Rev.	ECO	Description	Author	Approved	Date
01	32-037	Initial Release for comment	CSweeney		6/25/05
02	32-050	Update for 431-RQMT-000012 Rev -	RFGoeke		9/12/05
03	32-145	Add ICD verification tables	RFGoeke		6/12/06
04	32-146	Fix unintentional para drops in Section 8	RFGoeke		6/20/06

CRaTER
Performance and Environmental Verification Plan

Dwg. No. 32-01206

Revision 04
June 20, 2006

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Preface

Revision 01 of this document is being circulated for comment.

Revision 02 updates the references to the Observatory Mechanical Systems Specification, 431-RQMT-000012 Rev -.

Revision 03 updates mechanical loads and incorporates the interface performance requirements found in the four ICDs.

1.0 Introduction

1.1 Purpose

This verification plan defines the management approach that will be used to verify that the instrument performance and environmental verification requirements are met.

1.2 Scope

This plan describes the approach required to verify that the instrument meets the engineering performance requirements of the applicable Interface Control Documents and the Environmental Verification requirements. The verification of instrument functional science requirements are covered in the Instrument Requirements Document, 32-01205.

The verification program is designed to provide the verifications listed below:

- The instrument meets the requirements of its Data, Electrical, Mechanical, and Thermal Interface Control Documents.
- The instrument can survive and perform as required in the environments predicted to be encountered during transportation, handling, installation, launch, and operation.
- The instrument has meet its environmental test requirements.

1.3 Verification Program Philosophy

All instrument functional and design requirements will be verified by inspection, analysis, demonstration or test. Where test data and analysis results both exist, the test data will be utilized to verify the analysis results.

The instrument flight and flight spare models will be tested at Protoflight levels and durations.

1.4 Verification Categories

The four basic categories for verification are defined as follows:

Inspection: This is used to determine system characteristics by examination of and comparison with engineering drawings, or similar documentation. 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.

Demonstration: This is a variation of the test method used to verify conformance of functional characteristics with specified requirements by go/no-go criteria without the use of elaborate measurement equipment.

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.

1.5 Description of Assemblies

CRaTER consists of a single assembly comprised of a telescope and an electronics box. Both items are next detailed briefly.

1.5.1 Telescope

Composing the telescope are several charged-particle detectors (CPDs), charge-sensitive preamplifiers (CSAs), and tissue equivalent plastic (TEP). The CPDs and the TEP together provide a means of gathering linear energy transfer (LET) spectra which closely mimic those that occur when radiation passes through human tissue. The CSAs are made of field-effect transistors coupled to AMPTEK model A250 preamplifiers. All the items are housed in a rigid aluminum container affixed to the side of the CRaTER electronics box.

1.5.2 Electronics Box

The electronics box contains an analog board which does spectroscopy pulse-shaping amplification and a digital board which digitizes the pulse events. The digital board also handles both command and telemetry communication with the S/C. These items together with regulated power supplies are housed in a rigid aluminum structure.

2.0 Applicable Documents

The following documents form the basis for this plan and will be used, together with this plan, to generate the procedures necessary to accomplish instrument verification.

2.1 GSFC Configuration Controlled Documents

- LRO Technical Resource Allocation Requirements – 431-RQMT-000112
- LRO Electrical ICD – 431-ICD-00008
- CRaTER Electrical ICD – 431-ICD-000094
- LRO Radiation Requirements – 431-RQMT-000045
- 1553 Bus Specification – 431-SPEC-000102
- CRaTER Data ICD – 431-ICD-000104
- General Mechanical Systems Specification – 431-SPEC-000012
- CRaTER Mechanical ICD – 431-ICD-000085
- General Thermal Subsystem Specification – 431-SPEC-000091
- CRaTER Thermal ICD – 431-ICD-000118

2.2 CRaTER Configuration Controlled Documents

- CRaTER Performance Assurance Implementation Plan – 32-01204
- Mechanical Interface Drawing – 32-02003.02

3.0 General Verification Activities

3.1 Safety Considerations

Ground Support Equipment (GSE) will be designed, in conjunction with the design of the instrument itself, to ensure instrument safety in the presence of GSE failures. Similarly, the environmental equipment used to perform tests will be monitored to safeguard the instrument from being exposed to excessive levels and loss of power during the testing process. These include excessively high or low temperatures, loss of vacuum, or loss of power. For all situations, the safety of the operators and of the flight hardware is of paramount importance.

3.2 Personnel Responsibilities

CRaTER Mission Assurance personnel, whether at Boston University, Aerospace Corp, MIT, GSFC or an outside test facility, will monitor all verification tests. The NASA-GSFC Instrument Manager will be notified in advance of scheduled instrument level environmental verification tests. CRaTER Mission Assurance personnel will approve all formal test procedures and sign off formal test reports.

3.3 Detailed Verification Test Procedures

Every instrument-level test and analysis required by this plan will have a Verification Procedure. The procedure will describe the test item's configuration along with details of how the particular test or analysis will be performed. All activities to be accomplished will be logged, and places for the test conductor and quality representative's initials, along with the date of performance, will be provided.

Test procedures will address implementation, parameters, test item functions and performance limits, facility control, quality control checkpoints, data collection, reporting requirements, provisions for contamination control, and safety issues. For analyses methods and procedures will be indicated, along with parameters, acceptable item performance limits, reporting requirements, and data output.

If a test or analysis cannot be satisfactorily completed, then a malfunction report will be produced by the test conductor. It will provide all the particular information detailing the malfunction. A malfunction may result in premature test termination, depending on operation procedures. Regardless of this, a malfunction report will be filed with the Verification Report for the activity.

Detailed test procedures and specifications will be written, reviewed, and approved by the CRaTER Project, prior to instrument-level verification testing. The lead individual for each procedure depends upon the category.

- **Environmental Requirements:** Project Engineer
- **Performance Requirements:** Project Scientist
- **Contamination Requirements:** Contamination Engineer
- **Interface Requirements:** Cognizant Design Engineer

The Instrument Project Engineer and Instrument Mission Assurance Manager will approve all such procedures.

3.4 Facilities and Instrumentation

Environmental and electrical tests may be conducted at vendor, Boston University, Aerospace Corp, MIT or GSFC test facilities. At the instrument level, and in some cases the subsystem level, tests will be conducted using special purpose test equipment. GSE standard commercial test equipment will be used to conduct tests at lower levels. The planned facilities for the different verification activities are:

- **Acoustics** GSFC[1]
- **Shock** GSFC[2]
- **EMI/EMC** Chomerics, Woburn, MA
- **Interfaces**[3] MIT-MKI, Cambridge, MA
- **Vibration**[4] Draper Labs, Cambridge, MA
- **Thermal Vacuum**[5] MIT-MKI, Cambridge, MA

3.5 Interaction of Test and Analysis

Thermal characteristics measured during thermal balance testing will be analyzed and factored into the thermal model. In addition, the thermal analysis that will have been prepared for the instrument will be updated.

All test data will be appropriately used to verify design analyses for all critical hardware elements. Hardware failing to meet the requirements defined through the design analyses will be critically reviewed, reanalyzed, and/or modified as necessary.

3.6 Rationale for Retest

In the event of a failure during performance test and qualification/acceptance testing, depending on the nature of the failure, complete retesting may be required.

Thermal/vacuum testing, performance testing and instrument calibration are critical functions of the program. If a failure was to occur during performance testing of the instrument, and the failure was isolated to the test hardware or test profile, the test would only need to be repeated from the previous step. If it were due to the extreme of exposure to the environment, however, the entire test would have to be repeated upon correction of the problem. Malfunction and intermittent operation would be handled in a similar manner.

Since Electromagnetic Compatibility (EMC) tests are not strictly functional performance tests, if a failure, malfunction, or problem occurs with the instrument during an EMC test, complete retest generally will not be required. After incorporating changes to fix a problem and analytically verifying expected results, the test will be continued from the last successful step; only the step where the problem occurred would need to be repeated. Assessment will be made of the problem to ensure that previous test steps were not affected. This, to some extent, will depend on the type of problem, i.e., malfunction, intermittent or complete failure.

3.7 Functional Test Definition

3.7.1 Long Form Functional Test

The Long Form Functional test shall be a detailed demonstration that the hardware meets performance requirements within allowable tolerances. External interfaces shall be run through their allowable ranges, but the charged particle events constituting the science input will only be simulated. The test shall demonstrate operation of all redundant circuitry and exercises all operational modes. The initial Long Form results shall serve as a baseline against which all subsequent functional tests are compared.

Save those parts of the test that manipulate the spacecraft interfaces (*e.g.:* errors on the 1553 bus), the Long Form test can be run at the Observatory level, both during I&T and during in-flight checkout.

The Long Form Functional test can typically be performed in under 2 hours.

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[1] Instrument will be exposed to acoustics at the Observatory level.

[3] Data, Electrical, Mechanical, & Thermal
[4] Limit Loads, Modal Survey, Sine Sweep, Random Vibration
[5] Thermal Cycle, Thermal Balance

3.7.2 Short form Functional Test

The Short Form Functional Test is a subset of the Long Form used to verify that the instrument operates properly in a nominal science mode. This test is run many times in the life of the instrument, typically after every physical move, at thermal dwells during T/V, between axis of vibration tests, *etc.*

This test can be run unchanged at any time during spacecraft I&T and in-flight.

The Short Form Functional test can typically be performed in under 15 minutes..

3.8 Control of Unscheduled Activities During Verification

Instrument Mission Assurance is responsible for assuring that approved documentation is available prior to testing and employed during test activities. All testing not covered by a previously-approved procedure will be approved prior to its implementation. Activities covered include new tests, deviations from approved tests, and troubleshooting and correction of malfunctions. The person in charge of the test is responsible for documenting the action to be taken. Approval must be received from the Project Engineer prior to initiating any unscheduled activities.

3.9 Procedures and Reports

Upon completion of each verification activity a report will be prepared which details the procedure as performed, copies of all relevant data, and a description of any anomalous results. The report will be delivered to GSFC within 30 days of activity completion.

When a verification activity produces unsatisfactory results, it will typically be repeated upon resolution of the underlying problem. Complete verification reports will be produced for such cases, and will always be available for review upon request. Only the final report will be delivered to GSFC, but this report will include specific reference to any prior activities.

3.10 End to End Testing

It is understood that the responsibility for Observatory system end-to-end testing rests with the LRO Project. The CRaTER Project will provide appropriate personnel to support end-to-end system tests, other instrument related tests, and mission simulations conducted by the LRO Project. The verification tests described below will, except as noted, be performed prior to instrument delivery for Observatory I&T.

4.0 Data Interface Verification

Verification of the Data Interface Control Document, 32-02001, will be accomplished by use of the Electrical GSE operating the Flight and/or Flight Spare Instrument. The vast majority of the applicable items are verified by the Long Form Functional test for both instruments; the remaining items will be assumed verified by similarity to the first flight article verified.

4.1 Verification Matrix

All paragraph references are to the Data ICD, 32-02001 Rev. A (aka 431-ICD-000104). The test methods are denoted as **I**(inspection), **A**(nalysis), **D**(emonstration), and **T**(est)

Reference	Title	I	A	D	T	Comment
2	1553 Bus Protocol					(title)
2.1	Transfer Formats			x		
2.2	Mode Codes		x	x		
2.3	Unused Subaddresses		x	x		
2.4	Status Word Flags			x		
2.5	Data Bus Control					S/C requirement
2.6	Error Recovery					S/C requirement
2.7	Data Word Order			x		
3	Commends					(title)
3.1	Packet Description					S/C requirement
3.1.1	Primary Header Format					Ops requirement
3.1.2	Secondary Header Format					Ops & S/C requirement
3.2	1 Hz Reference					S/C requirement
3.3	Command Timing					S/C requirement
3.4	Command Application Format			x		
3.5	Command Descriptions					(explanatory text for para 3.4)
4	Telemetry					(title)
4.1	MIL-STD-1553 Packet Description					(explanatory text)
4.1.1	Primary Header Format	x				
4.1.2	Application ID Assignments	x				
4.1.3	Secondary Header Format	x				
4.1.4	Telemetry Flow Control			x		
4.1.5	1553 Primary Science Data Retrieval					S/C requirement
4.1.6	Telemetry Timing					S/C requirement
4.1.7	Telemetry Application Data Format					(title)
4.1.7.1	Primary Science	x				
4.1.7.2	Secondary Science	x				
4.1.7.3	Housekeeping	x				
4.2	Telemetry Description					(explanatory text for para 4.1.7.3)
4.3	Data File Formats					S/C requirement
4.3.1	Science Data Format					S/C requirement
4.3.2	Housekeeping Data Format					S/C requirement

5.0 Electrical Interface Verification

Verification of the Electrical Interface Control Document, 32-02002, will be accomplished by use of the Electrical GSE operating the Flight and Flight Spare Instrument together with such conventional laboratory instruments as may be required.

5.1 Verification Matrix

All paragraph references are to the Electrical ICD, 32-02002 Rev. A (aka 431-ICD-000094). The test methods are denoted as **I**(inspection), **A**(nalysis), **D**(emonstration), and **T**(est)

Reference	Title	I	A	D	T	Comment
3.0	LRO Electrical System Requirements					(title)
3.1	Power					S/C requireement
3.1.1	Power Profile	x				
3.1.2	Instrument Power Specifications				x	
3.2	System Grounding Requirements	x				
3.3	EMI/EMC Requirements				x	(see environmental test section)
3.4	Data and Signal Interfaces	x			x	
3.5	Multipaction and Corona		x			
3.6	Design for Radiation		x			
3.7	Charging and Discharging Req.		x			
3.8	Harness Requirements	x				
3.9	Temperature Sensors	x				
3.10	Operational Heater					(not applicable)
3.11	Survival Heater	x				
3.12	External Electrical Interfaces					(not applicable)
3.13	Connector/Pin Out Definition					(title)
3.13.1	Power Connector	x				
3.13.2	Housekeeping Connector	x				
3.13.3	1553 Connector	x				

6.0 Mechanical Interface Verification

Verification of the Mechanical Interface Control Document, 32-02003, will be accomplished by use standard laboratory metrology instruments.

6.1 Verification Matrix

All paragraph references are to the Mechanical ICD, 32-02003 Rev. A (aka 431-ICD-000085). The test methods are denoted as **I**(inspection), **A**(nalysis), **D**(emonstration), and **T**(est)

Reference	Title	I	A	D	T	Comment
2.0	Coordinate Systems					(title)
2.1	Spacecraft Reference Coordinate System					S/C requireement
2.2	Instrument Coordinate System	x				
3.0	Physical Properties					(titl.e)
3.1	Mass Properties				x	
3.1.1	Mass of Instrument Assembly				x	
3.1.2	Center of Mass				x	
3.1.3	Moments and Products of Inertia		x			
3.2	Physical Envelope	x				
3.3	Fields of View					(title)
3.3.1	Science Field of View	x				
3.3.2	Field of Regard	x				
4.0	Mounting;					(title)
4.1	Mounting Surface					(title)
4.1.1	Spacecraft Mounting Surface					S/C requirement
4.1.2	Instrument Mounting Surface	x				
4.2	Mounting Hole Locations	x				
4.3	Mounting Hardware					S/C requirement
4.4	Mounting Hardware Provider					S/C requirement
4.5	Grounding Straps					not applicable
4.6	Connector Locations	x				
5.0	Alignment	x				
6.0	Environments				x	(see environmental test section)
7.0	Ground Support Equipment					descriptive text

Reference	Title	I	A	D	T	Comment
8.0	Launch Vehicle Considerations					
8.1	Access in Launch Vehicle Fairing					S/C requirement
8.2	Red Tag Items					none
8.3	Green Tag Items					none
9.0	Contamination Purge Requirements					(title)
9.1	Contamination Control Plan					reference information
9.2	Purge					(title)
9.2.1	Purge Port Location and Access	x				
9.2.2	Other Considerations					none
10.0	Model Requirements					(title)
10.1	CAD Model Requirements			x		
10.2	Finite Element Model Requirements					not applicable
10.3	Mass Simulator			x		

7.0 Thermal Interface Verification

Verification of the Thermal Interface Control Document, 32-02004, will be accomplished by use of the Electrical GSE operating the Flight and Flight Spare Instrument together with such conventional laboratory instruments as may be required.

7.1 Verification Matrix

All paragraph references are to the Electrical ICD, 32-02004 Rev. - (aka 431-ICD-000118). The test methods are denoted as **I**(inspection), **A**(nalysis), **D**(emonstration), and **T**(est)

Reference	Title	I	A	D	T	Comment
3.0	Thermal Interfaces					(title)
3.1	Interface Definitions					explanatory text
3.2	Instrument Reference Locations	x				
3.3	Instrument Temperature Limits	x				
3.4	Specification of Instrument-side Temperatures	x				
3.5	Additional Thermal Information					not applicable
4.0	Thermal Design Concept					(title)
4.1	Thermal Coupling					(title)
4.1.1	Conductive Coupling	x				
4.1.2	Radiative Coupling	x				
4.2	Internal Controls					not applicable
4.3	Internal Power Dissipations				x	
4.4	Thermal Control Coatings	x				
4.5	Thermal Blankets	x				
4.5.1	Venting Requirements	x				
4.5.2	Grounding Requirements	x				
4.5.3	Cleanliness Requirements	x				
4.5.2	Blanket Interface with Spacecraft	x				
5.0	Interface Temperature Requirements					(title)
5.1	Temperature Range Requirements					S/C Requirement
5.2	Temperature Rate-of-Change Req.					none
5.3	Temperature Gradient Requirements					none
6.0	Temperature Monitoring					(title)
6.1	CRaTER Reference Locations	x				
6.2	Externally Mounted S/C Sensors					none
6.3	Internally Mounted S/C Sensors	x				
6.4	Instrument Mounted Sensors					none
6.5	Temperature Limits				x	(see environmental test section)
7.0	Heaters					S/C provided
8.0	Thermal Model Requirements/Formats			x		
9.0	Thermal Vacuum Test Considerations					explanatory text

8.0 Electromagnetic Compatibility

8.1 EMC Tests

These tests are for the purpose of ensuring and verifying that CRaTER does not generate Electromagnetic Interference (EMI), radiated or conducted, and also that it is not susceptible to EMI during orbital operations. The EMI requirements specified in Sect. 3.3 of the LRO Project Electrical Systems Interface Control Document (431-ICD-000008 Rev -) will be used to generate the appropriate procedures.

Only one flight unit will be subjected to EMI testing; the other unit will be accepted by similarity.

9.0 Mechanical and Structural Environmental Tests

Mechanical and structural tests and analyses will be performed on both Flight and Flight Spare instruments to show compliance with all applicable structural and mechanical requirements. Such tests demonstrate satisfactory design, safety factors, and workmanship. Test levels will be taken from the latest revision of the LRO Mechanical Systems Specification (431-SPEC-000012) for protoflight hardware. The levels given here are from current information.

9.1 Modal Survey

The instrument will undergo testing of its modal responses at room ambient conditions using a low level sine sweep up to 200Hz. Electrical power will not be supplied to the CRaTER instrument or any of its components during the test. Mounting will be done with a fixture designed to mimic the bolt pattern interface of the S/C, but not its rigidity. Testing will be performed in three orthogonal directions.

9.2 Finite Element Analysis

Since CRaTER's fundamental vibrational frequency is predicted to be higher than 75 Hz, FEM analysis is not required.

9.3 Structural Loads

The instrument will be subjected to a 5 cycle sine burst test at 26.8 g to verify structural integrity. The test will be conducted at room ambient conditions. The test will be performed in each of three mutually perpendicular axes. Power will not be applied to the electronics during structural testing.

9.4 Acoustics

CRaTER's design is such that acoustic testing is deemed unnecessary at the instrument level. CRaTER will, however, undergo acoustic testing once integrated with the S/C at the planned orbiter acoustic test.

9.5 Random Vibration

The instrument will be subjected to 3 axis random vibration at 14.1 grms.

9.6 Sine Vibration

The instrument will be subjected to a Sine Vibration test at 8 g peak load over the frequency range of 5 to 100 Hz, 4 octaves/minute sweep rate, in each of 3 axis.

9.7 Mechanical Shock

CRaTER is not considered susceptible to shock and will, therefore, defer shock testing to the Observatory level. A shock test on the engineering model telescope will be done to verify this assumption. The current numbers peak at 930 g at 10000 Hz.

9.8 Mechanical Functionality

CRaTER employs no mechanisms---no moving parts of any kind---obviating mechanical function testing.

9.9 Life Testing

Since there are no limited life items currently identified n CRaTER, life testing will not be undertaken.

9.10 Mass Properties

During the design and early development phase, analyses were performed on CRaTER's mass properties using the physical characteristics of the subassemblies and parts, assemblies, and components. These analyses will be updated with designed and measured data.

During verification testing, the mass properties of the instrument will be further verified my measurements. These will include measurements of the mass and centers of mass, but not the moments. A report of the analyses and measurements will be generated.

9.11 Pressure Profile

A single-compartment pressure venting analysis will be performed on CRaTER to determine if load margins are adequate to meet requirements as provided in the LRO General Thermal Subsystem Specification (431-SPEC-000091).

10.0 Vacuum and Thermal

10.1 General Discussion

The objective of these tests is to verify the CRaTER Instrument will perform satisfactorily in the vacuum and thermal environment of space. System tests will verify that the thermal design and control of the instrument will maintain the flight hardware within the specified mission thermal limits

10.2 Thermal Vacuum

Thermal-vacuum tests will be performed on the CRaTER flight and flight spare instruments. The tests will be conducted in accordance with the requirements of the Thermal System Specification (431-SPEC-000091), para. 6.1

In addition to the test chamber operating personnel, the following personnel will be required for the initiation of the test; Instrument Project Engineer, Mechanical Engineer, Calibration lead, Test lead, Operator for the GSE, and Mission Assurance representative. A safety review will be performed prior to the testing.

At this point in testing, nearly all analyses and control limits will have been validated or verified by previous testing except for the thermal model. Thermal characteristics derived during thermal-vacuum testing of CRaTER will be analyzed and factored into the thermal model. In addition, the thermal model will be updated.

During thermal-vacuum testing, performance tests will be conducted on the instrument. These consist of verifying compliance with the performance and operation specifications. These tests will be designed to verify the thermal design and thermal math model of the instrument and to demonstrate the ability of the thermal control system to maintain the established thermal limits specified in the CRaTER Requirements Document.

Thermal vacuum tests consist of Thermal Balance tests and Thermal Cycling, which are described below.

10.2.1 Balance

Numerical models of the thermal behavior of CRaTER will be constructed, and these models will be confirmed by data obtained during thermal-balance testing. Once verified the model will be employed to ensure that the thermal control system can maintain all hardware within the established limits of the mission.

10.2.2 Vacuum

Thermal vacuum testing will demonstrate CRaTER's ability to satisfactorily perform in functional modes simulating mission conditions in vacuum at nominal mission operational temperatures, at temperatures 10 ^{o}C above and 10 ^{o}C below predicted mission extremes, and during temperature changes. The ability of the hardware to perform post exposure to temperatures 10 ^{o}C above and 10 ^{o}C below predicted nonfunctional extremes will also be demonstrated during testing. A minimum of eight thermal vacuum cycles will be employed on both the flight model and flight spare. A minimum dwell of four hours will be maintained at each extreme. Power turn on will be demonstrated at the low temperature extreme. The temperature excursions experienced by the hardware during the course of these tests will be sufficient to expose any latent workmanship defects. The hardware will operate during testing, and its performance will be monitored and documented.

11.0 Verification Matrix

The CRaTER Environmental Verification Matrices are given in 32-01206.01 and is under separate revision control.