Rev.	ECO	Description	Author	Approved	Date
01	32-002	Initial Release for comment	JCKasper		6/3/05
02	32-044	Reposition from Level II MRD to an IRD	JCKasper		7/25/05
03	32-066	General Update	JCKasper		11/16/05
A	32-076	First Controlled Release	JCKasper	HESpence	2/15/06
B	32-243	Update maximum LET	JCKasper		10/24/07

CRaTER
Instrument Requirements Document
Instrument Performance and Data Products Specification

Dwg. No. 32-01205

Revision B
October 24, 2007

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Preface

This is the CRaTER Instrument Requirements Document (IRD). It is based on the original CRaTER Level 2 (L2) requirements document, which was written for the LRO Mission Requirements Document (MRD). This document contains the Instrument Performance Specification, in which the LRO measurement requirements that CRaTER is responsive to are flowed down to performance requirements on the instrument and its subassemblies and components.

Revision 02 took CRaTER components of the MRD and shaped it into the IRD. Several of the L2 requirements were moved to the Level 3 (L3). Traceability matrices were introduced at each level to summarize each requirement, its value, and list traceability to parent requirements.

Revision A incorporates comments from the Spacecraft Requirements Review and members of the CRaTER science team. An outline of the instrument verification plan has been added to demonstrate that the requirements can be verified. A description of the CRaTER data products from raw telemetry to final analysis has been added to demonstrate that the required data products are produced.

Revision B reduced the Maximum LET measurement (ref. 4.6) from 7 to 2 MeV/micron.

1.0 Introduction

The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) will investigate the effects of solar and galactic cosmic rays on tissue-equivalent plastics as a constraint on models of biological response to radiation in the lunar environment.

This document specifies the flow down from the Lunar Reconnaissance Orbiter (LRO) Level 1 (L1) requirements and the Data Product requirements levied on CRaTER to hardware requirements and data product requirements. The instrument requirements are outlined in the first part of this document, the Instrument Performance Specification, which comprises sections 2-6. Section 7 is an informal listing of the requirements levied on the spacecraft. This listing is informal but indicates the project documents in which the orbiter is responsive to these requirements. The second part of this document is a plan for the verification of requirements, in section 8. The final part of this document is section 9, the Data Product Specification, which relates the data products that flow from raw CRaTER observations back to the original L1 requirements for mission success.

In this document, we follow the terminology of the LRO Project, and adopt the following terminology. A requirement is identified by “shall,” a good practice by “should”, permission by “may”, or “can”, expectation by “will”, and descriptive material by “is.”

1.1 Instrument Performance Specification

This document levies general requirements on the CRaTER instrument. A separate document, the CRaTER Functional Instrument Description (FID, CRaTER document 32-01206), describes a specific instrument design that meets these requirements.

Level 1 (L1) requirements are a Project's fundamental and basic set of requirements levied by the Program or Headquarters on the Project. L1 requirements define the scope of scientific or technology validation objectives, describe the measurements required to achieve these objectives, and define success criteria for an expected mission and minimum mission. The L1 requirements to which CRaTER is responsive are enumerated in ESMD-RLEP-0010 Table 5.1, which maps L1 RLEP requirements to instrument Data Products. These items are repeated for reference in Section 2.

Level 2 (L2) requirements are allocated to all mission segments (instruments, spacecraft bus, ground system, and launch vehicle). L2 requirements also envelop Mission Assurance Requirements and technical resource allocations. Section 3 lists the L2 requirements and their traceability to L1 requirements. Section 4 presents each L2 requirement and associated rationale in detail.

Level 3 (L3) requirements are subsystem requirements. L3 requirements include instrument specifications and interface definitions. Section 5 lists the L2 requirements and their traceability to L1 requirements. Section 6 presents each L2 requirement and associated rationale in detail.

1.2 Instrument requirements verification plan

Section 8 presents an overview of the verification plan to demonstrate that the instrument meets the requirements outlined in this document.

1.3 Data product specification

Section 9 outlines the flow from the raw CRaTER science and housekeeping data products to higher order science products and demonstrates that the resulting data products meet the LRO observation products that CRaTER is responsive to.

1.4 Relevant documents

1.4.1 GSFC Configuration Controlled Documents

- ESMD-RLEP-0010 (Revision A effective November 30 2005)
- LRO Mission Requirements Document (MRD) – 431-RQMT-00004
- LRO Technical Resource Allocation Requirements – 431-RQMT-000112
- LRO Electrical ICD – 431-ICD-00008
- CRaTER Electrical ICD – 431-ICD-000094
- CRaTER Data ICD – 431-ICD-000104
- Mechanical Environments and Verification Requirements – 431-RQMT-00012
- CRaTER Mechanical ICD – 431-ICD-000085
- CRaTER Thermal ICD – 431-ICD-000118

1.4.2 CRaTER Configuration Controlled Documents

- CRaTER Performance Assurance Implementation Plan – 32-01204
- CRaTER Calibration Plan – 32-01207
- CRaTER Contamination Control Plan – 32-01203
- CRaTER Functional Instrument Description – 32-05002

2.0 Review of LRO Requirements Levied on CRaTER

NASA has established investigation measurement requirements for LRO based on RLEP Requirements and the LRO AO and refined further from the mission instrument selections and Project trade studies. In this section, the LRO Level 1 measurement requirements and rationales relevant to CRaTER are reproduced from Section 3.1.1 of ESMD-RLEP-0010, along with the associated product listed in Section 6.2 the instrument will produce in response to the LRO measurement requirements.

2.1 RLEP-LRO-M10

2.1.1 *Requirement*

The LRO shall characterize the deep space radiation environment at energies in excess of 10 MeV in lunar orbit, including neutron albedo.

2.1.2 *Rationale*

LRO should characterize the global lunar radiation environment in order to assess the biological impacts on people exploring the moon and to develop mitigation strategies.

2.1.3 *Data Product*

Provide Linear Energy Transfer (LET) spectra of cosmic rays (particularly above 10 MeV), most critically important to the engineering and modeling communities to assure safe, long-term, human presence in space.

2.2 RLEP-LRO-M20

2.2.1 *Requirement*

The LRO shall measure the deposition of deep space radiation on human equivalent tissue while in the lunar orbit environment.

2.2.2 *Rationale*

The radiation environment needs to be characterized in order to assess its biological impacts and potential mitigation approaches, including shielding capabilities of materials and validation of other deep space radiation mitigation strategies.

2.2.3 *Data Product*

Provide LET spectra behind different amounts and types of areal density, including tissue equivalent plastic.

3.0 Level 2 Traceability Matrix

The matrix in this section traces the flow down from the Level 1 requirements and data products stated in ESMD-RLEP-0010 and outlined in Section 2 to the CRaTER Level 2 requirements. The individual CRaTER Level 2 requirements, with detailed explanations of the rationale for each value, are provided in Section 4.

Item	Sec	Requirement	Quantity	Parent
CRaTER-L2-01	4.1	Measure the Linear Energy Transfer (LET) spectrum	LET	RLEP-LRO-M10
CRaTER-L2-02	4.2	Measure change in LET spectrum through Tissue Equivalent Plastic (TEP)	TEP	RLEP-LRO-M20
CRaTER-L2-03	4.3	Minimum pathlength through total TEP	> 60 mm	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-04	4.4	Two asymmetric TEP components	1/3 and 2/3 total length	RLEP-LRO-M20
CRaTER-L2-05	4.5	Minimum LET measurement	0.2 keV per micron	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-06	4.6	Maximum LET measurement	2 MeV per micron	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-07	4.7	Energy deposition resolution	< 0.5% max energy	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-08	4.8	Minimum full telescope geometrical factor	0.1 cm^2 sr	RLEP-LRO-M10

Table 3.1: CRaTER Level 2 instrument requirements and LRO parent Level 1 requirements.

4.0 Individual Level 2 Requirements

4.1 CRaTER-L2-01 Measure the Linear Energy Transfer Spectrum

4.1.1 *Requirement*

The fundamental measurement of the CRaTER instrument shall be of the linear energy transfer (LET) of charged energetic particles, defined as the mean energy absorbed (ΔE) locally, per unit path length (Δl), when the particle traverses a silicon solid-state detector.

4.1.2 *Rationale*

LET supplied to models for predicting radiation-induced human health risks and radiation effects in electronic devices. It is sufficient to measure the LET spectrum instead of the measuring the entire parent cosmic ray spectrum. This is the key direct measurement needed to bridge the gap between well-measured cosmic ray intensities that will be available from other spacecraft and specific energy deposition behind shielding materials, vital exploration-enabling knowledge needed for the safety of humans working in the space radiation environment.

4.2 CRaTER-L2-02 Measure Change in LET Spectrum after Passing through TEP

4.2.1 *Requirement*

The LET spectrum shall be measured before entering and after propagating though a compound with radiation absorption properties similar to human tissue such as A-150 Human Tissue Equivalent Plastic (TEP).

4.2.2 *Rationale*

Understand the evolution of the LET spectrum as it passes through human tissue. TEP is an inert solid substance that has radiation absorption characteristics that are similar to human tissue and has been used extensively in laboratory and space-based studies of radiation effects on humans.

4.3 CRaTER-L2-03 Minimum Pathlength through total TEP

4.3.1 *Requirement*

The minimum pathlength through the total amount of TEP in the telescope shall be at least 60 mm.

4.3.2 *Rationale*

The minimum energy of protons that can just exit the TEP is 100 MeV and the TEP rather than the silicon in the detectors dominates the areal density of the telescope stack.

4.4 CRaTER-L2-04 Two asymmetric TEP components

4.4.1 *Requirement*

The TEP shall consist of two components of different length, 1/3 and 2/3 the total length of the TEP. If the total TEP is 61 mm in length, then the TEP section closest to deep space will have a length of approximately 54 mm and the second section of TEP will have a length of approximately 27 mm.

4.4.2 *Rationale*

A variety of LET measurements behind various thicknesses and types of material is of great importance to spacecraft engineers, radiation health specialists, and to modelers who estimate impacts of the penetrating radiation. Simulations suggest splitting the TEP into two asymmetric components that are 1/3 and 2/3 the total length provides a useful combination of lengths, similar to typical thicknesses in human tissue.

4.5 CRaTER-L2-05 Minimum LET measurement

4.5.1 *Requirement*

At each point in the telescope where the LET spectrum is to be observed, the minimum LET measured shall be no greater than 0.25 keV/ micron in the Silicon.

4.5.2 *Rationale*

Within the limits of the noise level of the detectors, it is desirable to detect high energy particles with the asymptotic minimum ionizing deposition rate.

4.6 CRaTER-L2-06 Maximum LET measurement

4.6.1 *Requirement*

At each point in the telescope where the LET spectrum is to be observed, the maximum LET measured shall be no less than 2 MeV/ micron in the Silicon.

4.6.2 *Rationale*

Practical considerations effectively constrain the high end of the LET energy range. Slow moving, high-Z ions that give up much of their energy upon interaction will by definition yield large LET events. Therefore, the instrument should be able to measure such high-Z particles. On the other hand, the probability of a high energy heavy ion just stopping in a detector and depositing the maximum signal is small. Modeling and observations of heavy ions with prototype instruments show that these particles will produce signals commensurate with a deposition of 2 MeV/micron.

4.7 CRaTER-L2-07 Energy deposition resolution

4.7.1 *Requirement*

The pulse height analysis of the energy deposited in each detector shall have an energy resolution better than 1/200 the maximum energy measured by that detector.

4.7.2 *Rationale*

A high-resolution measurement of the energy deposited is required to characterize the LET spectrum and to distinguish between the effects of the primary radiation and secondaries produced through interactions.

4.8 CRaTER-L2-08 Geometrical Factor

4.8.1 *Requirement*

The geometrical factor created by the first and last detectors shall be at least 0.1 cm^2 sr.

4.8.2 *Rationale*

Statistically significant LET spectra should be accumulated over short enough time intervals to resolve dynamical features in the galactic cosmic ray (GCR) and solar energetic particle (SEP) flux. During quiescent intervals, the counting rate will be dominated by the slowly varying GCR foreground. With typical GCR fluxes, a geometrical factor of 0.3 cm^2-sr will yield several counts per second. In one hour, a statistically significant sampling of up to 10,000 events would permit construction of longer-term average spectra; this interval is still short compared to typical GCR modulation timescales. With this same geometrical factor, much higher time resolution and still reasonably high quality spectra could be constructed on times scales as short as half a minute (100 events). Such time resolution would allow us to construct maps of the LET spectra above the lunar surface, rather than as orbit averaged quantities.

5.0 Level 3 Traceability Matrix

The table in this section traces the flow down from the CRaTER Level 2 requirements to the individual CRaTER Level 3 requirements. The individual CRaTER level 3 requirements, with detailed explanations of the rationale for each value, are described in section 6.

Item	Ref	Requirement	Quantity	Parent
CraTER-L3-01	6.1	Thin and thick detector pairs	140 and 1000 microns	CRaTER-L2-01, CRaTER-L2-05, CRaTER-L2-06, CRaTER-L2-07
CraTER-L3-02	6.2	Minimum energy	< 250 keV	CRaTER-L2-01
CraTER-L3-03	6.3	Nominal instrument shielding	> 1524 micron Al	CRaTER-L2-01
CraTER-L3-04	6.4	Nadir and zenith field of view shielding	<= 762 micron Al	CRaTER-L2-01
CraTER-L3-05	6.5	Telescope stack	Shield, D1D2, A1, D3D4, A2, D5D6, shield	CRaTER-L2-01, CRaTER-L2-02, CRaTER-L2-04
CraTER-L3-06	6.6	Pathlength constraint	< 10% for D1D6	CRaTER-L2-01, CRaTER-L2-02, CRaTER-L2-03
CraTER-L3-07	6.7	Zenith field of view	<= 34 degrees D2D5	CRaTER-L2-01, CRaTER-L2-02
CraTER-L3-08	6.8	Nadir field of view	<= 70 degrees D4D5	CRaTER-L2-01
CraTER-L3-09	6.9	Calibration system	Variable rate and amplitude	CRaTER-L2-07
CraTER-L3-10	6.10	Event selection	64-bit mask	CRaTER-L2-01
CraTER-L3-11	6.11	Maximum event transmission rate	>= 1000 events/sec	CRaTER-L2-01
CraTER-L3-12	6.12	Telemetry interface	32-02001	
CraTER-L3-13	6.13	Power interface	32-02002	
CraTER-L3-14	6.14	Thermal interface	32-02004	
CraTER-L3-15	6.15	Mechanical interface	32-02003	

Table 5.1: CRaTER Level 3 instrument requirements and parent Level 2 requirements.

6.0 Individual Level 3 Requirements

When applicable, the relevant interface control document (ICD) that captures the Level 3 requirements listed below is provided. The ICDs and other supporting documents may be accessed *via* the CRaTER configuration database: http://snebulos.mit.edu/projects/crater/.

6.1 CRaTER-L3-01 Thin and thick detector pairs

6.1.1 *Requirement*

The telescope stack shall contain adjacent pairs of thin and thick Silicon detectors. The thickness of the thin detectors will be approximately 140 microns and the thick detectors will be approximately 1000 microns.

6.1.2 *Rational*

In order to cover the LET range required by CRaTER-L2-04 and CRaTER-L2-05 the detectors must operate over a dynamic range of > 35,000. This is not practical for a single detector. The dynamic range may be covered instead using two detectors with different thicknesses. The thicknesses were identified by considering the minimum and maximum energy deposited by protons and iron nuclei at normal and oblique incidence to the detectors. If the analog electronics have a dynamic range of 500, then the thick detectors will be used to characterize energy deposition between approximately 0.0002 MeV/micron and 0.1 MeV/micron and the thin detectors will be used to characterize energy deposits between 0.01 MeV/micron and 7.1 MeV/micron.

6.2 CRaTER-L3-02 Minimum Energy

6.2.1 *Requirement*

The Silicon detectors shall be capable of measuring a minimum energy deposition of 250 keV or lower.

6.2.2 *Rationale*

This will permit calibration and aliveness tests of the detectors and the integrated instrument with common ion beams and radiation sources. For the thin detectors, this minimum energy capability may require an additional operating mode.

6.3 CRaTER-L3-03 Nominal instrument shielding

6.3.1 *Requirement*

The equivalent shielding of the CRaTER telescope outside of the zenith and nadir fields of view shall be no less than 1524 microns (0.060 inches) of aluminum.

6.3.2 *Rationale*

Shielding on the sides of the telescope is needed to limit the flux of low energy particles – mainly protons - coming through the telescope at large angles of incidence. This will prevent protons with energies less than 15 MeV from entering the telescope.

6.4 CRaTER-L3-04 Nadir and zenith field of view shielding

6.4.1 *Requirement*

The zenith and nadir fields of view of the telescope shall have no more than 762 microns (0.030) of aluminum shielding.

6.4.2 *Rationale*

Reduce the flux of particles that pass through the telescope at acceptable angles of incidence but place a limit on the lowest energy particle that can enter the telescope. This is especially important during solar energetic particle events. The thickness of aluminum specified in this requirement would prevent protons of approximately 10 MeV and lower from entering the telescope. This energy was selected by examining the energy spectrum of protons during solar energetic particle events and the resulting single detector event rates.

6.5 CRaTER-L3-05 Telescope stack

6.5.1 *Requirement*

The telescope shall consist of a stack of components labeled from the zenith side as zenith shield (S1), the first pair of thin (D1) and thick (D2) detectors, the first TEP absorber (A1), the second pair of thin (D3) and thick (D4) detectors, the second TEP absorber (A2), the third pair of thin (D5) and thick (D6) detectors, and the final nadir shield (S2).

6.5.2 *Rationale*

LET measurements will be made on either side of each piece of TEP to understand the evolution of the spectrum as is passes through matter.

6.6 CRaTER-L3-06 Full telescope pathlength constraint

6.6.1 *Requirement*

The root mean squared (RMS) uncertainty in the length of TEP traversed by a particle that traverses the entire telescope axis shall be less than 10%.

6.6.2 *Rationale*

Particles with energies that exceed 100 MeV penetrate the entire telescope stack and produce the most secondaries. These events will provide the most significant challenge to modelers and a well-constrained pathlength simplifies the problem. This is a sufficient accuracy for subsequent modeling efforts to reproduce the observed LET spectra based on direct measurements of the primary particle spectrum.

6.7 CRaTER-L3-07 Zenith field of view

6.7.1 *Requirement*

The zenith field of view, defined as D2D5 coincident events incident from deep space using the naming convention in CRaTER-L3-04, shall be less than 34 degrees full width.

6.7.2 *Rationale*

This field of view, from which one derives a minimum detector radius and separation, leads to a sufficient geometrical factor while still limiting the uncertainty in the pathlength traveled by the incident particle.

6.8 CRaTER-L3-08 Nadir field of view

6.8.1 *Requirement*

The nadir field of view, defined as D4D5 coincident events incident from the lunar surface, shall be less than 70 degrees full width.

6.8.2 *Rationale*

The anticipated flux of particles reflected from the lunar surface is many orders of magnitude smaller than the incident flux of particles from space. It is felt that a larger geometrical factor, at the expense of a larger uncertainty in the pathlength, is a justified trade.

6.9 CRaTER-L3-09 Calibration system

6.9.1 *Requirement*

The CRaTER electronics shall be capable of injecting calibration signals at with different amplitudes and rates into the measurement chain.

6.9.2 *Rationale*

Verify instrument functionality without need for radiation sources. Identify changes in measurement chain response over time following launch.

6.10 CRaTER-L3-10 Event selection

6.10.1 *Requirement*

A command capability shall exist to allow specification of detector coincidences that will be analyzed and sent to the spacecraft for transmission to the ground.

6.10.2 *Rationale*

Allows for maximizing telemetry for events of interest. Allows for adjustments of coincidence definitions in the case of increased noise in any detector.

6.11 CRaTER-L3-11 Maximum event rate

6.11.1 *Requirement*

CRaTER will be capable of transmitting primary science data, namely the energy deposited in each of the detectors, on at least 1000 events per second.

6.11.2 *Rationale*

This rate will allow us to collect statistically significant samples of minor ions such as carbon, oxygen, and iron during periods of solar activity.

6.12 *CRaTER-L3-11 Telemetry interface*

LRO shall provide a 1553B bus to support CRaTER commands and telemetry. CRaTER will continually transmit 1200 events per second, with fill data in cases where 1200 events are not seen. The Data ICD is document number 32-02001.

6.13 CRATER-L3-12 Power Interface

CRaTER allocated power consumption is 9.0 W. Instrument power allocation is controlled by 431-SPEC-000112.

6.14 CRaTER-L3-13 Thermal Interface

CRaTER will be completely covered by multi-layer insulation (MLI) and thermally coupled to the spacecraft through the structure connection. The thermal design and interface to the spacecraft is outlined in the thermal ICD, 431-ICD-000118.

6.15 CRaTER-L3-14 Mechanical Interface

CRaTER allocated mass is 6.4 kg. Instrument mass allocation is controlled by 431-SPEC-000112.

7.0 Requirements levied on the spacecraft

This section does not formally levy requirements on LRO. It highlights how aforementioned requirements on CRaTER lead to requirements on the spacecraft. This section does not include requirements stated in the mechanical, electrical, and thermal ICDs.

7.1 Clear Nadir Field of Regard

The nadir field of view shall be less than 75 degrees full width and the spacecraft will not obstruct an 80 degree field of regard. This requirement levied on the spacecraft is captured in the LRO Project CRaTER to Spacecraft Mechanical Interface Requirements Document (Document 32-02003 in the CRaTER Engineering Configuration database and LRO Project Document 431-ICD-000085) in Section 3.3.

7.2 Clear Zenith Field of Regard

The nadir field of view shall be less than 34 degrees full width and the spacecraft will not obstruct a 35 degree full width field of regard. This requirement levied on the spacecraft is captured in the LRO Project CRaTER to Spacecraft Mechanical Interface Requirements Document (Document 32-02003 in the CRaTER Engineering Configuration database and LRO Project Document 431-ICD-000085) in Section 3.3.

7.3 Pointing knowledge

During normal operation, the spacecraft will point within 35 degrees of the lunar surface. The field of view of the nadir (lunar) pointing side of CRaTER will be less than 75 degrees. The angle subtended by the lunar surface in the projected LRO orbit will be approximately 150 degrees. As long as the instrument optical axis is pointed within 35 degrees of the lunar surface, the nadir side of the telescope will be looking completely at the lunar surface. Spacecraft will provide knowledge of the pointing of CRaTER's optical axis to within 10 degrees. The alignment and pointing requirements for CRaTER are documented in Lunar Reconnaissance Orbiter Pointing and Alignment Specification 431-SPEC-000113.

8.0 Instrument Requirements Verification Plan

8.1 Description

This section outlines the steps in the verification plan for demonstrating that the CRaTER instrument and subsystems meet the Level 2 and Level 3 requirements described in this Instrument Requirements Document. Aspects of the full verification plan for CRaTER are addressed in the CRaTER Performance and Environmental Verification Plan (32-01206), the CRaTER Calibration Plan (32-01207), the CRaTER Performance Assurance Implementation Plan (32-01204), and the CRaTER Detector

Specification (32-05001). The purpose of this section is to demonstrate that the requirements levied on CRaTER in this document may be verified and to provide a snapshot of that verification plan, but the aforementioned documents will take precedence and describe the final verification plans.

We categorize the verification methods into three categories, “inspection”, “test”, and “analysis”, which are described below:

Inspection: This is used to determine system characteristics by examination of and comparison with engineering drawings or flow diagrams and computer program listings during product development to verify conformance with specified requirements. Inspection is generally non-destructive and consists of visual examinations or simple measurements without the use of precision measurement equipment.

Test: Test is used to verify conformance of functional characteristics with operational and technical requirements. The test process will generate data, and precision measurement equipment or procedures normally record these data. Analysis or review is subsequently performed on the data derived from the testing. Analysis as described here is an integral part of this method and should not be confused with the "analysis" described in the third verification category.

Analysis: Analysis or review of simulation data is a study method resulting in data used to verify conformance of characteristics with specified requirements. Worst case data may be derived from design solutions where quantitative performance cannot be demonstrated cost-effectively.

8.2 Level 2 Requirements Verification Matrix

Item	Sec	Requirement	Quantity	Verification		
CRaTER-L2-01	8.3.1	Measure the Linear Energy Transfer (LET) spectrum	LET			A
CRaTER-L2-02	8.3.2	Measure change in LET spectrum through Tissue Equivalent Plastic (TEP)	TEP			A
CRaTER-L2-03	8.3.3	Minimum pathlength through total TEP	> 60 mm	I		
CRaTER-L2-04	8.3.4	Two asymmetric TEP components	1/3 and 2/3 (27 and 54 mm nominal)	I		
CRaTER-L2-05	8.3.5	Minimum LET measurement	< 0.25 keV per micron		T	
CRaTER-L2-06	8.3.6	Maximum LET measurement	> 2 MeV per micron		T	
CRaTER-L2-07	8.3.7	Energy deposition resolution	< 0.5% max energy		T	
CRaTER-L2-08	8.3.8	Minimum D1D6 geometrical factor	> 0.1 cm^2 sr	I		

Table 8.1: Verification matrix for Level 2 requirements, listing the relevant part of Section 8.3 , the requirement, the section in which the verification plan is outlined, and indicating the planned use of inspection, test, demonstration, and analysis for each requirement.

8.3 Level 2 Requirements Verification Plan

8.3.1 *CRaTER-L2-01 Measure the Linear Energy Transfer Spectrum*

8.3.1.1 Analysis

One dimensional numerical simulations will be used to predict the energy deposition in the silicon detectors as a function of input and evolving LET spectra through the instrument. These simulations will demonstrate that the energy deposition in the silicon detectors is sufficient to measure the local LET spectrum and provide predictions for comparison with the beam and radiation tests.

8.3.2 *CRaTER-L2-02 Measure Change in LET Spectrum through TEP*

8.3.2.1 Analysis

Numerical simulations will be used to model the expected evolution the LET spectrum of ions through the TEP sections.

8.3.3 *CRaTER-L2-03 Minimum Pathlength through total TEP*

8.3.3.1 Inspection

Mechanical diagrams will be reviewed to verify that the total length of TEP traversed by particles passing through the telescope is at least 60 mm of TEP. The length of the TEP components will be measured during fabrication.

8.3.4 *CRaTER-L2-04 Two asymmetric TEP components*

8.3.4.1 Inspection

Mechanical diagrams will be reviewed to verify that the lengths of the two components of TEP are 27 mm and 54 mm respectively. The flight sections of TEP will be measured at low resolution to verify the length.

8.3.5 *CRaTER-L2-05 Minimum LET measurement*

8.3.5.1 Test

The minimum LET threshold of the thick detectors will be measured in an accelerator facility.

8.3.6 *CRaTER-L2-06 Maximum LET measurement*

8.3.6.1 Test

The maximum LET we can measure in the thin detectors is greater than what we would expect from a stopping iron nucleus and therefore we are unlikely to be able to produce the maximum signal with a real beam. The maximum LET threshold of the thin detectors will be extrapolated based on the performance of the analog and digital electronics and of beam testing at lower LET values.

8.3.6.2 8.3.7.3 Analysis

Analysis will have to be used to extrapolate performance to higher LET values.

8.3.7 *CRaTER-L2-07 Energy deposition resolution*

8.3.7.1 Test

The detector provider will produce specifications of the energy resolution of each of the detectors, as determined with a pulser test and with an alpha source. The energy deposition resolution will be determined through analysis of pulsar data and through the use of line-emission from gamma-ray sources.

8.3.8 *CRaTER-L2-08 Geometrical factor*

8.3.8.1 Inspection

The geometrical factor will be determined through review of the telescope mechanical drawings. The geometrical factor is a function of the separation between the detectors and the radius of the detectors.

8.4 Level 3 Requirements Verification Matrix

Item	Ref	Requirement	Quantity	Verification		
CRaTER-L3-01	8.5.1	Thin and thick detector pairs	140 and 1000 microns	I		
CRaTER-L3-02	8.5.2	Minimum energy	< 250 keV		T	
CRaTER-L3-02	8.5.3	Nominal instrument shielding	0.060” Al	I		
CRaTER-L3-03	8.5.4	Nadir and zenith field of view shielding	0.030” Al	I		
CRaTER-L3-04	8.5.5	Telescope stack	Shield, D1D2, A1, D3D4, A2, D5D6, shield	I		
CRaTER-L3-05	8.5.6	Pathlength constraint	10% for D1D6	I		
CRaTER-L3-06	8.5.7	Zenith field of view	35 degrees D1D4	I		
CRaTER-L3-07	8.5.8	Nadir field of view	75 degrees D3D6	I		
CRaTER-L3-08	8.5.9	Calibration system	Variable rate and gain		T	
CRaTER-L3-09	8.5.10	Event selection	64-bit mask		T	
CRaTER-L3-10	8.5.11	Maximum event transmission rate	1,200 events/sec		T	

Table 8.2: Verification matrix for Level 3 requirements, listing the relevant part of Section 8.5, the requirement, the section in which the verification plan is outlined, and indicating the planned use of inspection, test, demonstration, and analysis for each requirement.

8.5 Level 3 Requirements Verification Plan

8.5.1 *CRaTER-L3-01 Thin and thick detector pairs*

8.5.1.1 Inspection

The detector provider will report the sizes of the thin and thick detectors pairs.

8.5.2 *CRaTER-L3-02 Minimum energy*

8.5.2.1 Test

The CRaTER silicon detectors are delivered from the provider, Micron Semiconductor Ltd, in boards with one thin and one thick detector. Before integration into the telescope stack, these boards will be taken to a beam facility and the minimum energy will be measured.

8.5.3 *CRaTER-L3-03 Nominal instrument shielding*

8.5.3.1 Inspection

Mechanical drawings of the instrument will be reviewed to visually gauge the range of shielding of the detectors.

8.5.4 *CRaTER-L3-04 Nadir and zenith field of view shielding*

8.5.4.1 Inspection

The thickness of the nadir and zenith aluminum plates will be measured with a micrometer at a minimum of five locations.

8.5.5 *CRaTER-L3-05 Telescope stack*

8.5.5.1 Inspection

The detector boards will be designed so they can only be mounted in the correct orientation (thin detector in zenith or deep space direction). The assembly will be inspected to verify the stack configuration.

8.5.6 *CRaTER-L3-06 Full telescope pathlength constraint*

8.5.6.1 Inspection

The minimum and maximum pathlength through pairs of detectors is determined through review of the mechanical drawings.

8.5.7 *CRaTER-L3-07 Zenith field of view*

8.5.7.1 Inspection

The zenith field of view will be determined by reviewing mechanical drawings of the telescope.

8.5.8 *CRaTER-L3-08 Nadir field of view*

8.5.8.1 Inspection

The nadir field of view will be determined by reviewing mechanical drawings of the telescope.

8.5.9 *CRaTER-L3-09 Calibration system*

8.5.9.1 Test

The pulse heights due to pulses from the calibration system will be compared with predictions derived from an analysis of the analog electronics.

8.5.10 *CRaTER-L3-10 Event selection*

8.5.10.1 Test

An automated program will be used to activate the calibration system on all combinations of detectors (64) and to step through all possible detector coincidences (63) and record the events that are sent to the ground support equipment. The resulting data will be analyzed to verify that the coincidence system functions correctly.

8.5.11 *CRaTER-L3-11 Maximum event rate*

8.5.11.1 8.5.10.2 Test

The calibration system will be commanded into a mode such that the synthesized event rate exceeds the maximum rate the digital system is capable of passing through the 1553 interface and it will be verified that the first 1200 events are correctly transmitted.

9.0 Data Product Traceability

9.1 Overview

This section demonstrates the flow from the raw CRaTER measurements back to the original LRO Level 1 data products. A detailed description of the production of data products from the raw instrument data is being written.

9.2 CRaTER data product table

Data Level	Description
Level 0	Unprocessed instrument data (pulse height at each detector, plus secondary science) and housekeeping data in CCSDS packets.
Level 1	Data extracted from CCSDS packets, with primary science data, at 1-s resolution. Ancillary data pulled in (spacecraft attitude, calibration files, etc.)
Level 2	Pulse heights converted into energy deposited in each detector using calibration conversion. Calculation of Si LET
Level 3	Data organized by particle environment (GCR, foreshock, magnetotail). SEP-associated events identified and extracted.
Level 4	Calculation of incident energies from modeling/calibration curves and TEP LET spectra

Table 9.1: Overview of the CRaTER data products.

9.3 Data product flow

9.3.1 *Level 0*

L0 science data consists of unprocessed instrument data (pulse height at each detector) at up to 25 packets of 48 events per second and secondary science counting rates (discarded events, good events, single detector rates) at a one second cadence.

L0 housekeeping data is at a cadence of 16 seconds and consists of bias voltage monitors and temperatures.

9.3.2 *Level 1*

L1 science data consists of unprocessed instrument data (pulse height at each detector), depacketed and grouped into 1 second data frames with secondary science placed in a header.

L1 housekeeping data is the raw L0 housekeeping data with analog voltages converted into physical quantities, such as temperature, voltage, and flow rate.

9.3.3 *Level 2*

L2 science data consists of energy deposited into each of the detectors, as determined by combing the L1 pulse heights with calibration tables (that may be functions of housekeeping data). The energy deposition is converted into an LET, using the nominal detector thickness and pathlength. Measurements are collected to produce a high time resolution LET spectrum. Quick look plots of singles rates and the

LET distribution are generated within one day of receipt for tracking instrument performance, identifying onset of solar energetic particle events, and maximizing interaction between CRaTER and other heliospheric observations.

The CRaTER Level 2 data product is responsive to the LRO Level 1 data product requirements (RLEP-LRO-M10 & RLEP-LRO-M20).

9.3.4 *Level 3*

L3 science data files add flags to identity the location of LRO with respect to the moon and the geospace environment (magnetosphere, foreshock, solar wind, lunar dayside/nightside) and the presence of sustained solar energetic particle events.

9.3.5 *Level 4*

9.3.5.1 Construction of typical LET spectra

LET measurements without solar energetic particle (SEP) flags will be combined to produce typical GCR LET spectra on a timescale of months. All LET spectra with SEP flags will be combined with observations of the primary SEP spectrum observed by other spacecraft to produce typical LET spectra as a function of the level of solar activity.

9.3.5.2 LET spectra classified by primary species

To the extent that the identify of the incident solar or galactic cosmic ray can be identified, the LET spectra will be calculated as a function of the incident particle species.

9.3.5.3 Closure between theory and observations

The primary spectrum of the GCR flux during quiet intervals and the SEP fluxes during individual solar events are gathered from other spacecraft, including Wind, ACE, GOES, and any other available observatories. These primary spectra are then combined with physical models of the instrument and radiation propagation codes to simulate the LET spectrum that should be observed by each of the detectors in CRaTER. Agreement between the observations and the predictions serves as a validation of these propagation codes.