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Lunar Reconnaissance Orbiter Project

CRaTER Instrument Team
Data Management and Archive Plan

32–01210

Revision A

10/25/2006

List of TBDs

Item	Location	Summary	Ind./Org.	Due Date
1	§1.3	CRaTER Instrument Calibration Plan to be written	10/27/06	
2	§1.3	Data Product & Archive Volume SIS to be written	10/27/06	
3	§1.3	CRaTER Educ. & Public Outreach Plan to be written	10/27/06	
4	§1.3	CRaTER SOC Test Plan to be written	10/27/06	
5	§3.2	Schedule for SOC Test Plan delivery	10/27/06	
6	§3.2	Post-launch SOC schedule	10/27/06	
7	§5	Description of calibration data & algorithms	10/27/06	
8	App. A	Naming convenstion for Level 1–4 test & calibration files	10/27/06	

Contents

1 Introduction

1.1 Purpose

This plan describes the plans for data management by the LRO CRaTER Instrument Team throughout all project phases, and the transfer of CRaTER data products, calibration tables, and documentation to the PDS for archival. It is both a data management plan and a data archive plan.

1.2 Scope

This document defines the roles and responsibilities of the CRaTER team in creating and distributing CRaTER data products, as specified in §1.3 of Applicable Document 10 (see §1.3, below, for a list of applicable documents). It also describes the Science Operations Center (SOC) data processing facility, where these activities are to be conducted. It details the management concepts to be used, the processing plans, data validation techniques, data release schedule, and SOC-related plans for education and public outreach.

It also describes the assumed roles and responsibilities of the PDS, and identifies the products (data and documentation) that are to be submitted to PDS in conformance with Applicable Document 8 and Applicable Document 13, and estimates their size and frequency of delivery, but the authoritative bit-level description of these products will be contained in Applicable Document 12.

Finally, it identifies the data and procedures that are to be used to create calibrated data products, and the documentation (Applicable Document 11) that describes the process. Both will be delivered to the PDS.

1.3 Applicable Documents

The following documents are applicable to the development and execution of this plan.

	Document Number	Document Title and Publication Date
1	431—OPS—000042	LRO Mission Concept of Operations, baseline, 08/12/2005
2	431—RQMT—000048	Detailed Mission Requirements LRO Ground System, Rev. B, 09/19/2006
3	431—ICD—000104	Spacecraft to CRaTER Data ICD, Rev. A, 08/11/2006
4	431—ICD—000049	External Systems ICD for the LRO Ground System, v1.0, 07/17/2006
5	582-2006-0009	C&DH Flight Software User's Guide, TBD
6	JPL D-7669	PDS Standards Reference, v.3.6, Part 2, 08/01/2003
7	JPL D-7116	PDS Data Dictionary Document, Rev. E, 08/28/2002
8	JPL D-26359	PDS Proposer's Archiving Guide, v.1.0, 06/15/2003
9	JPL D-31224	PDS Archive Preparation Guide, v.1.1, 08/29/2006
10	32—01209	CRaTER SOC Requirements Document, Rev. A, 10/25/2006
11	32—01207	CRaTER Instrument Calibration Plan, TBD
12	32—01211	CRaTER Data Product and Archive Volume SIS, TBD
13	32—01280	CRaTER Science Team and PDS–PPI Node ICD, Rev. A, 10/27/2006
14	32—01213	CRaTER Science Operations Center Test Plan, TBD
15	32-01208	CRaTER IT Security Plan, Rev. 01, 09/19/2005
16	TBD	CRaTER Educational and Public Outreach Plan, TBD

2 Roles and Responsibilities

This section describes the roles and responsibilities for the personnel and organizations involved in the generation, validation, archival, and distribution of CRaTER data.

2.1 LRO Project Responsibilities

The LRO Project has overall responsibility for the acquisition, integration, launch, and operations of the LRO Observatory. The LRO Project is also responsible for distribution of Level 0 data and pertinent orbit data to the CRaTER Science Operations Center, as specified in Applicable Document 4.

The LRO Data Working Group (LDWG), led by the Project Science Data Manager, will coordinate the planning of LRO data product generation, data validation, and provision of Planetary Data System (PDS)-compliant data to the PDS, as specified in Applicable Document 4. The SOC Manager represents the CRaTER Science Team on the LDWG. The LDWG will provide coordination to ensure that LRO data archives are assembled, validated, and delivered according to schedule.

2.2 CRaTER Instrument Team Responsibilities

The CRaTER Principal Investigator and his Instrument Team are tasked with implementing the data management functions described in detail in Applicable Document 10 and in §3, below.

- Writing and/or implementing Interface Control Documents describing data flow between
  - CRaTER and LRO spacecraft (Applicable Document 3),
  - MOC and SOC (Applicable Document 4), and
  - SOC and PDS (Applicable Document 13).
- Algorithm development and peer review (see Applicable Document 11).
- Code development and review; unit and integration testing (see §3.3).
- Data storage, internal transmission, and backup (see §3.5).
- Processing and reprocessing of standard products (see Appendix A).
- Reporting data processing activity to the MOC (see Applicable Document 4).
- Data release process and timing (see §4.2 and Applicable Document 13).
- Description of archival data products (Applicable Document 12).
- Support of uplink instrument commanding (see §3.4 and Applicable Document 4).
- Support of long-term archival by the PDS (Applicable Document 13).
- Support of SOC-related educational outreach activities (see §4.6).
- Investigation of instrument anomalies (see §3.6).

2.3 Planetary Data System Responsibilities

The PDS will be the long-term archive for all CRaTER products. The CRaTER SOC manager will work with the LDWG to ensure that CRaTER contributions to the LRO archives are compatible with PDS standards and formats. The PDS Geosciences Node will provide overall coordination of PDS activities for LRO, but CRaTER datasets will be reviewed and archived by the PPI Discipline Node as specified in Applicable Document 13.

Once CRaTER data products have been accepted by the PDS, the PDS is responsible for their maintenance and distribution to the planetary science community.

3 SOC Data Management

3.1 CRaTER Team Data Management Functions

The organization of the CRaTER SOC and measurement data product software development team is shown in Fig. 1. Also shown are the major software components for which each group has lead responsibility.

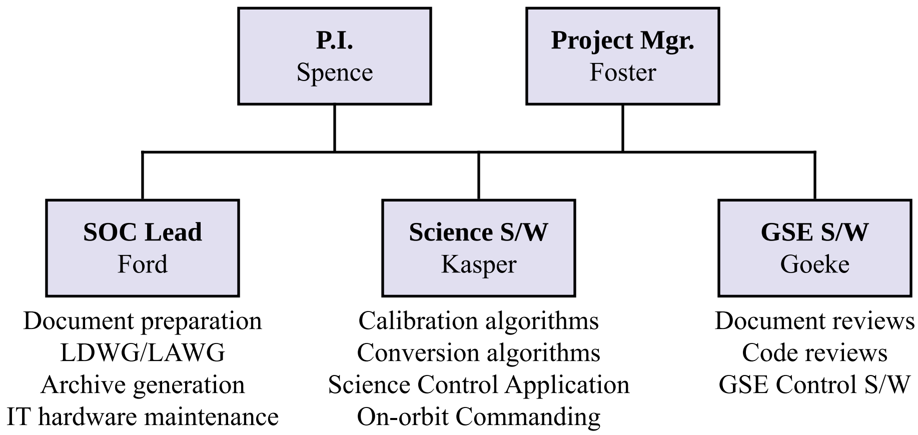


Figure 1. CRaTER SOC and Data Team Organization and Responsibilities

The principal members of the CRaTER SOC team and their responsibilities are listed below

- **CRaTER SOC Lead** (Peter Ford)
  Responsible for the development, maintenance and day-to-day operation of the SOC, both hardware & software, data processing & local archival, delivery to PDS & documentation.
- **CRaTER Project Scientist** (Justin Kasper)
  Responsible for the development of the algorithms used to convert Level 0 fields to Level 1 (detector calibration), Level 1 to Level 2 (Lineal Energy Transfer modeling), Level 2 to Level 3 (LET spectrum extraction), and Level 3 to Level 4 (equivalent LET in tissue). Also responsible for developing the Science Control Application (see Appendix H.)
- **CRaTER Project Engineer** (Robert Goeke)
  Responsible for managing SOC document and code reviews, and for many items of GSE control software and hardware (see Appendix G.)
- **CRaTER Science Team**
  Team members will provide regular input into SOC functionality and data production, and will be available as necessary to monitor the quality of data products.

See Appendix F on page 23 for further details.

3.2 SOC Development Schedule

The schedule for developing the SOC, and testing its interfaces with the LRO ground system and PDS, is shown in Table 1. SOC activities post-launch are TBD.

Table 1: CRaTER SOC Development Schedule

Action[a]	2006												2007												2008											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Mission PDR, CDR		P									C																									
SOC Requirements Doc.[b]					1			c		2																										
SOC-to-PDS ICD [b]							1					2																								
Data Mgmt & Archive Plan [b]								1				2																								
GS Single Design Review													X																							
SOC Test Plan																																				
SOC Code Development													•	•	•	•	•	•	•	•	•	•	•	•	•	•										
IT Security Plan [b,d]														1		2																				
Catalog Delivery to PDS [b]															1		2																			
SOC Code Testing																•	•	•	•	•	•	•	•	•	•	•										
Instrument Delivery																						X														
SOC-MOC Testing																							•	•	•	•	•	•	•	•						
CRaTER Products SIS [b]																							1			2										
SIS Review																								•	•	•										
SOC Acceptance Testing																											•	•	•							
LRO Launch																																		X		

a. SOC refers to the CRaTER Science Operations Center.
b. “1” refers to the preliminary release, and “2” to the final release
c. Red shading indicates a schedule slip
d. Revision 01 was submitted in 2005 (see Applicable Document 15)

3.3 SOC Configuration Management

SOC software will be controlled by a system that is capable of running on all SOC platforms through existing network gateways, *e.g.*, CVS or Subversion. The central repository will be located at *crater.bu.edu* and provision will be made for the remote submission and checkout of all components.

The SOC manager will designate certain SOC computers as “controlled”, meaning that any change to their hardware or system software must be approved and tested before these computers are permitted to resume SOC activities.

The software repository and all controlled system software will be backed up daily, along with processing logs, calibration data, etc., as determined by the SOC manager.

3.4 CRaTER Commanding

The SOC will develop the commands that are to be uplinked to LRO and sent to the instrument. The commands will be grouped into a series of CRaTER Activities Requests, as described in Applicable Document 4, and transmitted to the MOC. In addition, any desired CRaTER *power resets* will be grouped into a Power Reset Timeline file which will be sent to the MOC in the same manner.

3.5 SOC Data Processing Facility

The CRaTER SOC will provide the computing environment for production of the CRaTER Data Products. This includes the computation resources necessary to produce the products, and the necessary data storage. The SOC will employ Linux workstations with sufficient processing power and RAID storage capacity to process and archive at least one year's worth of CRaTER data products within the facility.

The central SOC computer will be physically located at the P. I. institution and will be accessible through the internet at domain address *crater.bu.edu*. Additional hardware will be maintained in a "hot backup" state so that daily SOC functions can be maintained in case of hardware failures.

3.6 SOC Operations Concept

Post-launch SOC operations will be designed for automatic operation, involving minimal interaction with the SOC team. The standard processing chain will create PDS-ready files from the moment that raw data are received from the MOC—standard data product labels will be generated as soon as the product files have been created—and the daily processing logs will be created automatically unless anomalies are suspected, in which case a SOC "duty scientist" will be alerted, a report will be created, and the anomaly will be tracked.

3.7 Data Security

All issues relating to IT security are addressed in Applicable Document 15, where the designated "CRaTER Data Management Lead" and the SOC Lead identified in §3.1 above are one and the same person.

3.8 SOC Hardware

The following hardware will be under SOC management:

- Primary and backup processing computers
- RAID storage system with offline backup
- CRaTER engineering unit with supporting GSE
- HTTP server with web interface
- Designated science and engineering workstations

3.9 SOC Software

The following software components will be under SOC management, and will be subject to code review, integration review, and independent validation and verification by SOC team members:

- System software for all controlled SOC computers (*i.e.*, those described in §3.8.)
- All software involved in the creation of archive products (see Appendix I)
- GSE control and data capture software (see Appendix F)
- The Science Control Application (see Appendix H)

3.10 Processing Logs and Quick-Look Displays

The SOC will log all phases of standard data processing, and will generate graphical displays of science data and housekeeping channels for every orbit file. The logs and displays will be available electronically (as web pages) and in hardcopy, and daily extracts will be sent to the MOC as described in Applicable Document 4.

3.11 Engineering Model

The performance of the CRaTER engineering model, or the Flight Spare, should be similar to that of the flight instrument. Using GSE control software (Appendix F) and the Science Control Application (Appendix H), the SOC can begin end-to-end testing of its post-launch environment before the flight instrument is delivered.

3.12 Anomaly Investigation

Once a software or GSE hardware anomaly is suspected, a "CRaTER Anomaly Report" is created and entered into an on-line database. A sample template is shown in Appendix E on page 22. Anomalies will be included in the daily reports to the LRO Project, and their status will be tracked at weekly SOP management meetings.

4 Data Processing Plan

4.1 Availability of Data for Processing

The LRO Mission Operations Center (MOC) will provide the SOC with a series of data products, as described in Applicable Document 4 and listed in Table 2. In addition, the MOC will supply SPICE kernel files describing the spacecraft (FK frame kernel), and the Earth-Moon system (PCK planetary constants).

Table 2: MOC data products to be delivered to the CRaTER SOC

Product Name	Description	Section
Beta angle (predicted)	Angle between Sun and LRO orbit plane	4.1.2.2
SPICE SCLK	Spacecraft-clock-to-UTC or -TT conversion	4.5.1.2
Spacecraft Housekeeping	Spacecraft engineering, selected by CRaTER[a]	4.5.1.5.3
CRaTER Housekeeping	CRaTER recorded housekeeping (see §A.1)	4.5.1.5.4
CRaTER Raw Measurements	CRaTER primary & secondary science data	4.5.1.5.5
CRaTER VC0 Housekeeping	CRaTER near real-time housekeeping	4.5.1.5.6
Daily Command Load	All commands uplinked to LRO	4.5.1.1
SPICE SPK (definitive)	*Post facto* ephemeris and pointing kernels	4.1.2.4
SPICE SPK (predicted)	Predicted ephemeris and pointing kernels	4.1.2.5
Orbit Ascending/Descending Nodes	Lunar equator plane crossings	4.1.2.6
Lunar Terminator Crossing Predictgs	Lunar terminator crossings	4.1.2.7
Eclipse Predicts	Solar eclipse crossings	4.1.2.8
Lunar Ground Track (predicted)	Nadir track in crust-fixed coordinates	4.1.2.15
Lunar Ground Track (definitive)	*Post facto* nadir track in crust-fixed coordinates	4.1.2.16

a. Including spacecraft attitude data

4.2 Data Release Schedule

The release schedule for CRaTER data products is shown in Table 3. Details of which products are to be delivered, their estimated sizes, and the roles and responsibilities of SOC and PDS personnel are detailed in Applicable Document 13.

Table 3: Data Product Release Frequency

Processing Level[a]	Product Name	Release Frequency	Elapsed Time since Observation
Level 0	raw science	Every 3 months	3–6 months
	raw housekeeping	Every 3 months	3–6 months
Level 1	primary science	Every 3 months	3–6 months
	secondary science	Every 3 months	3–6 months
	housekeeping	Every 3 months	3–6 months
Level 2	primary science	Every 3 months	3–6 months
	secondary science	Every 3 months	3–6 months
	housekeeping	Every 3 months	3–6 months
Level 3	LET science	Once per year	3–15 months
Level 4	LET science	Once per year	3–15 months

a. See Table 4 on page 11 and Applicable Document 8 for the definitions of NASA processing levels.

4.3 Reprocessing Plan

Since it is unlikely that our knowledge of CRaTER detector calibration will change after launch, no systematic reprocessing of the Level 0–2 data products is anticipated. Although individual orbit files may be reprocessed, this is only expected to occur in response to a re-delivery from the MOC or an anomaly during Level 0 SOC processing which will be corrected long before delivery to PDS. Level 3 and 4 products may be reprocessed one or more times.

4.4 Data Validation Plan

CRaTER measurements are such that an examination of the event rates for individial detectors and quick-look spectra (see §3.10) will provide immediate knowledge of the health of the instrument and the validity of the data. Background GCR spectra—using data from GOES, ACE, etc., to exclude periods of HIGH solar activity (*i.e.*, solar energetic protons)—will not change significantly over a period of weeks and months, so that any anomalous data will be noticed immediately.

The SOC manager will be responsible for ensuring that the logs from all daily processing through Level 2 have been examined and reported to the MOC, as described in Applicable Document 4.

4.5 Long term trending

To aid long-term trending of the instrument performance, the SOC will produce plots of science fields and housekeeping parameters *vs.* time, both as hardcopy and as web pages, updated daily.

4.6 Education and Public Outreach Data Distribution

The role of the SOC in support of Education and Public Outreach will be stipulated in Applicable Document 16.

5 Archive Plan

The Planetary Data System (PDS) PPI Node will be responsible for maintaining a permanent archival of the CRaTER instrument telemetry, derived data products, and selected pre-launch calibration data as described in Appendix A and in Applicable Document 11. The PDS will also distribute CRaTER data to the user community, will advertise its availability, and will provide user access and support.

5.1 Archive Generation

An Interface Control Document (ICD, Applicable Document 13) between the CRaTER SOC and the PDS PPI Discipline Node has been jointly developed by the SOC staff and PDS Discipline staff. This ICD includes:

- A description of the management interface between the two entities
- The roles and responsibilities of the CRaTER SOC and of the PDS
- Policies and procedures that govern the flow of data from the SOC to PDS
- A description of the data to be transferred across the interface, the frequency of delivery, and the volume of data at each transfer [1]

Following the procedures described in the ICD, the SOC will work with the PPI Node to create catalog files that describe the CRaTER instrument, and will write software that generates PDS labels and index files in the course of standard data processing.

5.2 Validation and Peer Review

The SOC Lead will be responsible for validating the contents of CRaTER data archives:

- verifying that the correct input files and processing software were employed
- verifying that samples of the archive conform to the SIS documents
- responding to possible anomalies reported by science team members
- reporting known problems in `ERROR.TXT` files within the delivered archives

The LDWG will provide oversight and coordination of the validation process. In addition, the PDS will subject the SIS (Applicable Document 12) and the deliverables to one or more peer reviews in order to verify that they meet PDS standards of completeness and scientific utility. The peer review may produce liens that are to be be resolved before PDS can accept the data, using the procedure described in Applicable Document 13.

The peer reviewers will have an opportunity to view the revised products and supporting materials to ensure that the liens have been resolved. Data Product SIS documents may need to be updated as necessary to describe the revised products.

1. While the ICD will describe the types of data and an estimate of their total size, the authoritative description of the data sets themselves will be contained in Applicable Document 12.

With each data product delivery, the PPI node will perform a set of validation procedures to ensure that products conform to the SIS.

5.3 CRaTER Data Transfer

The transfer of data to the PDS PPI Discipline Node will be accomplished as described in Applicable Document 13.

The standard processing procedures will be designed so as to create PDS-ready deliverables directly from the data received from the MOC. PDS labels will be created while the data are processed from Level 0 to Level 1 to Level 2. This minimizes the task of assembling the archive for delivery to PDS.

Data will be transfered to the PPI node via internet, *e.g.*, FTP. The directory structure is described in Applicable Document 12.

5.4 CRaTER Data Distribution

Once released by the PDS, LRO CRaTER data will be available to the public via the usual PDS interfaces, using standard search and retrieval tools.

Appendix A CRaTER Data Products

This section identifies the Level 0–3 CRaTER data products that are to be delivered to the PDS. The calibration products are described in Applicable Document 11. The detailed descriptions in this section of file contents and sizes are *provisional*, and included at the request of the PDS. The definitive bit-level description of these products is contained in Applicable Document 12.

Table 4: CRaTER Data Products

Data Product Name	Key/Physical Parameters in Data Product	NASA Data Level	CODMAC Level	Processing Inputs	Data Product Format	Estimated Size MB/day
CR_L0_SC CR_L0_HK	Raw CRaTER data: pulse heights, secondary science, and housekeeping	0	2	Raw data from LRO MOC as recorded on LRO	Binary CCSDS Packets	55
CR_L1_PS CR_L1_SS CR_L1_HK	Science data, split into primary and secondary science, and housekeeping	1	3	Level 0 data with pulse heights converted to energy	ASCII	435[a]
CR_L2_PS CR_L2_SS CR_L2_HK	LET deposition in silicon. Pulse heights converted into energy deposited within each detector.	2	3/4[b]	Level 1 data with pulse heights converted to LET energy and UTC time tags added	ASCII	966[a]
CR_L3_SCI	LET spectra in silicon associated with background (GCRs) and specific SEP events	3	5	Level 2 data accumulated over specific time intervals	ASCII	0.3[a]
CR_L4_SCI	Modelled LET spectra in tissue	4	5	Level 3 data converted to modelled LET in tissue	ASCII	0.3[a]

a. Uncompressed size; *gzip* compression is expected to reduce these values by 60–80%.
b. The CR_L2_HK and CR_L2_SS products are CODMAC Level 3, CR_L2_PS is Level 4.

Table 5: On-Orbit Data File Nomenclature

Level	Contents	File Name	Record bytes
0	raw science	CRAT_*yyyyddd*_*nnnnnnn*.sci	var
	raw housekeeping	CRAT_*yyyyddd*_*nnnnnnn*.hk	64
1	primary science	CR_L1_PS_*nnnnn*_v*nn*.tab	82
	secondary science	CR_L1_SS_*nnnnn*_v*nn*.tab	102
	housekeeping	CR_L1_HK_*nnnnn*_v*nn*.tab	218
2	primary science	CR_L2_PS_*nnnnn*_v*nn*.tab	182
	secondary science	CR_L2_SS_*nnnnn*_v*nn*.tab	142
	housekeeping	CR_L2_HK_*nnnnn*_v*nn*.tab	252
3	LET science	CR_L3_SCI_*mmm*_v*nn*.tab	var
4	LET science	CR_L4_SCI_*mmm*_v*nn*.tab	var

CRaTER Level 0 Files are created on the spacecraft and assigned a name by the flight software that is preserved during ground processing through the MOC and the CRaTER SOC. The naming convention is described in Applicable Document 4. Files generated at the SOC during the normal course of the mission will be organized on a per-orbit basis, using the PDS file-naming conventions specified in Applicable Document 9. Suggested names of the principal data files are shown in Table 5, where *nnnnn* represents the LRO orbit number, but the final naming convention is described in Applicable Document 12. Level 3 and 4 products are not orbit-oriented—they are generated in response to specific events, *e.g.*, solar flares, and will be denoted by an index number, *mmm*.

Table 6: Pre-Launch Data File Nomenclature

Contents	File Name
Raw science and housekeeping data from CRaTER	`CRA`*`vvmmddyyhhmmss`*`L0.bin`

Prior to launch, calibration and test data is collected as an interleaved stream of three types of CCSDS packets, as defined in Table 7, below. 64-byte headers are added to each packet to mimic those generated by LRO flight software. The data are written to files whose names are described in Table 6, where "*vv*" is the instrument serial number and "*mmddyyhhmmss*" is the date and time (UTC) at which collection started. The naming convention for higher level test and calibration products is TBD.

A.1 Level 0 Data Products

CRaTER output is stored on the LRO spacecraft in pairs of data files, one containing interleaved primary and secondary science records (CCSDS *APIDs* 120 and 121) and the other containing instrument housekeeping data (*APID* 122). These files comprise the CRaTER Level 0 data, one pair per orbit. Since the nominal LRO orbital period is ~110 minutes, the CRaTER SOC will expect to receive 13 pairs of orbit files per day. Level 0 data product files are indistinguishable from the raw files stored on the spacecraft.

Level 0 science data contains both primary and secondary science records. Up to 25 CRaTER primary science records are recorded per second, and each record can contain from zero to 48 events, for a maximum reporting rate of 1200 events/second. Secondary science records are generated once per second. The detailed contents of the records are shown in Table 7. The time-resolution of CRaTER science data is 1-s, referenced to a 1 Hz spacecraft timing signal. The spacecraft clock time of the pulse preceding the telemetry record is stored in each secondary header (see Section 4.1.3 of Applicable Document 3).

Upon arrival within the CRaTER SOC, all level 0 files will be examined to ensure sequential packet sequence numbers and no duplication of packets. Should time-step errors be found, the SOC manager will be notified via e-mail and an error will be noted in the log file. A re-send will typically be requested from the MOC.

Table 7: Level 0 Data Format

Offset bytes	**Length** bytes	**Description**
0	64	64-byte Header inserted by LRO flight software (see Applicable Document 5)
		Primary science (varying length records)
0	6	CCSDS Primary Header, *APID*=120 (see Applicable Document 3, Table 3–1)
6	6	Secondary Header (see Applicable Document 3, Table 4–2)
6	4	— Spacecraft time in seconds
10	2	— Sub-seconds, flags and serial number
12	9*n	12-bit amplitudes fromeach of 6 Detectors for n events ($0 \le n \le 48$)
		Secondary science (fixed length records)
0	6	CCSDS Primary Header, *APID*=121 (see Applicable Document 3, Table 3–1)
6	6	Secondary Header (see Applicable Document 3, Table 4–2)
12	2	Instrument Flags (see Applicable Document 3, section 4.2.7)
14	2	Contents of Last Command
16	4	Event Amplitude Discriminator Settings
20	8	Discriminator Accept Mask
28	12	Detector D1–D6 Singles Counters
40	2	Telemetry Stall Counter 4.2.2
42	2	Event Reject Counter 4.2.4
44	2	Total Event Counter
		Instrument housekeeping (fixed length records)
0	6	CCSDS Primary Header, *APID*=122 (see Applicable Document 3, Table 3–1)
6	6	Secondary Header (see Applicable Document 3, Table 4–2)
12	2	28VDC Monitor
14	2	+5VDC Digital Monitor
16	2	+5VDC Analog Monitor
18	2	–5VDC Analog Monitor
20	2	+2.5VDC Internal Reference
22	12	Detector D1–D6 Bias Current Monitors
34	2	Thin Detector Bias Voltage Monitor
36	2	Thick Detector Bias Voltage Monitor
38	2	Electrical Calibration Amplitude Monitor
40	2	Thin Detector LLD Voltage Monitor
42	2	Thick Detector LLD Voltage Monitor
44	2	Telescope Temperature
46	2	Analog Board Temperature
48	2	Digital Board Temperature

Table 7: Level 0 Data Format (Continued)

Offset bytes	Length bytes	Description
50	2	Power Supply Temperature
52	2	Bulkhead Reference Temperature
54	6	Reserve Channels A, B, C
60	2	PRT Reference – Ground Test Only
62	2	Purge Flow Rate – Ground Test Only

A.2 Level 1 Data Products

CRaTER Level 1 data consists of 3 file types, as shown in Table 8, all in ASCII format with fixed record lengths. One file contains the primary science data, the second contains secondary science data, and the third contains instrument housekeeping. Each science file is derived directly from the corresponding Level 0 science file, and each housekeeping file from the Level 0 file.

Each record begins with a 9-digit time field—the number of seconds elapsed from 2001 (*i.e.*, 0h UTC on January 1, 2001) to the 1-Hz pulse that precedes the event or housekeeping record.

The second field in the primary science record is the number of events within the 1–s interval. Its maximum value is 1200. Since there is only one secondary science record per second, and no more than one housekeeping record every '*n*' seconds, there is no corresponding index field in their records. ('*n*' is selected by LRO flight software, and is typically 16 seconds).

The remaining fields are converted from the binary fields in Level 0 products into a mixture of fixed- and floating-point ASCII values by the decalibration algorithms defined in Applicable Document 11.

Level 1 housekeeping fields describe instrument voltages, bias currents and temperatures (see Section 4.1.7.3 of Applicable Document 3). These will be used to construct data quality flags in the Level 2 products, and also to help monitor the health of the CRaTER instrument during the course of the mission.

Table 8: Level 1 Data Products

Offset bytes	Length bytes	Format	Units	Description
				Primary science record
0	9	I9	secs	Elapsed time from 0h UT Jan 1 2001 to timing pulse
10	4	I4	1–1200	Index of event within the current second
15	10	E10.4	eV	Energy deposited in Detector 1
26	10	E10.4	eV	Energy deposited in Detector 2
37	10	E10.4	eV	Energy deposited in Detector 3
48	10	E10.4	eV	Energy deposited in Detector 4
59	10	E10.4	eV	Energy deposited in Detector 5
70	10	E10.4	eV	Energy deposited in Detector 6

Table 8: Level 1 Data Products (Continued)

Offset bytes	Length bytes	Format	Units	Description
81	1			LF end-of-record delimiter
				Secondary science record
0	9	I9	secs	Elapsed time from 0h UT Jan 1 2001 to timing pulse
10	16	16I1	N/A	Instrument Flags (see Applicable Document 3, section 4.2.7)
27	4	I4	N/A	Contents of Last Command
32	4	4I1	N/A	Event Amplitude Discriminator Settings
37	8	H8	N/A	Discriminator Accept Mask (upper 32 bits)
46	8	H8	N/A	Discriminator Accept Mask (lower 32 bits)
55	4	I4	counts	Detector D1 Singles Counter
60	4	I4	counts	Detector D2 Singles Counter
65	4	I4	counts	Detector D3 Singles Counter
70	4	I4	counts	Detector D4 Singles Counter
75	4	I4	counts	Detector D5 Singles Counter
80	4	I4	counts	Detector D6 Singles Counter
85	4	I4	counts	Telemetry Stall Counter
90	4	I4	counts	Event Reject Counter
95	4	I4	counts	Total Event Counter
100	1			LF end-of-record delimiter
				Instrument housekeeping record
0	9	I9	secs	Elapsed time from 0h UT Jan 1 2001 to timing pulse
10	6	F6.3	VDC	28VDC Monitor
17	6	F6.3	VDC	+5VDC Digital Monitor
24	6	F6.3	VDC	+5VDC Analog Monitor
31	6	F6.3	VDC	–5VDC Analog Monitor
38	6	F6.3	VDC	+2.5VDC Internal Reference
45	6	F6.3	A	Detector D1 Bias Current Monitor
52	6	F6.3	A	Detector D2 Bias Current Monitor
59	6	F6.3	A	Detector D3 Bias Current Monitor
66	6	F6.3	A	Detector D4 Bias Current Monitor
73	6	F6.3	A	Detector D5 Bias Current Monitor
80	6	F6.3	A	Detector D6 Bias Current Monitor
87	6	F6.3	VDC	Thin Detector Bias Voltage Monitor
94	6	F6.3	VDC	Thick Detector Bias Voltage Monitor
101	6	F6.3	VDC	Electrical Calibration Amplitude Monitor
108	6	F6.3	VDC	Thin Detector LLD Voltage Monitor

Table 8: Level 1 Data Products (Continued)

Offset bytes	**Length** bytes	**Format**	**Units**	**Description**
115	6	F6.3	VDC	Thick Detector LLD Voltage Monitor
122	7	F7.2	C	Telescope Temperature
130	7	F7.2	C	Analog Board Temperature
138	7	F7.2	C	Digital Board Temperature
146	7	F7.2	C	Power Supply Temperature
154	7	F7.2	C	Bulkhead Reference Temperature
162	10	E10.4	TBD	Reserve Channel A
173	10	E10.4	TBD	Reserve Channel B
184	10	E10.4	TBD	Reserve Channel C
195	10	E10.4	TBD	PRT Reference – Ground Test Only
206	10	E10.4	TBD	Purge Flow Rate – Ground Test Only
217	1			LF end-of-record delimiter

The individual fields are separated by commas (`0x2C`) and non-numeric fields are enclosed in double quotes (`0x22`). Lines terminate in LF (`0x0A`), preceded where necessary by a blank space (`0x20`) to make each line an even number of bytes long.

A.3 Level 2 Data Products

Level 2 data products are similar to the Level 1 products described in §A.2, both in content and structure. UTC is calculated from the time fields in the Level 0 products and is added as a new data column, and the primary science Level 2 product contains 6 additional columns reporting the Lineal Energy Transfer (LET) deposited in each of the 6 silicon detectors.

Table 9: Level 2 Data Products

Offset bytes	**Length** bytes	**Format**	**Units**	**Description**
				Primary science
0	9	I9	secs	Elapsed time from 0h UT Jan 1 2001 to timing pulse
10	23	A23	UTC	Timestamp (*mm-hh-yyyy*T*hh:mm:ss*.000)
34	4	I4	0–1200	Number of events recorded within the current second
39	10	E10.4	eV	Energy deposited in Detector 1
50	10	E10.4	eV	Energy deposited in Detector 2
61	10	E10.4	eV	Energy deposited in Detector 3
72	10	E10.4	eV	Energy deposited in Detector 4
83	10	E10.4	eV	Energy deposited in Detector 5
94	10	E10.4	eV	Energy deposited in Detector 6
105	10	E10.4	eV/µm	Lineal Energy Transfer in Detector 1

Table 9: Level 2 Data Products (Continued)

Offset bytes	Length bytes	Format	Units	Description
116	10	E10.4	eV/µm	Lineal Energy Transfer in Detector 2
127	10	E10.4	eV/µm	Lineal Energy Transfer in Detector 3
138	10	E10.4	eV/µm	Lineal Energy Transfer in Detector 4
149	10	E10.4	eV/µm	Lineal Energy Transfer in Detector 5
160	10	E10.4	eV/µm	Lineal Energy Transfer in Detector 6
171	8	I8	TBD	Data quality field
180	1			LF end-of-record delimiter
Secondary science				
0	9	I9	secs	Elapsed time from 0h UT Jan 1 2001 to timing pulse
10	23	A23	UTC	Timestamp (*mm-hh-yyyy*T*hh:mm:ss*.000)
34	90	see Table 8		Remaining Level 1 fields
125	14	3I5	N/A	Level 2 data quality fields (3 4-digit integers)
140	1			LF end-of-record delimiter
Instrument housekeeping				
0	9	I9	secs	Elapsed time from 0h UT Jan 1 2001 to timing pulse
10	23	A23	UTC	Timestamp (*mm-hh-yyyy*T*hh:mm:ss*.000)
34	207	see Table 8		Remaining Level 1 fields
242	10	E10.4	TBD	Cumulative instrument radiation dosage
253	1			LF end-of-record delimiter

A.4 Level 3 and 4 Data Products

To obtain an accurate representation of the LET deposited within CRaTER, the data obtained during solar energetic proton events (SEPs) will be analyzed separately from nominal galactic cosmic ray (GCR) data. Level 4 products are derived from Level 3 by transforming the LET values for silicon into tissue equivalents by a model-dependent algorithm (see Applicable Document 11).

Following the convention used by the Space Environment Center (SEC), an SEP is defined as an event with at least 3 consecutive 5-minute averages ≥10 MeV proton fluxes measured by GOES spacecraft ≥10 particle flux units (*pfu*).

A single Level 3 or 4 data product will be created for each SEP period, and also at infrequent intervals during the mission in order to monitor the GCR background. The algorithms used to create these products are described in Applicable Document 11.

Each Level 3 or 4 product file can contain from 1 to 100 individual spectra, one per "column." Table 10 shows the contents of each column of each record. Columns are 11 bytes wide, separated by commas (`0x2C`), and terminated by LF (`0x0A`), preceded where necessary by a blank space (`0x20`) to make each line an even number of bytes long. Hence the records of a file describing *n* spectra will contain 12*n–mod(n,2) bytes, plus carriage return, plus line-feed, for a total size of 4115*(12*n+2–mod(n,2)) bytes.

Table 10: Level 3 Data Products

Row	Width bytes	Format	Units	Description
1	10	I10	TBD	Data set identifier
2	10	I10	1–6	Detector contributing the spectrum (1–6)
3	8	A8	UTC	Starting date (*mm-hh-yyyy*), enclosed in quotes (0x22)
4	8	A8	UTC	Starting time (*hh:mm:ss*), enclosed in quotes (0x22)
5	8	A8	UTC	Ending date (*mm-hh-yyyy*), enclosed in quotes (0x22)
6	8	A8	UTC	Starting date (*hh:mm:ss*), enclosed in quotes (0x22)
7	11	E11.5	eV	Detector 1 minimum energy
8	11	E11.5	eV	Detector 1 maximum energy
9	11	E11.5	eV	Detector 2 minimum energy
10	11	E11.5	eV	Detector 2 maximum energy
11	11	E11.5	eV	Detector 3 minimum energy
12	11	E11.5	eV	Detector 3 maximum energy
13	11	E11.5	eV	Detector 4 minimum energy
14	11	E11.5	eV	Detector 4 maximum energy
15	11	E11.5	eV	Detector 5 minimum energy
16	11	E11.5	eV	Detector 5 maximum energy
17	11	E11.5	eV	Detector 6 minimum energy
18	11	E11.5	eV	Detector 6 maximum energy
19–4115	11	E11.5	eV/µm	Lineal Energy Transfer at each of 4096 energies

Appendix B Abbreviations and Acronyms

Abbreviation/ Acronym	Definition
APID	(CCSDS) Application Identifier (within primary headers)
CCSDS	Consultative Committee for Space Data Systems
CDR	Critical Design Review
CODMAC	(NRC) Committee on Data Management and Computation
CRaTER	Cosmic Ray Telescope for the Effects of Radiation
LF	Line-Feed (ASCII line-ending character)
GCR	Galactic Cosmic Ray
GN&C	Guidance, Navigation, & Control
GS	Ground System
GSE	Ground Support Equipment
ICD	Interface Control Document
IT	Information Technology
LDWG	LRO Data Working Group
LET	Lineal Energy Transfer
LRO	Lunar Reconnaissance Orbiter
MOC	Missions Operations Center
NAIF	(NASA/PDS) Navigation and Ancillary Information Facility
PCK	A SPICE Planetary Constants Kernel file
PDR	Preliminary Design Review
PDS	Planetary Data System
PPI	Planetary Plasma Interactions (node of the PDS)
PRT	Platinum Resistance Thermometer
QL	Quick-Look
RAID	Redundant Array of Independent (or Inexpensive) Disks
SCR	System Concept Review
SEP	Solar Energetic Proton (event)
SIS	Software Interface Specification
SOC	Science Operations Center
SPICE	(NAIF's) Spacecraft, Planet, Instrument, C-matrix (pointing), and Events
SPK	A SPICE Kernel file
SRR	System Requirements Review
TBD	To Be Determined
TBR	To Be Resolved

Appendix C SOC Software routines

Routine Name	Function
validate_crater_L0.pro	Validates the raw L0 CCSDS files
convert_crater_L0_to_L1.pro	Converts crater L0 files to L1 ascii files
convert_crater_l1_to_l2.pro	Converts crater L1 files to L2 ascii files
read_crater_l1.pro	Read a crater l1 file into IDL
read_crater_l2.pro	Read a crater l2 file into IDL

Appendix D SOC Directory Structure and File-naming Convention

Table 11: Structure of SOC Directory

Path	Contents
~/incoming/	Upload directory for L0 data, kernels, etc.
~/cal/	Storage for pre-flight calibration data and information
~/cal/BNL/	Archive of Brookhaven calibration runs
~/cal/MGH/	Archive of Mass General Hospital calibration runs
~/cal/LBL/	Archive of Berkeley 88” calibration runs
~/pri/	Data associated with primary & extended mission
~/pri/L0/	Contains primary & extended mission Level 0 data
~/pri/L1/	Contains primary & extended mission Level 1 data
~/pri/L2/	Contains primary & extended mission Level 2 data
~/pri/kernels/	Repository for spice kernels
~/pri/plots/	Location of Quick-look plots
~/stage/	Used for staging writes to hard media
~/pds/	Directory for PDS archive creation, associated documents
~/pds/stage/	used for staging uploads to PDS-PPI
~/pds/doc/	documents related to PDS archive creation
~/bin/	CRaTER specific software directory
~/bin/idl/	Contains idl routines used for CRaTER processing
~/bin/spice/	Contains NAIF SPICE routines
~/models/	Repository for model runs
~/trend/	Plots used for trending analysis (continuously updated)
~/log/	Directory for log files

Appendix E CRaTER Anomaly Report template

LRO CRATER ANOMALY REPORT

CRATER SCIENCE OPERATIONS CENTER
BOSTON UNIVERSITY, CENTER FOR SPACE PHYSICS

FOR: Part Number	Rev:	Sub-Section Name:	Used on hardware: Rev:	Human Interface:

Originator:	Phone:	Date:	ITOS Rev:	SOP Rev:

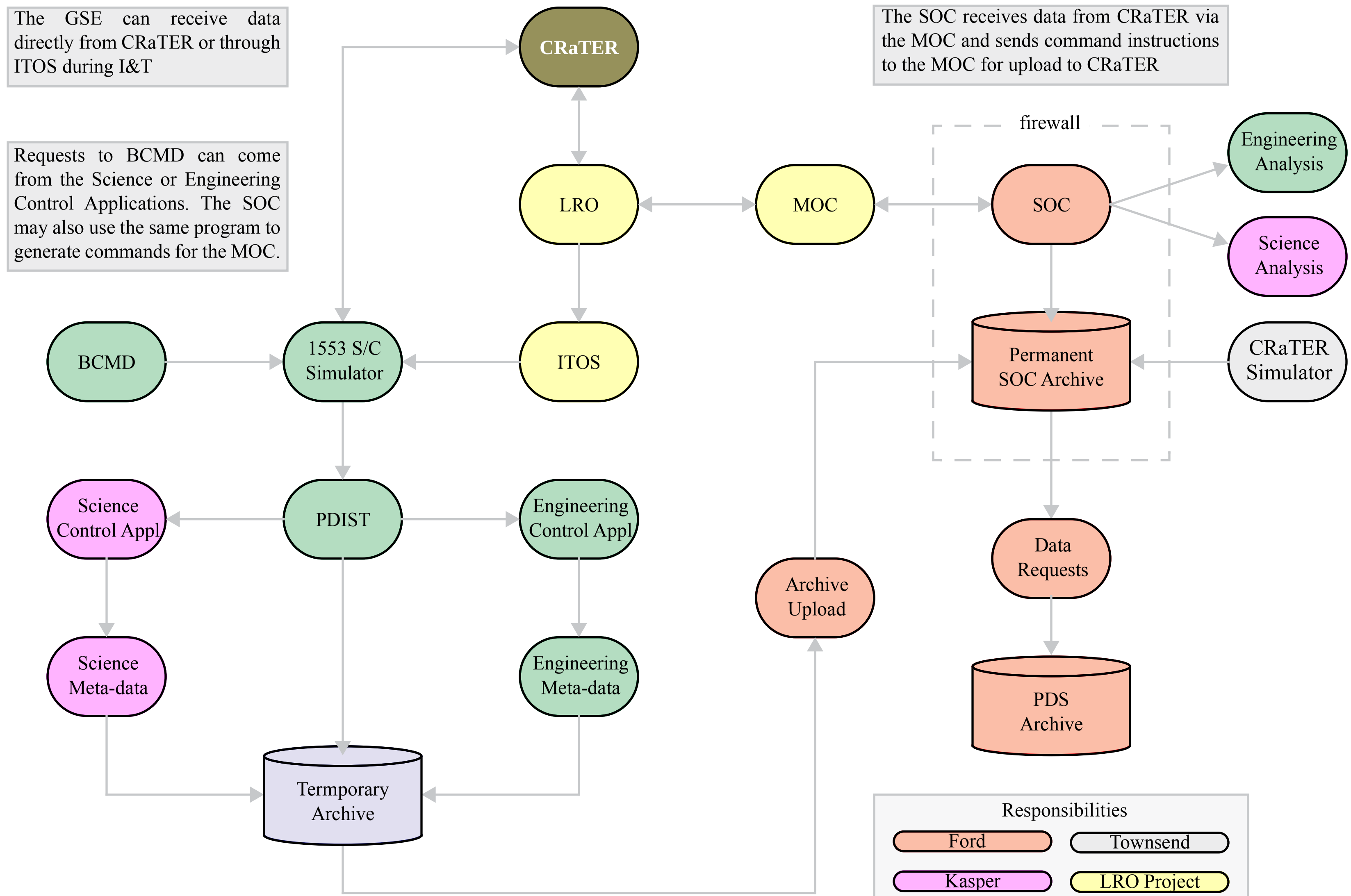
Description of Problem: (should be sufficiently complete to be duplicated by engineering):

Corrective Action:

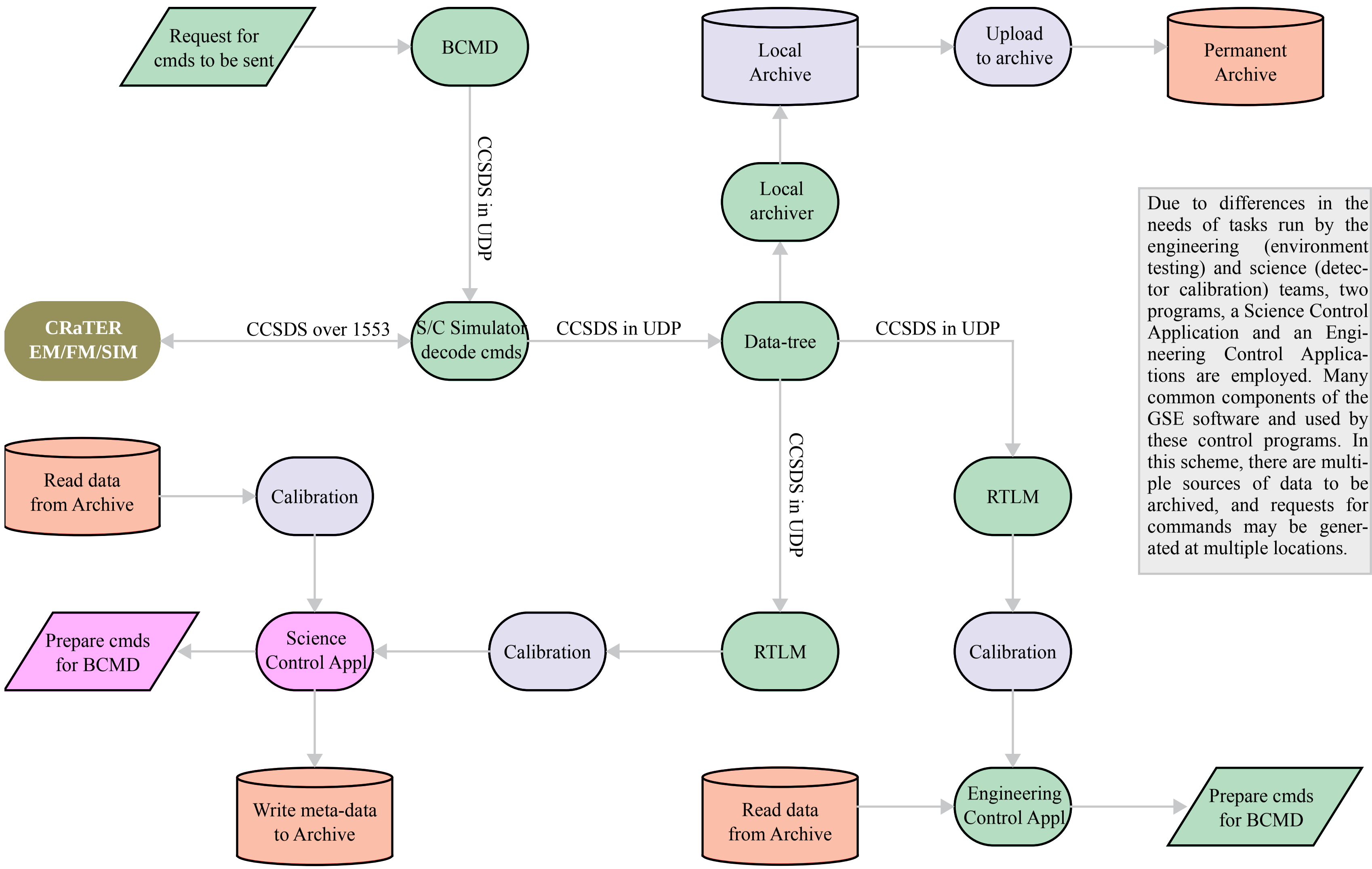
Problem closed on: Date:	Refer to ECO #:	Refer to Change ID:

Problem ID: C	Status:	Sheet: # of 22

Appendix F. CRaTER Architecture and Management

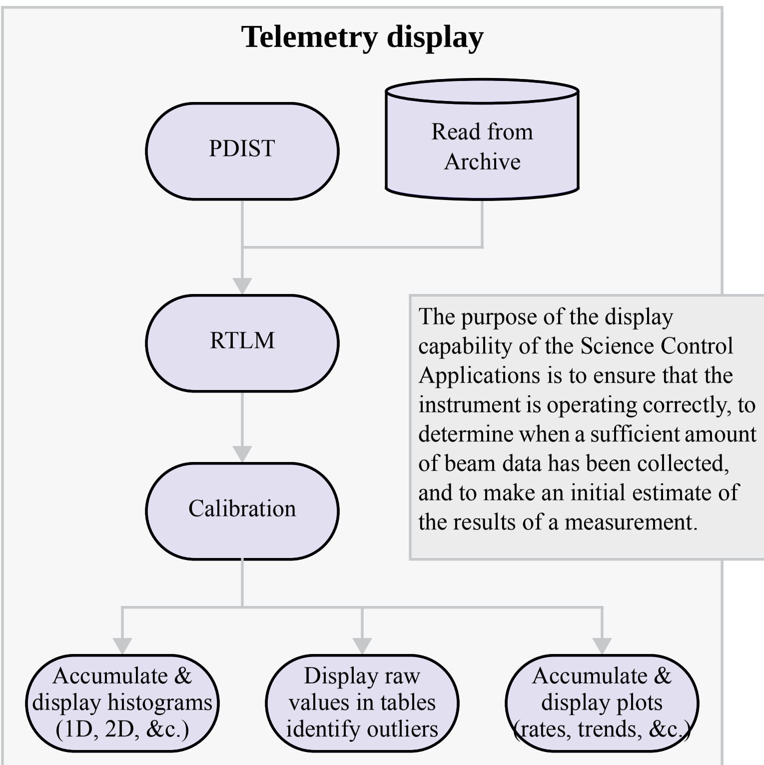


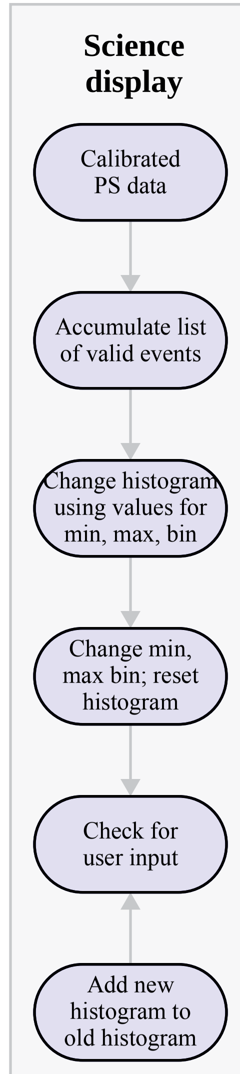
Appendix G. GSE Software Overview

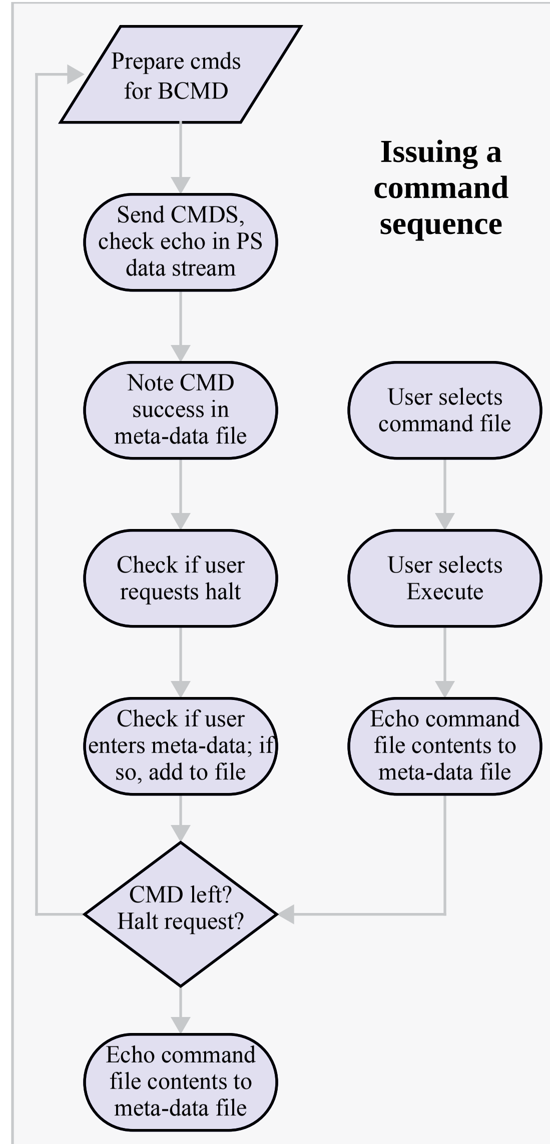


Appendix H. Science Control Application

The main purpose of the Science Control Application is to allow the science team to record data during beam runs at particle accelerators. In particular, this involves the ability to monitor time series plots of rates, track histograms of energy deposition, and save additional beam run specific meta-data such as beam type and energy, and comments. It is desired that this application also be capable of stepping through a sequence of pre-flight commands, e.g., prototype calibration sequences.







Appendix I. Crater Data Archival