

# Lunar Reconnaissance Orbiter Project

## Cosmic Ray Telescope for the Effects of Radiation to Spacecraft Data Interface Control Document

LRO GSFC CMO

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**LUNAR RECONNAISSANCE ORBITER PROJECT****DOCUMENT CHANGE RECORD**

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## Preface

Revision 01 of this document is being circulated for comment. It contains a general proposal for the implementation of the experiment command and data interface. (It is derived from the SPIDR ICD.)

Revision 02 responds to the change in overall detector architecture from 1 thin and 5 thick detectors, to 3 thin/thick pairs of detectors. It adds both high and low rate calibration signals for testing telemetry performance, and further adds the ability to guarantee a telemetry allocation for particular sets of grade-coded events.

Revision 03 incorporated many comments. For the instrument team we

- Add the “Good Event” counter in secondary science. We will get this information in real time during flight, whereas the primary science delivery might well be delayed;
- Clarify what the System Reset command does;
- Separate the detector bias on/off commands for thick and thin detectors;
- Add commands to individually switch detector video chains on/off;
- Remove the packet priority scheme – s/c C&DH monitoring of secondary science can handle the functionality required to switch discriminator accept masks;
- Redo the Secondary Science and Housekeeping definitions to keep up with command changes;
- The analog housekeeping awaits detailed hardware design before we determine the final entries for the telemetry table.

Per Goddard request, the following changes are implemented:

- The command function codes have been moved from the Application ID to the Secondary Header;
- The 1 Hz clock drifts relative to GMT, so we add a few sub-second bits to guarantee that each science interval will be uniquely tagged;
- Maximum data packets per second command removed;
- The command sub-address range has been compressed;
- We increase the time-of-next-sync-pulse command to 64 bits (to include the sub-seconds) and change the secondary header of the telemetry packets to be consistent with spacecraft usage;
- The telemetry Application ID assignments will be made later by the spacecraft folks;
- The description of primary telemetry packet flow control has been expanded and now explicitly references the use of the 1553 RT status word.

Revision A is the first controlled release and incorporates GSFC comments to Rev. 03, especially the details of 1553 protocol now in Section 2. It removes the 1553 RT status word from the flow control (or not) and substitutes the use of null strings in the primary science data flow. We also added a section on 1553 data transactions for primary science to attempt to explain how CCSDS packets fit into the 1553 transaction packets. We also added an 8-bit quantity to adjust the amplitude of the electrical cal signal.

Revision B fills in the values of telemetry sub-addresses on the 1553 data bus and adds a synchronizing flag to mark the end of primary science packet retrieval. The bit assignment in the secondary command header has changed. The 1 Hz pulse is now backstopped by a free-running clock. We also added a more robust method to accomplish a hard reset.

Upon GSFC signature, they will become a mandatory member of the ECO Review Board for future revisions of this document.

Revision C adds two features requested by science: a per-detector event (“singles”) counter and a per-detector leakage current measurement. The electrical cal on/off command was separated into two separate lines, one each for high and low amplitude ranges. A restatement of what happens when the 1 Hz pulse is absent was made. Current estimates of the housekeeping conversion values were added. Finally, GSFC decided to generate their own document based, in content, entirely upon ours. We therefore removed the

signature page and demoted this document from 32-02001 to 32-02001.01; it will serve as our proposed input to theirs.

Note that the current housekeeping telemetry packet is 2 words larger than a single 1553 data transaction; we may well want to trim back to 32 words in a future revision.

Rev. D moved the Discriminator Amplitude Settings and Mask housekeeping quantities from the Housekeeping packet to the Secondary Science packet; this keeps the associated 1553 transfer to a single 32 word retrieval in each case. At the same time the High Level Discriminator function has been removed. A requirement was added that no command may be sent to the instrument within 0.1 second of the 1Hz reference pulse.

Rev. E changed to a single detector bias on/off command to reflect current hardware implementation. It also added a bit in the Secondary Telemetry Header indicating when the Test Mode was enabled. Generally updated housekeeping temperature algorithm to reflect flight design. Deleted Stall event counter and substituted Good event counter. The 1553 Mode Codes have been finalized. Lastly, we modified the distribution of application Ids in the CRaTER data files generated by the spacecraft C&DH.

Rev. F changed the Discriminator Mask echo from least to most significant word. The 28VDC Voltage and Current Monitor words are no longer functional in the flight instrument.

# 1 Introduction

The flight hardware for the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument on the Lunar Reconnaissance Orbiter (LRO) is composed of a single assembly incorporating both radiation detector and all associated power, command, data processing, and telemetry electronics. Other ICDs control electrical (32-02002), mechanical (32-02003), and thermal (32-02004) interfaces.

## 1.1 Scope

This document describes the data interface between the CRaTER science instrument and the spacecraft bus. The meanings of individual bits and data words are defined, their composition into data and telemetry packets, and the timing relationships among those packets. All information necessary to define both command and telemetry dictionaries are contained herein.

## 1.2 Bit Numbering Convention

The following convention is used to identify each bit in an N-bit field. The first bit in the field to be transmitted (*i.e.* the most left justified when drawing a figure) is defined to be “Bit 0”; the following bit is defined to be “Bit 1” and so on up to “Bit N-1”. When the field is used to express a numeric value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field. Unless otherwise noted, such values will be expressed in decimal notation within this document.

## 1.3 Detector Numbering Convention

The six silicon particle detectors are numbered sequentially {1 .. 6} from zenith to nadir when the instrument is on the spacecraft bus in orbit around the moon. Under the current instrument accommodation design, the instrument baseplate faces the zenith. Within the instrument the silicon detectors are mounted in pairs {1,2}, {3,4} and {5,6}; each pair consisting of a thin (150 $\mu$ m) and a thick (1000 $\mu$ m) detector. The thin detectors are located at positions {1,3,5} and the thick detectors are located at positions {2,4,6}.

## 2 1553 Bus Protocol

### 2.1 Information Transfer Formats

CRaTER shall respond to 1553 transactions on Remote Terminal (RT) address 16.

The RT shall implement the following non-broadcast message formats in accordance with 4.3.3.6 of MIL-STD-1553: BC-to-RT transfers, RT-to-BC transfers, and mode code transfers. No broadcast message formats or RT-to-RT transfer formats shall be used.

### 2.2 Mode Codes

The RT shall implement the following mode codes as described in MIL-STD-1553B.

T/R Bit	Mode Code	Function	Bus Response
1	00000	Dynamic Bus Control	No
1	00001	Synchronize	Yes
1	00010	Transmit Status Word	Yes
1	00011	Initiate Self Test	Yes
1	00100	Transmitter Shutdown	Yes
1	00101	Override Transmitter Shutdown	Yes
1	00110	Inhibit Terminal Flag Bit	Yes
1	00111	Override Inhibit Terminal Flag Bit	Yes
1	01000	Reset Remote Terminal	Yes
1	10000	Transmit Vector Word	Yes
0	10001	Synchronize	Yes
1	10010	Transmit Last Command	Yes
1	10011	Transmit BIT Word	Yes
0	10100	Selected Transmitter Shutdown	Yes
0	10101	Override Selected Transmitter Shutdown	Yes

### 2.3 Unused Subaddresses

Illegal subaddresses will not be implemented by the RT. Any attempt by the Bus Controller (BC) to read an unused subaddress will result in a valid 1553 transaction, but the data will be meaningless. Any attempt by the Bus Controller (BC) to write to an unused subaddress will result in a valid 1553 transaction, but the command will have no effect on the operation or configuration of the RT.

### 2.4 Status Word Flags

The 1553 Status Word Flags in the RT response messages shall be used in accordance with the following table:

<b>Bit</b>	<b>Status Bit</b>	<b>Requirement</b>
9	Message Error Bit	Active
10	Instrumentation Bit	Always Logic Zero
11	Service Request	Always Logic Zero
12-14	Reserved Status Bits	Always Logic Zero
15	Broadcast Command Received	Always Logic Zero
16	Busy Bit	Always Logic Zero
17	Subsystem Flag	Always Logic Zero
18	Dynamic Bus Control Acceptance	Always Logic Zero
19	Terminal Flag	Normally Logic Zero, Set to Logic One on failure of the RT's Built-in-Test (BIT).

## 2.5 Data Bus Control

Control of information transfer on the bus shall reside with the LRO Spacecraft Computer. CRaTER's 1553 bus interface shall always be configured as a Remote Terminal (RT). The BC shall not use the Dynamic Bus Control Acceptance status word bit.

## 2.6 Error Recovery

The RT shall implement the word validation requirements stated in MIL-STD-1553, paragraph 4.4 and its subparagraphs. If an invalid word transfer has occurred, the bus controller shall retransmit the entire message on the standby bus. If the word transfer is still invalid the message will be flagged as failed. The bus controller then shall transmit the next message on the primary bus.

The bus controller shall exchange the primary and standby busses only via ground command. The default bus configuration upon power-on-reset will assign Bus A as the primary and Bus B as the standby. However, all other combinations of bus configurations (B-A, A-A, or B-B) may be used during testing or fault recovery.

## 2.7 Data Word Order

For a bus transfer, the most significant bit shall be transmitted first with the less significant bits following in descending order of value in the data word. The most significant byte is followed by the least significant byte. Spare bits and words are all set to zero.

## 3 Commands

### 3.1 Packet Description

The following describes command packets which conform to the Consultative Committee for Space Data Systems (CCSDS) Recommendations for Packet Telecommands (CCSDS 201.0-B-3 and CCSDS 202.0-B-2) except as noted below. These telecommand (referred to hereafter simply as “command”) packets are generated by ground software and uplinked to the spacecraft for delivery. The spacecraft C&DH maps the Application Process ID and Secondary Header value to a particular MIL-STD-1553 Remote Terminal (RT) address and sub-address and forwards only the data content of the packet to the individual instrument.

#### 3.1.1 Primary Header Format

The format of the primary CCSDS header is as follows:

Bit Positions	Description	Usage Notes
0-2	Version Number	Static value of 0
3	Type	Value of 1 for Telecommand Packets
4	Secondary Header Flag	Value of 1 when a secondary header is present, as it is for command and telemetry packets.
5-15	Application Process ID	Value 100 (0x64) for the CRaTER instrument
16-17	Segmentation Flags	Static value of 3; no segmentation will be used
18-31	Sources Sequence Count	This counter is meant to be incremented separately for each Application ID.
32-47	Packet Length	The number of data bytes following the primary header - 1

#### 3.1.2 Secondary Header Format

The Secondary Header is used by the C&DH to route the packet data to the appropriate 1553 RT Sub-Address. Note that the primary and secondary headers are not forwarded to the instrument, only the 16 or 64 bit application data. The table below shows the bit assignments:

Bit Positions	Description	Usage Notes
48	Reserved	Fixed value = 0
49-55	Command ID	Individual command decoding shown in Section 3.4
56-63	Checksum	Set to make XOR of all command bytes = 0xFF

The spacecraft will validate the checksum of each command before forwarding the application data to the instrument. If the checksum validation fails, the spacecraft will report the error and discard the command.

### 3.2 1 Hz Reference

A time synchronization pulse will be delivered to the instruments once each second. The leading edge will be correlated to spacecraft time to within 10 ms. These pulses delimit one second data intervals in which telemetry data is accumulated. NB: the 1Hz clock is not synchronized to GMT, and will slowly drift relative to GMT. For this reason alone we monitor the sub-seconds field of the time-of-next-sync command so that we are guaranteed a unique, incrementing time tag. In the absence of the 1Hz pulse, the instrument will “free wheel” at 0.954Hz.

### **3.3 *Command Timing***

Instrument commands (with the exception of Time of Next Sync Pulse, see section 3.5) shall occur no more often than once per (1 second) data interval. On the one hand, there is no minimum time requirement between commands (including the Time of Next Sync Pulse). There is, however, a requirement that no command (including the Time of Next Sync Pulse) may occur within 0.1 seconds of the 1 Hz Reference Pulse.

The time of command execution is not currently defined. Commands may take effect either on receipt or at the next 1 Hz Reference Pulse (the later is preferred).

### **3.4 *Command Application Data Format***

There are three types of commands sent to the instrument -- spacecraft time updates, magnitude commands, and discrete bit commands -- distinguished by the least significant 5 bits of the Secondary Header. The RT Sub-Addresses are identical to the Command ID bits in the Secondary Header.

Sub-Add	No. of Data Bits	Description	Default	Reference
1	64	Time of next sync pulse Bits 0-31 = seconds Bits 32-63 = sub-seconds	(none)	3.5.1
2	16	Command Echo	(none)	3.5.2
3	16	Global Discrete Commands Bit 2 = Detector Bias Off Bit 3 = Detector Bias On Bit 4 = Electrical Cal Low Range Off Bit 5 = Electrical Cal Low Range On Bit 6 = Electrical Cal High Range Off Bit 7 = Electrical Cal High Range On Bit 8 = Electrical Cal Rate 8Hz Bit 9 = Electrical Cal Rate 2KHz Bit 11 = Data Test Mode Bit 14 = Clear all Commands Bit 15 = System Reset	Off Off Off Off 8Hz Off (none)	3.5.3
4	16	Video Processing Commands Bit 0 = Detector D1 Processing Off Bit 1 = Detector D1 Processing On Bit 2 = Detector D2 Processing Off Bit 3 = Detector D2 Processing On Bit 4 = Detector D3 Processing Off Bit 5 = Detector D3 Processing On Bit 6 = Detector D4 Processing Off Bit 7 = Detector D4 Processing On Bit 8 = Detector D5 Processing Off Bit 9 = Detector D5 Processing On Bit 10 = Detector D6 Processing Off Bit 11 = Detector D6 Processing On	On On On On On On	3.5.4
5	64	Discriminator Accept mask	All "1"s	3.5.5
6	16	Event Amplitude Discriminator, Thin Detectors {1,3,5}	128	3.5.6
7	16	Event Amplitude Discriminator, Thick Detectors {2,4,6}	128	3.5.6
8	16	Electrical Cal Amplitude	0	3.5.7
9-30	16	Reserved		

### 3.5 Command Descriptions

#### 3.5.1 Time of Next Sync Pulse

This is the value of a counter maintained by the C&DH which represents, nominally, the number of seconds which have elapsed since the Mission Epoch. The value is valid on the next received 1Hz Reference Pulse (Section 3.2). This command shall be sent during each (1 second) data interval, at least 100 milliseconds before the Reference Pulse to which its value applies, and at least 100 milliseconds following the previous Reference Pulse.

#### 3.5.2 Command Echo

This command has no effect within the instrument. The echo may be used for command/telemetry integrity tests on the ground and to tag science observations while on orbit (since the command is echoed into the data stream).

### 3.5.3 Global Discrete Commands

The discrete commands are used to control specific state changes within the instrument.

- Thin Detector Bias on/off controls the application of (fixed) bias voltage to the thin silicon detectors
- Thick Detector Bias on/off controls the application of (fixed) bias voltage to the thick silicon detectors
- Electrical Cal High/Low Range on/off gates an energy calibration clock signal injected into the event chains; separate control is provided for high and low amplitude ranges.
- Electrical Cal Rate selects between a low (8 Hz) rate and a high (2KHz) clock rate for calibration.
- The test mode is intended to verify internal data logic during instrument verification and is not intended for use at the orbiter level.
- Clearing all commands will result in all values or functions reverting to their default (also initial power up) state.
- A System Reset command resets all FPGA subsystems, except for the 1553 Bus Interface Command Receiver state machine. (System Reset has no effect on the external circuitry, *i.e.* the 1553 Bus protocol IC.)

### 3.5.4 Video Processing Commands

The discrete commands are used to gate on/off the individual video processing chains for each detector. When “off” the chains are electrically active, but the data is ignored; a noisy chain can thus be logically removed from processing and not adversely affect system dead time.

### 3.5.5 Discriminator Accept Mask

The six silicon detectors are numbered {1 .. 6} starting with the detector closest to the zenith window. Treating the output of the low level threshold detectors as a 6 bit number, there are 63 possible states by which a single event may be categorized. We set the corresponding bit in a lookup table to a one for each threshold state we wish to accept. For example:

- mask := 0x0000 0001 0001 0116 selects events which trigger one and only one detector threshold.
- mask := 0xFFFF FFFF FFFF FFFE accepts all events;
- mask := 0x0000 0000 0000 0000 rejects all events.

### 3.5.6 Event Amplitude Discriminators

Amplitude discrimination is applied to the energy content of the events detected by an individual detector. The Least Significant 8 bits of the command are a Low Level Discriminator (LLD), defining a limit below which events are considered invalid. The settings are applied separately to Detectors {1,3,5} and Detectors {2,4,6}. The Least Significant 8 bits are treated as an unsigned value; the Most Significant 8 bits are ignored.

The LLD is implemented as a hardware comparator that, if triggered by any one detector event, will cause all enabled detector chains to perform an A/D conversion.

### 3.5.7 Electrical Cal Amplitude

The electrical cal amplitude governs the magnitude of the energy calibration signal injected into the event chains; only the Least Significant 8 bits are used, interpreted as an unsigned value starting nominally at zero amplitude.

## 4 Telemetry

The following describes telemetry packets which conform to the Consultative Committee for Space Data Systems (CCSDS) Recommendations for Packet Telemetry (CCSDS 102.0-B-4) except as noted below.

### 4.1 MIL-STD-1553 Packet Description

The MIL-STD-1553 telemetry packets are of three separate types: a primary science packet, a secondary science packet, and a general housekeeping packet.

#### 4.1.1 Primary Header Format

The Primary Header format for telemetry packets is identical to that described for use in telecommands (see section 3.1.1 ).

#### 4.1.2 Application ID Assignments

The Application ID assignments for telemetry as follows:

Bit Positions	Description	Application Process ID	RT Sub-Address	Usage Notes
5-15	Data ID	120 (0x78)	10	Value = 10 for primary science block 0
			11	Value = 11 for primary science block 1
			12	Value = 12 for primary science block 2
			13	Value = 13 for primary science block 3
			14	Value = 14 for primary science block 4
			15	Value = 15 for primary science block 5
			16	Value = 16 for primary science block 6
		n/a	17	Value = 17 for primary science block end flag
		121 (0x79)	20	Value = 20 for secondary science
		122 (0x7A)	21	Value = 21 for housekeeping

#### 4.1.3 Secondary Header Format

The secondary header contains the spacecraft time valid at the leading edge of the 1 Hz pulse preceding this telemetry request (note that bit 48 must be 0 to be CCSDS compliant): Although bits 80-95 would normally contain a 16-bit sub-seconds value, we truncate that information and jam an Instrument Serial Number into this field. (This bit allocation is required to be consistent with the spacecraft utilization of the secondary header.)

If the spacecraft time is not received prior to the 1 Hz pulse, the time is zero filled. If the 1 Hz pulse fails to occur within 1.05 seconds of the previous pulse, the “1Hz not received” bit will be set.

Bit Position	Data Description
48	Reserved; value = 0
49-79	Spacecraft time in seconds
80-83	Spacecraft time in sub-seconds
84-88	Reserved; value = 0
89	Test Mode enabled = 1
90	1Hz not received = 1
91-95	Instrument Serial Number

#### 4.1.4 Telemetry Flow Control

Primary science events are collected in a buffer up to a maximum of 1200 events in a single one second interval; data collection will then stall until the next 1 second sync pulse arrives.

At the 1 second sync the data buffer containing the previous second's data will be packaged into CCSDS packets, each event being represented in a 9 byte format, up to a maximum of 48 events per packet. The resulting 444 byte packets (6 bytes of primary header, 6 bytes of secondary header, and 432 bytes of data) are then queued for collection by the spacecraft C&DH system.

The last packet in the queue will, in general, not be the full 444 bytes in length. (In fact, it is valid to have a single zero data length packet in the queue – when, for example, the detector bias is off.) The length field in the primary header will indicate the extent of valid data.

If the 1Hz pulse does not arrive and the system starts to “free wheel” (see para 3.2), bit 90 of the secondary header is set.

#### 4.1.5 1553 Primary Science Data Retrieval

The 1553 interface can retrieve a maximum of 32 16-bit words per transaction. From the primary science sub-addresses it will always retrieve groups of 448 bytes -- 7 data transactions of 32 16-bit words taken sequentially from sub-addresses 10 -> 16 – followed immediately by a request for a single data word on sub-address 17. This last request signals the end of the current packet retrieval and enables the instrument to load the next CCSDS data packet into the output queue; the contents of the single word retrieved is undefined and will be discarded by the spacecraft data system. The first retrieval after the 1 second sync pulse will always receive a valid CCSDS-formatted packet, padded with null bytes to fill out the full 448 byte transaction. Subsequent retrievals will return a full 448 null byte string if a completely filled CCSDS science packet is not available.

#### 4.1.6 Telemetry Timing

Primary science telemetry packets queries would optimally occur every 40 ms, resulting in a maximum primary science throughput of 1200 events, or 86400 data bits per second. There are no hardware restrictions on when or how often such 1553 bus queries occur, however.

Secondary science and housekeeping telemetry packets must be retrieved from the 1553 Remote Terminal in the interval between 100 and 900 milliseconds following a 1 Hz Reference Pulse.

Secondary science packets shall be read during every 1 second data interval during which primary science data is being collected.

Housekeeping packets shall be read every 16 seconds while 28VDC power is supplied to the instrument.

## 4.1.7 Telemetry Application Data Format

### 4.1.7.1 Primary Science

The event data for a single event in the primary science packet consists of a 9 byte block:

Relative Bit Position	Data Description
0-11	Event Amplitude, Detector 1
12-23	Event Amplitude, Detector 2
24-35	Event Amplitude, Detector 3
36-47	Event Amplitude, Detector 4
48-59	Event Amplitude, Detector 5
60-71	Event Amplitude, Detector 6

### 4.1.7.2 Secondary Science

The application data contents of the secondary science packet are as follows (note that words 0-5 contain the primary and secondary packet header). A word in this context is a 16-bit unsigned value unless specified otherwise.

Word in Packet	Relative Bit Position	Data Description	Reference
6	0	Detector Bias Delayed Control On = 1	4.2.6
	1	Detector Bias On = 1	
	2	Electrical Cal Low Range On = 1	
	3	Electrical Cal High Range On = 1	
	4	Electrical Cal Rate High = 1	
	5	Detector D1 Processing Enabled = 1	
	6	Detector D2 Processing Enabled = 1	
	7	Detector D3 Processing Enabled = 1	
	8	Detector D4 Processing Enabled = 1	
	9	Detector D5 Processing Enabled = 1	
	10	Detector D6 Processing Enabled = 1	
	11-15	RT SubAddr of Last Command	
7		Contents of Last Command	4.2.5
8		Event Amplitude Discriminator Setting: D1,3,5	4.2.7
9		Event Amplitude Discriminator Setting: D2,4,6	
10-13		Discriminator Accept Mask	4.2.2
14		Detector D1 Singles Counter	
15		Detector D2 Singles Counter	
16		Detector D3 Singles Counter	
17		Detector D4 Singles Counter	
18		Detector D5 Singles Counter	
19		Detector D6 Singles Counter	
20		Good Event Counter	
21		Rejected Event Counter	4.2.3
22		Total Event Counter	4.2.4

The data in this packet were latched by the immediately preceding 1 Hz Reference Pulse.

### 4.1.7.3 Housekeeping

The application data contents of the housekeeping packet are as follows (note that words 0-5 contain the primary and secondary packet header). Each word described here is a 16-bit quantity whose least significant 12 bits are treated as an unsigned integer. The most significant 4 bits are undefined and should be masked out by ground software applications.

Word in packet	Data Description	Reference
6	(reserved)	
7	+5VDC Digital Monitor	4.2.8
8	+5VDC Analog Monitor	4.2.9
9	-5VDC Analog Monitor	4.2.10
10	(reserved)	
11	Detector D1 Bias Current Monitor	4.2.11
12	Detector D2 Bias Current Monitor	
13	Detector D3 Bias Current Monitor	
14	Detector D4 Bias Current Monitor	
15	Detector D5 Bias Current Monitor	
16	Detector D6 Bias Current Monitor	
17	Thin Detector Bias Voltage Monitor	4.2.12
18	Thick Detector Bias Voltage Monitor	
19	Electrical Cal Amplitude Monitor	4.2.13
20	Thin Detector LLD Voltage Monitor	4.2.14
21	Thick Detector LLD Voltage Monitor	
22	Telescope Temperature	4.2.15
23	Analog Board Temperature	
24	Digital Board Temperature	
25	Power Supply Temperature	
26	Bulkhead Reference Temperature	
27	Radiation Monitor High Sensitivity	4.2.16
28	Radiation Monitor Med. Sensitivity	
29	Radiation Monitor Low Sensitivity	
30	PRT Reference – Ground Test Only	4.2.17
31	Purge Flow Rate – Ground Test Only	4.2.18

The data in this packet are accumulated once per second and available to telemetry in the following interval. To save telemetry bandwidth, the spacecraft will read these data at a slower rate - as specified in section 4.1.6.

## 4.2 Telemetry Description

### 4.2.1 Good Event Counter

This counter records all detected events which meet the Low Level Discriminator and Coincidence Mask criteria. Even if the output telemetry stream saturates, this counter will continue to increment properly. Upon receipt of the 1 Hz Reference Pulse the counter is read out into Secondary Science and reset to zero.

### 4.2.2 Singles Event Counter

For each detector this counter keeps track of every incident event which triggers a fixed hardware threshold in the analog signal chain. Upon receipt of the 1 Hz Reference Pulse the counter is read out into Secondary Science and reset to zero.

### 4.2.3 Rejected Event Counter

This counter keeps track of every incident event *not* put into the data stream as a valid event because it has failed the discriminator mask criteria. Upon receipt of the 1 Hz Reference Pulse the counter is read out into Secondary Science and reset to zero.

### 4.2.4 Total Event Counter

This counter keeps track of every incident event processed by the enabled chains. It is redundant in that it is simply reporting the sum of Valid and Rejected Events, but is provided as a convenience to other spacecraft modules wishing to monitor total radiation levels on board.

The Valid, Rejected, and Total Events counters are implemented as 16 bit counters; the counters will stall at full scale and not roll over. Because all event processing – whether valid or invalid – takes the same length of time (12  $\mu$ s), the Total Event counter provides an accurate dead-time correction for each 1 second data interval.

### 4.2.5 Contents of Last Command

In this context “Last Command” means the command received during that preceding data interval; if no command was received during that interval, these bits have a value of zero. If the last command received was a “Discriminator Accept Mask”, which has 64 bits of data content, only the most 16 significant bits are echoed.

### 4.2.6 Discrete State Indicators

There are ten one bit state indicators:

- Electrical Calibration High/Low Range On/Off – indicates whether the calibration clock circuitry is currently enabled.
- Electrical Calibration Rate High/Low – indicates whether the calibration signal is injected at 2KHz or 8Hz.
- Thin/Thick Detector Bias On/Off Command – indicates the state of the last detector bias command.
- Detector Processing Enable Command – indicates the state of the detector processing matrix.

### 4.2.7 Command Settings

The telemetry words for

- Event Amplitude Discriminator Levels, Detector 1,3,5
- Event Amplitude Discriminator Levels, Detector 2,4,6
- Discriminator Mask

are readouts of the respective registers. The values should be identical to the last command that set these registers.

### 4.2.8 Digital +5VDC Monitor

A value indicating the voltage of the instrument regulated digital +5VDC. The nominal engineering value in volts is

$$V = K * \text{count}, \text{ where } K \text{ is } 2.00 \times 10^{-3}.$$

### 4.2.9 Analog +5VDC Monitor

A value indicating the voltage of the instrument regulated analog +5VDC. The nominal engineering value in volts is

$$V = K * \text{count}, \text{ where } K \text{ is } 2.00 \times 10^{-3}.$$

#### 4.2.10 Analog -5VDC Monitor

A value indicating the voltage of the instrument regulated analog -5VDC. The nominal engineering value in volts is

$$V = K * \text{count}, \text{ where } K \text{ is } -2.01 \times 10^{-3}.$$

#### 4.2.11 Detector Bias Current Monitor

A value indicating the DC current flowing through the reversed biased detector. The nominal engineering value in microamperes is

$$\text{Thin: } I = K * \text{count}, \text{ where } K \text{ is } 0.50 \times 10^{-3}.$$

$$\text{Thick: } I = K * \text{count}, \text{ where } K \text{ is } 5.0 \times 10^{-3}.$$

#### 4.2.12 Detector Bias Voltage Monitor

A value indicating the voltage of the instrument high voltage. The nominal engineering value in volts is

$$V = K * \text{count}, \text{ where } K \text{ is } 0.101$$

#### 4.2.13 Electrical Cal Voltage Monitor

A value indicating the magnitude of the electrical cal voltage. The nominal engineering value in volts is

$$V = K * \text{count}, \text{ where } K \text{ is } 1.00 \times 10^{-3}.$$

#### 4.2.14 LLD Voltage Monitor

A value indicating the voltage being applied to the Low Level Discriminators. The nominal engineering value in volts is

$$V = K * \text{count} - L, \text{ where } K \text{ is } 0.124 \times 10^{-3} \text{ and } L \text{ is } 0.124$$

The nominal engineering value on energy deposit in KeV is

$$\text{Thin: } D = K * (\text{count} - 1024), \text{ where } K \text{ is } 41.3$$

$$\text{Thick: } D = K * (\text{count} - 1024), \text{ where } K \text{ is } 4.13$$

#### 4.2.15 Temperatures

A value indicating the temperature of a particular location is given by

$$T \text{ (in Kelvin)} = 100 * VAP - K * \text{count} - L$$

where VAP is the corrected, engineering value of the analog +5VDC

and K is 0.100 and L is 273.2

Instrument temperature is measured by biasing an AD590 temperature transducer with a 10.0K resistor to the analog +5VDC. This yields a nominal scale factor of 10.0 mv/C.

#### 4.2.16 Radiation Monitor

The total dose radiation monitor, which resets to zero on power up, has three outputs, each of which is an analog voltage derived from an 8-bit counter; the sum of these equals the total dose.

The nominal value in rads for each output is given by

$$\text{High Resolution: } R = K * \text{count}, \text{ where } K \text{ is } 2.500 \times 10^{-6}$$

$$\text{Medium Resolution: } R = K * \text{count}, \text{ where } K \text{ is } 6.400 \times 10^{-4}$$

$$\text{Low Resolution: } R = K * \text{count}, \text{ where } K \text{ is } 1.638 \times 10^{-1}$$

#### 4.2.17 PRT Reference Temperature

A value indicating the temperature of the spacecraft-provided PRT mounted within the instrument. This measurement is only valid during ground test when a special test connector is used. The temperature is given by

$$T \text{ (in C)} = 0.1299 * (4 * \text{count} - 10^4) / (5 - 10^{-3} * \text{count})$$

This equation is valid for a 2K PRT with a temperature coefficient of 0.00385 ohm/ohm/C. The scale factor is approximately 0.21C/LSB

#### 4.2.18 Purge Flow Rate

A value indicating the flow rate of the (ground system) Nitrogen purge. This function is implemented as a 2.25K differential thermistor bridge and calibrated to numbers of 20% accuracy after initial assembly. The nominal gas flow rate in cubic feet per hour is given by

$$S \text{ (in CFH)} = \text{count} + 3.058 * \text{CAP} - 1.900 * \text{CTREF} - 293.2$$

where CAP is the number of counts measured for the analog +5VDC and CTREF is the number of counts measured for the bulkhead (ref) temperature

### 4.3 Data File Formats

The LRO spacecraft will store CRaTER data in files on the spacecraft data recorder in a subdirectory called “SSR2/CRAT/”. There will be two files open at the same time, one for science data and one for housekeeping data. Prior to starting CRaTER data acquisition, the spacecraft will open the data files and write a 64 byte LRO standard file header data. The format of the header is described in the C&DH Flight Software User’s Guide (582-2006-0009). As new data packets are received, the Spacecraft will write them to the files in the formats described below (sections 4.3.1 and 4.3.2). When the science file reaches a pre-defined maximum size, the spacecraft will close both files, open new files, and write another file header. New files can also be started by ground command.

#### 4.3.1 Science Data Format

The science file will contain only primary science data. The data will be stored in the form of CCSDS packets, exactly as received from the instrument. For primary science packets the spacecraft will truncate the data to the length indicated in the packet primary header. There will be no sync markers or fill data inserted in between the CCSDS packets.

#### 4.3.2 Housekeeping Data Format

The housekeeping file will contain both CRaTER housekeeping and secondary science data. Both sets of data will be stored in the form of CCSDS packets, interleaved exactly as received from the instrument. There will be no sync markers or fill data inserted in between the CCSDS packets.