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CRaTER
Instrument Requirements Document
Instrument Performance and Data Products Specification

Dwg. No. 32-01205

Revision 02
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Preface

This is the CRaTER Instrument Requirements Document (IRD). It is based on the original CRaTER Level 2 requirements document. This document contains the Instrument Performance Specification and Data Product Specification.

Revision 02 took the MRD and shaped it into the IRD. Several of the L2 requirements were moved down to the L3 level. Traceability matrices are provided at each level.

1. Introduction

The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) will investigate the effect of galactic cosmic rays on tissue-equivalent plastics as a constraint on models of biological response to background space radiation.

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 hardware requirements are outlined in Part I of this document, the Instrument Performance Specification. Part 2 of this document is 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.

1.1 Instrument Performance Specification

This document levies many general requirements on the CRaTER instrument. A separate document, the CRaTER Functional Instrument Description (FID), describes the specific instrument that we will produce to meet these requirements. It is in the FID that absolute performance requirements are listed in addition to goal performance requirements.

Level 1 Requirements are a Project's fundamental and basic set of requirements levied by the Program or Headquarters on the Project. Level 1 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 Level 1 requirements that CRaTER is responsive to are enumerated in ESMD-RLEP-0010 Table 5.1, which maps Level 1 RLEP requirements to instrument Data Products.

Level 2 Requirements are allocated to all mission segments (instruments, spacecraft bus, ground system, and launch vehicle). Level 2 Requirements also envelop Mission Assurance Requirements and technical resource allocations.

Level 3 Requirements Subsystem requirements. Level 3 Requirements include instrument specifications and interface definitions.

1.2 Data Product Specification

1.3 Relevant Documents

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 relavent 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 spectrum	LET	RLEP-LRO-M10
CRaTER-L2-02	4.2	Measure change in LET spectrum through TEP	TEP	RLEP-LRO-M20
CRaTER-L2-03	4.3	Minimum pathlength through total TEP	61 mm	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-04	4.4	Two asymmetric TEP components	27 mm and 54 mm	RLEP-LRO-M20
CRaTER-L2-05	4.5	Minimum energy measurement	200 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	0.3% max energy	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-09	4.9	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 will 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 harsh space radiation environment.

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

4.2.1 Requirement

The LET spectrum will 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.

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 will be 61 mm.

4.3.2 Rationale

Minimum energy of particles that can just exit the TEP is 100 MeV and the areal density of the stack is dominated by the TEP.

4.4 CRaTER-L2-04 Two asymmetric TEP components

4.4.1 Requirement

Break the TEP into two components, of 27 mm and 54 mm in length.

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.

4.5 CRaTER-L2-05 Minimum Energy

4.5.1 Requirement

The minimum energy deposition measured by the Silicon detectors is 200 keV.

4.5.2 Rationale

A low minimum energy allows the instrument to identify both primary and secondary particles that just pass through the TEP.

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 will be no greater than 0.2 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.

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 will 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 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 will have an energy resolution of at least 1/300 the maximum energy of 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 spectra should be accumulated over short enough time intervals such that dynamical features in the GCR/SEP can be resolved well. During quiescent intervals, the counting rate will be dominated by the very slowly varying GCR foreground. With typical GCR fluxes, the CRaTER 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	0.060” 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	8-bit	CRaTER-L2-08
CRaTER-L3-09	6.9	Event selection	64-bit mask	CRaTER-L2-01
CRaTER-L3-10	6.10	Maximum event rate	1,250 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

The numbers quoted in these sections are mainly taken from the most recent revision of the associated ICD. Links are provided to the most current appropriate ICD and should be followed to identify the current values. 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 will contain adjacent pairs of thin (approximately 140 micron) and thick (approximately 1000 micron) Si detectors. The thick detectors will be used to characterize energy deposition between approximately 200 keV and 100 MeV. The thin detectors will be used to characterize energy deposits between 2 MeV and 1 GeV.

6.1.2 Rational

Covering the energy range from 200 keV to 1 GeV requires a dynamic range in energy of 5000, 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

Reduce the flux of low energy particles (protons with energies below approximately 17 MeV) coming through the telescope at large angles of incidence.

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 0.06” 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 0.06” of aluminum would prevent protons of approximately 17 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. This is also a good thickness because above this energy protons will begin to produce nuclear fragmentations in the shield.

6.4 CRaTER-L3-04 Telescope stack

6.4.1 Requirement

The telescope will 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 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 D1D4 coincident events incident from deep space, will be 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 D3D6 coincident events incident from the lunar surface, will be 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 restriction on the pathlength, is a justified trade.

6.8 CRaTER-L3-08 Calibration system

6.8.1 Requirement

The CRaTER electronics will be capable of injecting calibration signals at 256 energies 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 may be send to CRaTER to identify the set of detector coincidences that should be analyzed and sent to the spacecraft.

6.9.2 Rationale

Particles which only deposit energy in a single detector, for example, do not provide sufficient information for study and should not be sent down to conserve telemetry.

6.10 CRaTER-L3-10 Maximum event rate

6.10.1 Requirement

The maximum event rate CRaTER will transmit will be 1,250 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 1250 events per second, with fill data in cases where

1200 events are not seen. 1250 events corresponds to approximately 100 kbs. 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 will be 35 degrees full width and the spacecraft will not obstruct a 40 degree field of regard.

7.2 Clear Zenith Field of Regard

The nadir field of view will be 75 degrees full width and the spacecraft will not obstruct an 80 degree full width field of regard.

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.

8. Data Product Overview

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	Reconstructured unprocessed instrument/payload data at full resolution; raw engineering measurements
Level 1	Reconstructured unprocessed instrument data at full resolution, timereferenced, 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.

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.

Data Level	Description
Level 4	Calculation of incident energies from modeling/calibration curves and TEP LET spectra

Table 11.2: Overview of the CRaTER data products.