CRaTER Performance Verification

Lunar Reconnaissance Orbiter
CRaTER Critical Design Review
Justin Kasper (CRaTER Proj. Sci.)
Verification Overview

• Sources
  – Instrument Requirements Document 32-01205
  – (Derived requirements, e.g. Detector Specification 32-05001)

• Division of Responsibilities
  – **Science and Functional Performance:** Project Scientist
    • Plan is documented in Functional Instrument Description 32-02105
    • Show in this presentation that IRD requirements have been met and can be verified
  – Quality & Reliability: Project MA
    • See Performance Assurance presentation by Klatt
  – Interfaces & Environments: Project Engineer
    • See Verification/Ground Support presentation by Goeke

• Related CRaTER Team Activities
  – Instrument Calibration
  – Instrument Characterization
  – Data Production and Science Operations (See Mission Operations presentation by Kepko)
Outline

- Instrument Overview (One slide)
- Verification Methods (One slide)
- Science Requirements Flowdown
  - Level 1 Requirements in ESMD-RLEP-0010
  - Level 2 and Level 3 in Instrument Requirements Document (IRD)
  - Presented at spacecraft requirements review, PDR – summary unless detail requested
- Examples of Performance Verification of Instrument Requirements
  - Testing prototype system at particle accelerator facilities
  - Inspection of mechanical drawings combined with simulations
  - Summary of verification plan for all Level 2 and Level 3 requirements
- Conclusions
CRaTER Functional Diagram

Telescope assembly

Telescope stack

Telescope board

D1

Preamp

D2

Preamp

TEP

D3

Preamp

D4

Preamp

TEP

D5

Preamp

D8

Preamp

Electronics box assembly

Analog processing Board (APB)

Pulse shape

Peak

ADC

Digital processing Board (DPB)

Pulse shape

Peak

ADC

FPGA

±5V

1553

+5V

+75V Bias

+225V Bias

28V

1 Hz clock

Spacecraft Bus
Verification Methods

- **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.
Cosmic Ray Telescope for the Effects of Radiation

Level 1 Requirements

RLEP-LRO-M10
The LRO shall characterize the deep space radiation environment at energies in excess of 10 MeV in lunar orbit, including neutron albedo.

RLEP-LRO-M20
The LRO shall measure the deposition of deep space radiation on human equivalent tissue while in the lunar orbit environment.

Level 1 Data Products

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.

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

Level 2 Instrument Requirements

- Measure the Linear Energy Transfer (LET) spectrum
- Measure change in LET spectrum through Tissue Equivalent Plastic (TEP)
- Minimum pathlength through total TEP > 60 mm
- Two asymmetric TEP components 1/3 and 2/3 total length
- Minimum LET measurement 0.2 keV per micron
- Maximum LET measurement 7 MeV per micron
- Energy deposition resolution < 0.5% max energy
- Minimum full telescope geometrical factor 0.1 cm² sr

RLEP-LRO-M10
Characterize deep space radiation environment

RLEP-LRO-M20
Radiation effects on human equivalent tissue

Cosmic Ray Telescope for the Effects of Radiation
Flow of Requirements

**Level 2 Parent Requirements**

- 01
- 02
- 03
- 04
- 05
- 06
- 07

**Level 3 Instrument Requirements**

1. Thin and thick detector pairs 140 & 1000 µm
2. Minimum energy < 250 keV
3. Nominal instrument shielding > 1524 µm Al
4. Nadir and zenith field of view shielding < 762 µm
5. Telescope stack
6. Pathlength constraint < 10% for D1D6
7. Zenith field of view < 35°
8. Nadir field of view < 75°
9. Calibration system
10. Event selection
11. Maximum transmission rate > 1200 events/second
Testing Validation Techniques with the CRaTER Prototype

- Four detectors instead of six
- Adjustable TEP sections and detector holders mounted on optical bench
- External PHA and DAQ systems
- Remotely controlled by PC
- Convergence with CRaTER DAQ philosophy
Testing Validation Techniques with the CRaTER Prototype

**Cosmic Ray Telescope for the Effects of Radiation**

- Berkeley National Laboratory 88” Cyclotron (Ions, 20 MeV/nuc)
- Massachusetts General Hospital Proton Therapy Center (0-300 MeV p)
- Brookhaven National Laboratory (Gev/nuc Fe)

MGH Proton Accelerator

**Minimum LET measurement 0.2 keV per micron**

**Maximum LET measurement 7 MeV per micron**

**Energy deposition resolution < 0.5% max energy**
Testing Validation Techniques with the CRaTER Prototype

• Change proton energy
• Change thickness of TEP

Cosmic Ray Telescope for the Effects of Radiation

Minimum LET measurement 0.2 keV per micron
Maximum LET measurement 7 MeV per micron
Energy deposition resolution < 0.5% max energy
Testing Validation Techniques with the CRaTER Prototype

Cosmic Ray Telescope for the Effects of Radiation

Minimum LET measurement 0.2 keV per micron

Maximum LET measurement 7 MeV per micron

Energy deposition resolution < 0.5% max energy
Cosmic Ray Telescope for the Effects of Radiation

Pathlength constraint < 10% for D1D6

Zenith field of view < 35°

Nadir field of view < 75°
## Level 2 Requirements Verification Outline

<table>
<thead>
<tr>
<th>Item</th>
<th>Sec</th>
<th>Requirement</th>
<th>Quantity</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRaTER-L2-01</td>
<td>8.3.1</td>
<td>Measure the Linear Energy Transfer (LET) spectrum</td>
<td>LET</td>
<td>A</td>
</tr>
<tr>
<td>CRaTER-L2-02</td>
<td>8.3.2</td>
<td>Measure change in LET spectrum through Tissue Equivalent Plastic (TEP)</td>
<td>TEP</td>
<td>A</td>
</tr>
<tr>
<td>CRaTER-L2-03</td>
<td>8.3.3</td>
<td>Minimum pathlength through total TEP</td>
<td>&gt; 60 mm</td>
<td>I</td>
</tr>
<tr>
<td>CRaTER-L2-04</td>
<td>8.3.4</td>
<td>Two asymmetric TEP components</td>
<td>1/3 and 2/3 (27 and 54 mm nominal)</td>
<td>I</td>
</tr>
<tr>
<td>CRaTER-L2-05</td>
<td>8.3.5</td>
<td>Minimum LET measurement</td>
<td>&lt; 0.25 keV per micron</td>
<td>T</td>
</tr>
<tr>
<td>CRaTER-L2-06</td>
<td>8.3.6</td>
<td>Maximum LET measurement</td>
<td>&gt; 7 MeV per micron</td>
<td>T</td>
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<tr>
<td>CRaTER-L2-07</td>
<td>8.3.7</td>
<td>Energy deposition resolution</td>
<td>&lt; 0.5% max energy</td>
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<tr>
<td>CRaTER-L2-08</td>
<td>8.3.8</td>
<td>Minimum D1D6 geometrical factor</td>
<td>&gt; 0.1 cm² sr</td>
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## Level 3 Requirements Verification Outline

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

- The design for CRaTER presented at CDR meets the performance requirements specified in the Instrument Requirements Document
- We have developed a plan for verifying that the engineering and final flight models of CRaTER meet these requirements
- These conclusions are guided by:
  - Experience with a prototype instrument
  - Testing at particle accelerator facilities
  - Analysis of engineering documents
  - Numerical simulations
  - Comparison with other instruments (such as CR-39)
Cosmic Ray Telescope for the Effects of Radiation
• CRaTER-L2-01 Measure the Linear Energy Transfer Spectrum
• *Verification by 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.
• CRaTER-L2-02 Measure Change in LET Spectrum through TEP
• *Verification by Analysis*
• We have used numerical simulations to model the expected evolution the LET spectrum of ions through the TEP sections. These simulations have agreed very well (within our needed measurement accuracy) with measurements at the proton beam at Mass General Hospital.
• CRaTER-L2-03 Minimum Pathlength through total TEP
• **Current Value**
• The current value of the minimum pathlength through the TEP in the engineering model is 61mm.
• **Verification by 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. We also found that the length of the TEP could be double checked by examining beam data.
• CRaTER-L2-04 Two asymmetric TEP components

• **Current Value**
  • The short section of TEP is 27 mm long and the long piece of TEP is 54 mm long.

• **Verification by 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.
• CRaTER-L2-05 Minimum LET measurement
• Test
• The minimum LET threshold of the thick detectors will be measured in an accelerator facility.
• CRaTER-L2-06 Maximum LET measurement

**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 beam testing at lower LET values. We have demonstrated this procedure using the MGH measurements and the TEP Test Assembly.
• CRaTER-L2-07 Energy deposition resolution

• **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. We have performed this in the lab with old Micron detectors to demonstrate that it can be done successfully.
• CRaTER-L2-08 Geometrical factor
• 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.
• CRaTER-L3-01 Thin and thick detector pairs
• **Inspection**
• The detector provider will report the sizes of the thin and thick detectors pairs.
- CRaTER-L3-02 Minimum energy
- *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. Additionally, we demonstrated at BNL that an alpha source may be used to quickly place an upper limit on the thickness of any dead layers on the detectors.
• CRaTER-L3-03 Nominal instrument shielding
• **Inspection**
• Mechanical drawings of the instrument will be reviewed to visually gauge the range of shielding of the detectors.
• CRaTER-L3-04 Nadir and zenith field of view shielding
• **Inspection**
• The thickness of the nadir and zenith aluminum plates will be measured with a micrometer at a minimum of five locations.
• CRaTER-L3-05 Telescope stack
• **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.
• CRaTER-L3-06 Full telescope pathlength constraint
• **Inspection**
• The minimum and maximum pathlength through pairs of detectors is determined through review of the mechanical drawings.
• CRaTER-L3-07 Zenith field of view
• **Inspection**
• The zenith field of view will be determined by reviewing mechanical drawings of the telescope.
• CRaTER-L3-08 Nadir field of view
• **Inspection**
• The nadir field of view will be determined by reviewing mechanical drawings of the telescope.
• CRaTER-L3-09 Calibration system

**Test**

• The pulse heights due to pulses from the calibration system will be compared with predictions derived from an analysis of the analog electronics.
• CRaTER-L3-10 Event selection
• 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.
• CRaTER-L3-11 Maximum event rate

  *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.