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
A	32-066	Initial Controlled Release	JCKasper		

CRaTER
Instrument Requirements Document
Instrument Performance and Data Products Specification

Dwg. No. 32-01205

Revision A-
November 14, 2005

Table of Contents

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 the 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.

1. 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 LRO Level 1 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 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 are from raw CRaTER observations back to the original Level 1 requirements for mission success.

In this document, 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 the 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 that CRaTER is responsive to 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

- 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
- Instrument Mechanical Interface Control – 431-ICD-000084
- CRaTER Mechanical ICD – 431-ICD-000085
- CRaTER Thermal ICD – 431-ICD-000118
- LRO Ground System ICD – 431-OPS-000049

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 – 32-01206

2. Review of Requirements Levied on CRaTER

ESMD-RLEP-0010 Table 5.1 maps Level 1 RLEP requirements to Data Products. These are the data products relevant to CRaTER. For each of the two elements in ESMD-RELP-0010 that CRaTER is responsive to we list the requirement, the rationale, and the explicit data product to be produced.

2.1 RLEP-LRO-M10

2.1.1 Requirement

The LRO shall characterize the deep space radiation environment in lunar orbit, including neutron albedo.

2.1.2 Rationale

The ORDT specified that LRO should characterize the global lunar radiation environment, in particular at energies in excess of 10 MeV, and its biological impacts and potential mitigation, as well as investigate shielding capabilities and validation of other deep space radiation mitigation strategies involving materials.

2.1.3 Data Product

Measure and characterize that aspect of the deep space radiation environment, Linear Energy Transfer (LET) spectra of galactic and solar 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 characterize the deep space radiation environment in lunar orbit, including biological effects caused by exposure to the lunar orbital radiation environment.

2.2.2 Rationale

The ORDT specified that LRO should characterize the global lunar radiation environment and its biological impacts and potential mitigation, as well as investigate shielding capabilities and validation of other deep space radiation mitigation strategies involving materials.

2.2.3 Data Product

Investigate the effects of shielding by measuring LET spectra behind different amounts and types of areal density, including tissue-equivalent plastic.

3. Level 2 Traceability Matrix

The table in this section traces the flowdown from the Level 1 requirements and Data Products to CRaTER level 2 requirements. The individual CRaTER Level 2 requirements, with detailed explanations of the rationale for each value, are described 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 energy measurement	< 250 keV	RLEP-LRO-M20
CRaTER-L2-06	4.6	Minimum LET measurement	0.2 keV per micron	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-07	4.7	Maximum LET measurement	7 MeV per micron	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-08	4.8	Energy deposition resolution	< 0.5% max energy	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-09	4.9	Minimum D1D6 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. Individual Level 2 Requirements

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

4.1.1 Requirement

A linear energy transfer (or LET) spectrometer measures the amount of energy deposited in a detector of some known thickness and material property as a particle passes through it. The fundamental measurement of the CRaTER instrument shall be of the 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 is one of the most important quantitative inputs to models for predicting human health risks and radiation effects in electronic devices. By relaxing the demand to measure the entire parent cosmic ray spectrum to one where only that part of the energy spectrum deposited in a certain thickness of material is needed, the challenging requirements of measuring total incident cosmic ray particle energy is removed. This change in focus greatly simplifies the complexity, cost, and volume of the required instrument. In addition to these savings, an LET spectrometer essentially provides 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 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). The diameter of the TEP will be larger than the silicon detectors so all particles passing between the detectors pass through the 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

Minimum energy of particles that can just exit the TEP is 100 MeV and the TEP rather than the silicon 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 27 mm and the second section of TEP will have a length of approximately 54 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 Energy

4.5.1 Requirement

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

4.5.2 Rationale

This will permit calibration and aliveness tests of the detectors and the integrated instrument with common ion beams and radiation sources.

4.6 CRaTER-L2-06 Minimum LET measurement

4.6.1 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.

4.6.2 Rationale

Within the limits of the noise level of the detectors, it is desirable to detect particles that just stop in each detector and high energy particles with the asymptotic minimum ionizing deposition rate.

4.7 CRaTER-L2-07 Maximum LET measurement

4.7.1 Requirement

At each point in the telescope where the LET spectrum is to be observed, the maximum LET measured shall be no less than 7 MeV/ micron.

4.7.2 Rationale

Practical considerations effectively constrain the high end of the LET energy range. Slow moving, high-Z ions at large angles of incidence to the telescope stack 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. Models show that these particles will produce signals commensurate with a deposition of 7 MeV/micron.

4.8 CRaTER-L2-08 Energy deposition resolution

4.8.1 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.

4.8.2 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.

4.9 CRaTER-L2-09 Geometrical Factor

4.9.1 Requirement

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

4.9.2 Rationale

Statistically significant LET spectra should be accumulated over short enough time intervals to resolve dynamical features in the GCR/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. 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-L2-08
CRaTER-L3-02	6.2	Nominal instrument shielding	0.060” Al	CRaTER-L2-05
CRaTER-L3-03	6.3	Nadir and zenith field of view shielding	0.030” Al	CRaTER-L2-05
CRaTER-L3-04	6.4	Telescope stack	Shield, D1D2, A1, D3D4, A2, D5D6, shield	CRaTER-L2-01, CRaTER-L2-02, CRaTER-L2-04, CRaTER-L2-05
CRaTER-L3-05	6.5	Pathlength constraint	< 10% for D1D6	CRaTER-L2-01, CRaTER-L2-02, CRaTER-L2-03
CRaTER-L3-06	6.6	Zenith field of view	< 35 degrees D1D4	CRaTER-L2-01, CRaTER-L2-02
CRaTER-L3-07	6.7	Nadir field of view	< 75 degrees D3D6	CRaTER-L2-01
CRaTER-L3-08	6.8	Calibration system	Variable rate and amplitude	CRaTER-L2-08
CRaTER-L3-09	6.9	Event selection	64-bit mask	CRaTER-L2-01
CRaTER-L3-10	6.10	Maximum event transmission rate	1200 events/sec	CRaTER-L2-01
CRaTER-L3-11	6.11	Telemetry interface	32-02001	
CRaTER-L3-10	6.12	Power interface	32-02002	
CRaTER-L3-11	6.13	Thermal interface	32-02004	
CRaTER-L3-12	6.14	Mechanical interface	32-02003	

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

6. 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/dbout/32-data.html.

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. The thick detectors will be used to characterize energy deposition between approximately 200 keV and 100 MeV and the thin detectors will be used to characterize energy deposits between 2 MeV and 1 GeV.

6.1.2 Rational

Covering LET range requires a dynamic range of ~ 35,000, which 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.

6.2 CRaTER-L3-02 Nominal instrument shielding

6.2.1 Requirement

The shielding due to the mechanical housing the CRaTER telescope outside of the zenith and nadir fields of view shall be no less than 0.06” of aluminum.

6.2.2 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 particles with energies less than 10 MeV from entering the telescope.

6.3 CRaTER-L3-03 Nadir and zenith field of view shielding

6.3.1 Requirement

The zenith and nadir sides of the telescope shall have no less than 0.03” of aluminum shielding.

6.3.2 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. A thickness of 0.03” of aluminum 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.

6.4 CRaTER-L3-04 Telescope stack

6.4.1 Requirement

The telescope shall consist of a stack of components labeled from the nadir 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).

6.4.2 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.

6.5 CRaTER-L3-05 Full telescope pathlength constraint

6.5.1 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%.

6.5.2 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.

6.6 CRaTER-L3-06 Zenith field of view

6.6.1 Requirement

The zenith field of view, defined as D2D5 coincident events incident from deep space, shall be less than 35 degrees full width.

6.6.2 Rationale

This field of view, combined with the radius and separation of the detectors, leads to a sufficient geometrical factor while still limiting the uncertainty in the pathlength traveled by the incident particle.

6.7 CRaTER-L3-07 Nadir field of view

6.7.1 Requirement

The nadir field of view, defined as D4D5 coincident events incident from the lunar surface, shall be less than 75 degrees full width.

6.7.2 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.

6.8 CRaTER-L3-08 Calibration system

6.8.1 Requirement

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

6.8.2 Rationale

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

6.9 CRaTER-L3-09 Event selection

6.9.1 Requirement

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

6.9.2 Rationale

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

6.10 CRaTER-L3-10 Maximum event rate

6.10.1 Requirement

The maximum event rate CRaTER will transmit will be 1,200 events per second.

6.10.2 Rationale

Keep up with rates during intense storms, but recognize that this rate is sufficient to yield necessary statistics during flares.

6.11 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.

6.12 CRATER-L3-12 Power Interface

CRaTER target power consumption is 9.0 W. Instrument power consumption is discussed in the electrical ICD, 32-02002

6.13 CRaTER-L3-13 Thermal Interface

CRaTER will be completely covered by MLI and thermally coupled to the spacecraft through the optical bench. The thermal design and interface to the spacecraft is outlined in the thermal ICD, 32-02004.

6.14 CRaTER-L3-14 Mechanical Interface

CRaTER target mass is approximately 5.6 kg. Total instrument mass is discussed in the mechanical ICD, 32-02003.

7. 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 for mass, power, and heating.

7.1 Clear Nadir Field of Regard

The nadir field of view shall be less than 35 degrees full width and the spacecraft will not obstruct a 35 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 75 degrees full width and the spacecraft will not obstruct an 80 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 no more than 80 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. 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 four 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 fourth 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		T	A
CRaTER-L2-02	8.3.2	Measure change in LET spectrum through Tissue Equivalent Plastic (TEP)	TEP	I	T	A
CRaTER-L2-03	8.3.3	Minimum pathlength through total TEP	> 60 mm	I	T	
CRaTER-L2-04	8.3.4	Two asymmetric TEP components	1/3 and 2/3 (27 and 54 mm nominal)	I	T	
CRaTER-L2-05	8.3.5	Minimum energy measurement	< 250 keV	I	T	A
CRaTER-L2-06	8.3.6	Minimum LET measurement	< 0.25 keV per micron	I	T	A
CRaTER-L2-07	8.3.7	Maximum LET measurement	> 7 MeV per micron		T	A
CRaTER-L2-08	8.3.8	Energy deposition resolution	< 0.5% max energy	I	T	A
CRaTER-L2-09	8.3.9	Minimum D1D6 geometrical factor	> 0.1 cm^2 sr	I		A

Table 4: 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 Inspection

N/A

8.3.1.2 Test

Ion accelerator facilities and radiation sources will be used to verify that the instrument is correctly measuring the LET spectrum. The calibration pulser will be used to verify that the pulse heights measured by the electronics are consistent with expectations.

8.3.1.3 Analysis

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 Inspection

Mechanical drawings will be inspected to verify that particles passing between the detector pairs always pass through the TEP. This will be verified visually during construction of the CRaTER telescope stack.

8.3.2.2 Test

The instrument will be taken to a beam facility and subjected to high energy ions such as GeV/nucleon iron nuclei with narrow energy ranges to verify that the LET spectrum evolves through the TEP as expected. This will be done by measuring the LET spectrum in the silicon detectors and analyzing the observations through comparison with simulations. The evolution of ionizing radiation and nuclear interactions in the TEP will be demonstrated through proton and heavy ion beam tests.

8.3.2.3 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 inspected 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.

8.3.3.2 Test

The minimum pathlength through the TEP is the sum of the heights of the two TEP components. The height of the two asymmetric TEP components will be measured through appropriate means and the sum will be calculated.

8.3.3.3 Analysis

N/A

8.3.4 CRaTER-L2-04 Two asymmetric TEP components

8.3.4.1 Inspection

Mechanical diagrams will be inspected 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.

8.3.4.2 Test

The RMS variation of the length of the TEP sections will be measured through appropriate means.

8.3.4.3 Analysis

N/A

8.3.5 CRaTER-L2-05 Minimum energy

8.3.5.1 Inspection

The analog and digital electronics design will be inspected to verify that 200 keV energy deposition in the thin and thick detectors can be measured. For the thin detectors, this may involve a special mode with a lower amplification of the pulse from the detector.

8.3.5.2 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.

8.3.5.3 Analysis

Calculations will demonstrate that factors such as the amplification and discriminator thresholds permit 200 keV signals to be observed.

8.3.6 CRaTER-L2-06 Minimum LET measurement

8.3.6.1 Inspection

The minimum energy measured by the thick detectors will be combined with the thickness of the detector to calculated the minimum LET observable by that detector.

8.3.6.2 Test

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

8.3.6.3 Analysis

Numerical simulations will be conducted to predict the incident beam energies required to produce a particle LET spectrum in the detectors in the telescope stack.

8.3.7 CRaTER-L2-07 Maximum LET measurement

8.3.7.1 Inspection

N/A

8.3.7.2 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.

8.3.7.3 Analysis

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

8.3.8 CRaTER-L2-08 Energy deposition resolution

8.3.8.1 Inspection

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.

8.3.8.2 Test

The energy deposition resolution will be determined through analysis of pulsar data and through the use of line-emission from gamma-ray sources.

8.3.8.3 Analysis

Factors such as leakage current, detector capacitance, preamplifier characteristics, operating temperatures, and the signal processing design will be analyzed to predict the energy resolution of each of the detectors.

8.3.9 CRaTER-L2-09 Geometrical factor

8.3.9.1 Inspection

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

8.3.9.2 Test

N/A

8.3.9.3 Analysis

Numerical simulations will be used to verify the geometrical factor of the telescope detector pairs.

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	T	
CRaTER-L3-02	8.5.2	Nominal instrument shielding	0.060" Al	I	T	A
CRaTER-L3-03	8.5.3	Nadir and zenith field of view shielding	0.030" Al	I	T	A
CRaTER-L3-04	8.5.4	Telescope stack	Shield, D1D2, A1, D3D4, A2, D5D6, shield	I		
CRaTER-L3-05	8.5.5	Pathlength constraint	10% for D1D6	I	T	A
CRaTER-L3-06	8.5.6	Zenith field of view	35 degrees D1D4	I	T	A
CRaTER-L3-07	8.5.7	Nadir field of view	75 degrees D3D6	I	T	A
CRaTER-L3-08	8.5.8	Calibration system	Variable rate and gain	I	T	A
CRaTER-L3-09	8.5.9	Event selection	64-bit mask		T	A
CRaTER-L3-10	8.5.10	Maximum event transmission rate	1,200 events/sec		T	
CRaTER-L3-11	8.5.11	Telemetry interface	32-02001			
CRaTER-L3-12	8.5.12	Power interface	32-02002			
CRaTER-L3-13	8.5.13	Thermal interface	32-02004			
CRaTER-L3-14	8.5.14	Mechanical interface	32-02003			

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 measure the sizes of the thin and thick detectors pairs.

8.5.1.2 Test

The effective thickness of the detectors will be determined by measuring the energy loss of particles passing through the detectors at normal incidence in beam facilities.

8.5.1.3 Analysis

N/A

8.5.2 CRaTER-L3-02 Nominal instrument shielding

8.5.2.1 Inspection

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

8.5.2.2 Test

The telescope will be placed on a rotating mount in a beam facility and exposed to a broad energy spectrum of protons.

8.5.2.3 Analysis

Several cross-sections of the telescope stack will be analyzed to simulate the typical mass in shielding for the detectors as a function of direction. This method will be used to quantify the optimum allocation of shielding mass.

8.5.3 CRaTER-L3-03 Nadir and zenith field of view shielding

8.5.3.1 Inspection

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

8.5.3.2 Test

The thickness of the zenith and nadir shielding will be verified through testing by determining experimentally the minimum ion energy needed for particles to reach the upper (D1) and lower (D6) detectors respectively.

8.5.3.3 Analysis

Simple numerical simulations using ionizing radiation rates from the Stopping and Range of Ions in Matter (SRIM) program will be used to relate the thickness of the nadir and zenith shields to the minimum energy required to penetrate the telescope.

8.5.4 CRaTER-L3-04 Telescope stack

8.5.4.1 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). Mechanical drawings will be inspected to verify the stack configuration.

8.5.4.2 Test

N/A

8.5.4.3 Analysis

N/A

8.5.5 CRaTER-L3-05 Full telescope pathlength constraint

8.5.5.1 Inspection

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

8.5.5.2 Test

The range of pathlengths will be verified by analyzing the range of energy deposition in detectors of ion beams with known incident energy and variable angles of incidence on the telescope.

8.5.5.3 Analysis

The RMS variation of the pathlength through pairs of detectors is simulated by tracking the trajectories of particles with isotropic incidence.

8.5.6 CRaTER-L3-06 Zenith field of view

8.5.6.1 Inspection

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

8.5.6.2 Test

The zenith field of view can be verified by examining the flux of particles with a that produce a given set of detector coincidences as a function of the angle of incidence of a beam of test particles.

8.5.6.3 Analysis

Numerical simulations of primary particles incident on the telescope with an isotropic distribution will be used to predict the zenith field of view.

8.5.7 CRaTER-L3-07 Nadir field of view

8.5.7.1 Inspection

Same as 8.5.6.1.

8.5.7.2 Test

Same as 8.5.6.2.

8.5.7.3 Analysis

Same as 8.5.6.3.

8.5.8 CRaTER-L3-08 Calibration system

8.5.8.1 Inspection

The calibration system will be used to perform liveness tests.

8.5.8.2 Test

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

8.5.8.3 Analysis

The analog electronics will be analyzed to predict the pulse heights expected from the calibration system.

8.5.9 CRaTER-L3-09 Event selection

8.5.9.1 Inspection

N/A

8.5.9.2 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.

8.5.9.3 Analysis

N/A

8.5.10 CRaTER-L3-10 Maximum event rate

8.5.10.1 Inspection

N/A

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.

8.5.10.3 Analysis

N/A

8.5.11 CRaTER-L3-11 Telemetry interface

8.5.12 CRaTER-L3-12 Power interface

8.5.13 CRaTER-L3-13 Thermal interface

8.5.14 CRaTER-L3-14 Mechanical interface

9. 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 by Larry Kepko in the data analysis document.

Data Level	Description
Level 0	Reconstructed unprocessed instrument/payload data at full resolution; raw engineering measurements
Level 1	Reconstructed unprocessed instrument data at full resolution, time referenced, and annotated with ancillary information, computed and appended, but not applied, to the Level 0: processed tracking data
Level 2	Derived geophysical variables at the same resolution and location as the Level 1 source data.
Level 3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
Level 4	Model output or results from analyses of lower level data (i.e., variables derived from multiple measurements)

Table 8.1: CODMAC data level definitions.

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.
Level 1	Depacketed 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. 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 11.2: 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, temperature, and gas purge rate.

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 for tracking instrument performance and identifying onset of solar energetic particle events.

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 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.