrometer Package:

Pulse: SES   on,off
             Sensors   off

GRS:

Pulse: On

Serial:

1)	GRS HVPS1 Level	8 bits	(High Voltage Power #1 Supply Level)
2)	GRS HVPS2 Level	8 bits	(High Voltage Power #2 Supply Level)
3)	BGOWL	8 bits	(BGO Low-end Energy Window)
4)	BGOWH	8 bits	(BGO High-end Energy Window)
5)	BC454WL	8 bits	(BC454 Low-end Energy Window)
6)	BC454WH	8 bits	(BC454 High-end Energy Window)
7)	ETL	8 bits	(Early-Time Low-end TTSP Window)
8)	ETH	8 bits	(Early-Time High-end TTSP Window)
9)	LTL	8 bits	(Late-Time Low-end TTSP Window)
10)	LTH	8 bits	(Late-Time High-end TTSP Window)
11)	Spare		
12)	Spare		

NS:

Pulse: On

Serial:

1)	NS HVPS1 Level	8 bits	(High Voltage Power #1 Supply Level)
2)	NS HVPS2 Level	8 bits	(High Voltage Power #2 Supply Level)
3)	HECDWL	8 bits	(Low-end Window for Cadmium Counter)
4)	HECDWH	8 bits	(High-end Window for Cadmium Counter)
5)	HESNWL	8 bits	(Low-end Window for Tin-covered Counter)
6)	HESNWH	8 bits	(High-end Window for Tin Counter)
7)	Spare		
8)	Spare		

APS:

Pulse: On

Serial:

1)	APSEWL	8 bits	(Low threshold for Energy Window)
2)	APSED	8 bits	(Enable-Disable Sensor Indicator, and
3)	Spare		threshold for analysis by the shaping amplifier)
4)	Spare		

TOTAL: 5 Pulse Plus 24 Serial

TABLE V

SUMMARY OF SPECTROMETER INSTRUMENT PARAMETERS

Parameter	GRS	NS	APS	SES
Mass (kg) Total	6.4	?	?	6.2
Detectors	4.4	1.1	0.1	N/A
Electronics	0.4	0.3	0.3	4.3
Structure	1.6	?	?	2.5
Dimensions (cm)	16.7ϕ x 55.4	6ϕ x 64	20 x 20 x 11	21.8x23.1x16.5
Detectors	7.6ϕ x 7.6 12ϕ x 20	(2) 5.75ϕ x 29	(10) 3 x 3 x 0.25	N/A
Electronics	(4) 7.6ϕ x 15	(2) 5 x 5 x 1	(10) 5 x 5 x 1	(10) 13.6x18.7
Power (W)/Cycle(%)	0.06/100	0.024/100	0.88/100	FEE= 3.960/100 DPU=7.576/100

Total Power Requirement (Including a Low Voltage Efficiency of 75%)   = 12.5

Heaters	3/100	0.2/(0-40)	0.5/(0-40)	0/0
DC Voltage (V)				
Internal	+5, -5, +2000	+5, -5, +2000	+5, -5, +5, -5, +12, -25	-12
S/C supplied	28	28	28	28
Temperature (°C)				
Operational	(-45 to -35)±1	- 20 to + 10	-20 to + 10	10 ± 20
Testing	-50 to + 35	- 25 to + 35	-25 to + 35	-40 to + 40
Survival	-50 to + 45	- 25 to + 45	-25 to + 45	-50 to + 50

Data Rate (bps)				
Science	690	49	181	8
Engineering	4	2	1	1

Max Bit error Rate	<10-6	<10-6	<10-6	

FOV	4π	4π	3.4π	N/A

Commands   1 pulse, 12 serial   1 pulse, 8 serial   1 pulse, 4 serial   2 pulse
(See Table IV for Definitions, uplink bitrate = 30 bps)

Modes	Off, On	Off, On	Off, On	Off, On

Duty Cycle	Continuous	Continuous	Continuous	

Pointing (o)				
Knowledge	$\pm 1^o$	$\pm 1^o$	$\pm 1^o$	N/A
Alignment	$\pm 1^o$	$\pm 1^o$	$\pm 1^o$	N/A

Rotation Rate (rpm)	12 (prefer 3)	12 (prefer 3)	12 (prefer 3)	N/A

Harness (#/ϕ mm)				
Low Voltage	3 / 0.7	3 / 0.7	5 / 0.7	N/A
HV coaxial	1 / 3.8	2 / 3.8	N/A	N/A
shield/twist/prs	2 / 3.8	1 / 3.8	5 / 3.8	N/A
Mass (g/m)	?	?	?	N/A
Heaters (# / g/m)	? / ?	? / ?	? / ?	N/A
Temp Monitors	? / ?	? / ?	? / ?	N/A
28 V Power	N/A	N/A	N/A	?
C,D&H	N/A	N/A	N/A	?

Turn On Sequence	Boom Deploy	Boom Deploy	Boom Deploy	
	Off	Off	Off	On
	On	On	On	On
	1 Day Outgas	1 Day Outgas	1 Day Outgas	
	HV ON	HV On	On	
	Adjust HV	Adjust HV	On	

Mounting   GRS: At end of #1 boom, 2.5 m in length, with GRS long axis parallel to
           S/C spin axis.
       NS and APS: In single housing at end of #2 boom. NS long axis in S/C
           spin plane, perpendicular to the radial.
       SES: On equipment shelf bottom in S/C.

Special Rqmts.   3,5,6,7,8,9,10   6,8,9   1, 2, 3, 4,6,8,9

1:      Dry nitrogen purge
2:      Red-tag covers for Alpha-particle sensors
3:      No solvents except for isopropyl alcohol
4:      Store sensors at Los Alamos when not undergoing tests at LMSC or launch site
5:      Radioactive level of S/C must be such that the photon counts are < 0.03 cm^{-2} s^{-1} above
        100 keV at the GRS position
6:      Temperature monitor accurate to $\pm 1^{o}$ K, digitized for inclusion in Engineering data.
7:      Abundances of Fe, Ti, Ca, Al, and Mg impurities in the GRS Carbon-Epoxy housing
        material.
8:      Access to test connector on sensor during S/C integration
9:      Request use of 10 µCi each of ^{241}Am, ^{137}Cs, ^{22}Na, ^{88}Y, ^{228}Th gamma-ray sources, an ~
10^{5} s^{-1} ^{252}Cf neutron source, and a ^{241}Am alpha-particle source for instrument
checkout   and verification at LMSC.
10:     PMTs cannot be exposed to He gas.

TABLE VI

SPECTROMETER ENGINEERING DATA

<u>GRS</u>:

1)	TGRS, Temperature	8 bits
2)	+ 5 V monitor	8 bits
3)	+ 12 V monitor	8 bits
4)	HVG1	8 bits
5)	HVG2	8 bits

<u>NS</u>:

1)	TNS, Temperature	8 bits
2)	HVN1	8 bits
3)	HVN2	8 bits

<u>APS</u>:

1)	TAPS, Temperature	8 bits
2)	- 25 V Bias	8 bits

<u>SES</u>:

1)	TELE, Temperature	8 bits
2)	IELE, Spectrometer Current	8 bits

Total: 12 Data Words,   Time Resolution need be no shorter than 32 s

TABLE VII

DATA-PACKET DEFINITION

GRS:

Category 1;

PHS of BGO, giving [8 (bits/channel) x 512 (channels)] / 32 (s) = 128 bps.

Category 2;

a) PHS of BGO, giving [8 (bits/channel) x 512 (channels)] / 32 (s) = 128 bps
b) PHS of BGO for BC454W=1, giving [8 (bits/channel) x 64 (channels)] / 32 (s)
= 16 bps
c) PHS of BC454 for BGOW=1, giving [8 (bits/channel) x 64 (channels)] / 32 (s)
= 16 bps
d) Number of events having BGOW=BC454W=1 accumulated during successive
0.5 s intervals, giving [8 (bits/scaler) x 1 (scaler)] / 0.5 (s) = 16 bps.

Categories 3&4;

a) two sets of PHS (corresponding to early and late times) of:
i) prompt BC454 PHS (16 channels),
ii) delayed BC454 PHS (64 channels),
iii) delayed BGO PHS (64 channels) for ET=1 and LT=1 separately,
yielding a contribution to the GRS bit rate amounting to 2 x [(16 +
64 + 64) channels] x 8 (bits/channel) / 32 = 72 bps.
b) The first 412 individual event addresses consisting of:
i) a 4-bit prompt BC454 address,
ii) a 6-bit delayed BC454 address,
iii) a 6-bit delayed BGO address, and
iv) an 8-bit time-difference address, yielding [412 x 24] / 32 = 309 bps.

These pulse-height spectra will be supplemented by the three 16-bit scalers (1.5 bps), a readout of one 10-bit scaler every 4 s (2.5 bps), and a 32-bit ID header (1 bps) yielding [128 + 128 + 16 + 16 + 16 + 72 + 309 + 1.5 + 2.5 + 1] = 690 bps.

NS:

Cadmium covered ^{3}He counter scaler: 8 (bits) / 0.5 (s) = 16 bps
Cadmium covered ^{3}He counter spectrum   8 (bits/chan.) x 32 (chan.) / 32 (s) = 8 bps

Tin covered ³He counter scaler: 8 (bits) / 0.5 (s) = 16 bps
Tin covered ³He counter spectrum   8 (bits/chan.) x 32 (chan.) / 32 (s) = 8 bps
Header ID   32 (bits) / 32 (s) = 1 bps

Total bitrate   49 bps

APS:

    1) a 32-bit ID header followed by the 128-channel pulse height spectrum for the summed output of all 10 sensors (contributing 33 bps to the APS data rate).

    2) a data train consisting of;

        a) a 16-bit ID header,
        b) the 16-bit EM counter, and
        c) a sequence of 294, 16-bit words.   If the number of detected events given by the EM counter value, N, is less than 294 then only 16 x N bits of the EM data block will contain non-zero values.   If N is greater than 294, then information for only the first 294 detected events will be stored in the EM data block.

    The APS data rate then totals:

        [32 (bits/header) + 8 (bits/channel) x 128 (channels) + 16 (bits/header) + 16 (EM counter bits) + 16 (bits/event) x 294 (events)] / 32 s = [1 + 32 + 0.5 + 0.5 + 147] = 181 bps.

Appendix I: 16-bit to 8-bit Compression and De-Compression Algorithm

To carry out the 16-bit to 8-bit compression, the following steps are used:

$I = 0$

while $(N \geq N_o[I])$ // Locate N within Table A1

    $I = I + 1$

$J = N - N_o[I] >> R[I]$ // Shift difference right by R, i.e. divide difference by 2^R

$IJ = (I << 4) + J$ // Concatinate I and J

The variables are defined as:

$N = 16$ bit values to be compressed

$IJ = 8$ bit values resulting from the compression of N

$I = $ Integer indices into table of N_o and R

$N_o = $ Base of range

$2^R = $ Interval size

$J = $ Number of 2^R intervals into the range

I	N_o	R	2^R	Worst cast % error
0	0	0	1	0.0
1	16	0	1	0.0
2	32	1	2	1.6
3	34	2	4	2.3
4	128	3	8	2.7
5	256	4	16	2.9
6	512	4	16	1.5
7	768	4	16	1.0
8	1024	5	32	1.5
9	1536	5	32	1.0
10	2048	6	64	1.5
11	3072	7	128	2.1
12	5120	8	256	2.5
13	9216	9	512	2.8
14	17408	10	1024	2.9
15	33792	11	2048	3.0

Table A1

To carry out the 8-bit to 16-bit de-compression, the number *IJ* is broken up as:

$$IJ = \begin{bmatrix} B7, & B6, & B5, & B4, & B3, & B2, & B1, & B0 \end{bmatrix}$$

where

$$I = \begin{bmatrix} B7, & B6, & B5, & B4 \end{bmatrix} \text{ and } J = \begin{bmatrix} B3, & B2, & B1, & B0 \end{bmatrix}.$$

To create the original 16-bit number use the following equation:

$$N = N_o[I] + \left(J 2^{R[I]} \right) + \frac{\left(2^{R[I]} - 1 \right)}{2}.$$